University of Southern Indiana

Pott College of Science, Engineering, and Education

Engineering Department

8600 University Boulevard
Evansville, Indiana 47712

Grease Zerk Cleaning Device

Cleaning the Exterior of a Grease Zerk Using Rotational Motion

Logan Graber and Wyatt Vincent

ENGR 491 – Senior Design
Fall 2024

ACKNOWLEDGEMENTS

In this section, we would like to acknowledge Dr. Rad, our advisor for this project, for his continued support and guidance in helping create the best final product possible. We would also like to thank the University of Southern Indiana Engineering department and faculty for their suggestions through the design of this project and guidance through the last four years of our education. Lastly, we would like to thank all our peers and fellow students for any help and support they have provided us throughout the course of this project.

ABSTRACT

The objective of this project is to create a device that will clean the exterior of grease fittings to eliminate any foreign debris from entering the grease cavity when servicing machines. Many machines utilize grease fittings to insert new grease into grease cavities to extend the longevity of the lubricating grease as well as the parts being lubricated. The device will eliminate surface debris using a rotational cleaning attachment and degreasing, cleaning solution simultaneously. This device will eliminate the need for paper towels, which are typically used for the cleaning of grease fittings. Using paper towels to clean grease fittings produces a lot of unnecessary waste. This new device will create a more environmentally friendly way of cleaning fittings. To fulfill the goal of making this product require minimal effort from the user, the rotational end and the cleaning system will be electrically propelled and can be activated by a trigger and switch. The team members will use their engineering knowledge acquired in previous classes to make a product that fulfills the requirements for this project. The product should also be user friendly and effective by following design requirements set forth by potential end users. The final goal of this project is to create a working prototype while staying under the proposed budget of 150 dollars.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GREASE ZERK CLEANING DEVICE:

CLEANING THE EXTERIOR OF A GREASE ZERK USING ROTATIONAL MOTION

1 INTRODUCTION

A grease fitting or more commonly referred to as a grease zerk, is a mechanism that threads into the opening of a grease cavity and seals it off keeping water and debris from entering the grease cavity but allows an operator to refill the grease cavity when it is needed using a grease gun. The grease gun forces grease towards the zerk until there is enough internal pressure inside the grease gun hose to depress the spring inside the grease cavity. These grease fittings can be found on almost every mechanical device that includes a part with rotational motion whether it be a shaft being supported by a journal bearing or a wheel bearing, as well as pivoting parts. A grease fitting that has not been installed yet can be seen in Figure 1. By keeping these cavities full of grease, all the moving parts in a machine will be well lubricated saving money for the operator of the machine as wear parts will have to be replaced less often creating less machine downtime that would typically be spent replacing said parts. In the United States alone, the Massachusetts Institute of Technology estimates that around 240 billion dollars is lost per year due to downtime and repairs on manufacturing equipment damaged by poor lubrication **[1].** These cavities must be refilled periodically through operation due to the deterioration of grease. This time varies for different machines but is specified in the operating manual. The process of refilling these cavities with lubricating grease is very simple. The first step is to clean the exterior of the fitting, and then secure the end of the grease gun to the grease fitting and pump the specified amount into the cavity.

Figure 2: Uninstalled Grease Fitting

2 STATEMENT OF THE PROBLEM

The reason the grease fitting must be cleaned before the fitting is greased is due to the presence of surface contaminants on the fitting whether it be dust, dirt, old grease, water, etc. If the fitting is not cleaned beforehand, this debris would be the first thing pushed into the grease cavity by the new grease, and the introduction of debris or contaminants into the grease cavity would increase the chance of bearing failure. Studies have shown that 20 percent of all bearing failures are a result of when these contaminants on the exterior of a zerk make their way into the interior of a bearing **[2].** When combing this information with the data above from MIT it shows that contaminants in grease are responsible for around 48 billion dollars per year in maintenance cost and equipment downtime.

The method of cleaning the exterior of these grease fittings to ensure contaminants are not pushed inside a grease zerk has been the same for a long time, which is to take a cloth rag or shop towel quickly wipe off the dirt and begin greasing **[3]**. This basic cleaning method had several flaws which include high amounts of waste from the towels being used, inability to ensure all contaminants are removed from the fitting, and the operator cleaning the zerk usually ends with a mix of grease and dirt on them and other machine components from the exposed grease sitting on the exterior of the rag when trying to maximize the number of fittings cleaned with one rag. The calculations in appendix A which use numbers based off the author's time employed on a 1,000-acre farm, estimate that in one year a 1,000 acre farm practicing correct greasing practices the farm will use around 1000 square feet worth of paper towels a year. All these issues combined with the fact that sometimes the operator needs to wipe the zerk multiple times to ensure a clean exterior leads to a very inefficient process. This cleaning problem has inspired the creation of a solution that guarantees a clean exterior of the fitting while also reducing the amount of waste generated in the process. Figure 2 shows an image of a grease fitting that is dirty and would need to be thoroughly cleaned before any grease could be inserted into it to ensure that contaminants would not end up inside the grease cavity.

Figure 2: Grease Zerk and Potential Contaminants Prior to Cleaning

3 BACKGROUND

To solve the problem at hand, the device being created should be battery powered to increase the efficiency and effectiveness of cleaning grease fittings. With a battery powered device, the team is looking to take out all the manual wiping and cleaning that users would normally have to do. The overall goal for the project is:

to design, build, and test this battery powered device that will clean the exterior of grease fittings using rotational motion and spray with a budget of $150.

This report will track the progress as the team works to meet the goals and requirements that will be listed in the following sections. By the end of the project, the team hopes to have a working prototype to test on grease fittings and measure the performance of the device. Figure 3 presents a concept of operations that has been developed to provide an overview of the topics to be discussed in this report, and the approach taken to satisfy the project goal.

Figure 3: Concept of Operations

At this point in the project, all the research the team has conducted has found no product that is designed to achieve the same goal that this project will be designed to complete because of this the team cannot look to see how past designers approached this issue and how well their product worked. However, machines designed to simplify the cleaning process and reduce physical exertion is a process that has been dealt with in various areas and created a starting point for research to solve some of the design problems already encountered. The first problem that the team ran into was what cleaning solution would be best to incorporate into the device, as dried up grease and other foreign debris is present on the exterior of grease fitting and the rotational motion of the end would not be enough to completely clean the fitting without the use of some solvent to loosen the debris. Often this foreign debris accumulates very quickly even in standard operation. Figure 2 shows a grease zerk located on the front-end loader of a tractor that was previously greased and has been used for several hours since then. The number of debris that has since accumulated on the fitting illustrates the need for both rotational motion and the cleaning solution.

An unknown in this project was what kind of motion should be used to clean the zerk. As mentioned above there were no articles that discussed what motion is the most effective to clean the surface of grease fittings, because of this finding a starting point for the research had to be creative when researching what kind of motion should be used. The pre-existing knowledge that users typically used a rotational wiping method when cleaning zerks with a towel was applied along with studies from the dental field. Teeth and zerks are similar in size and they both need to be very clean to maximize longevity. The *Journal of Dental Hygiene* claims that a powered oscillating motion cleaning toothbrush is superior to the typical manual power toothbrush this reinforced the idea that a rotational motion would be the best way to clean the zerks **[3]**. Another article found in the dental hygiene field supports this idea that powered toothbrushes are much more effective at cleaning, as well includes a schematic of the mechanical breakdown of the structure of a standard rotation-oscillation powered toothbrush **[5].** This is a great source because it not only reassures that rotational motion will be the best cleaning method, but it also creates a starting point for the design of the motor and drive system. This solidified the idea that early design concepts would include a rotational end to clean the exterior, and that this end would be powered by an electrical motor to reduce the physical input by the operator to ensure that the device is enjoyable to use.

The cleaning solution for our design has not yet been finalized. Consequently, is it still uncertain whether the product will be an aerosol-propelled solution or a liquid house in a solid container. If a solution presents itself that will not be aerosol propelled there will be a need for finding a means of pressuring the liquid to propel into the end of the hose. A means of pressuring cleaning solutions has already been created and the team can integrate this system into the design. This machine is called the Sureshot. It operates by filling a metal canister with whatever liquid is desired, and then the system is charged with a typical air hose by attaching the hose end to the air valve on the canister. After this is completed, any liquid is pressurized and can be dispensed with the touch of a button. This device is already made to be used with degreasing solutions so corrosion would not be an area of worry. This device in line also follows the goal of having as little physical user input as possible making it a great solution if the problem arises of using a cleaning solution that is not sold in a pressurized can.

4 PROJECT REQUIRMENTS

There are several goals that must be met with this project for it to be called a success. As mentioned previously, the main goal of the project is to clean grease fittings to keep contaminants and debris out of grease cavities on various types of machinery. The device the team is trying to create for this project not only needs to clean the grease fittings, but it needs to clean them effectively and quickly. There is another way to clean grease fittings, but this device is trying to make the process cleaner and more efficient. The device should also be comfortable to carry while being operable with one hand so that users will be able to clean as many fittings as they need to without wasting a lot of time in between. The device should also be battery powered to ensure that the user just activates the end and lets it clean the fitting on its own. With a battery powered device, this device should minimize the amount of work the user must do while still getting the job done effectively. The device should also be able to withstand frequent, heavy abuse. This device will be used on a lot of heavy machinery that will most likely require it to be in high stress situations while still functioning correctly. The last requirement for the device is that it should not compress the spring function inside the fittings when releasing its pressurized spray to clean the fitting. The device will have a spray function that will help to clean the outside of the fitting, but the pressure will need to be regulated so that it does not put spray and other things into the grease cavity to preserve the integrity of the grease inside the cavity, as most heavy solution deteriorates lubricating greases.

To determine how quickly the device can clean the grease fitting, a simple timed test can be used. The team would like the device to be able to effectively clean one grease fitting in under four seconds with the ideal value being one second. The effectiveness of the device can be judged using an “eye test” to see if all debris is removed from the fitting. To determine if the device is operable with one hand, measurements can be made to find the distance between operational controls. With some research, the team has found that the average hand circumference is 7.6 inches so the device controls and handle should not exceed this length. Ideally, the device will be four to 6 inches long to ensure comfort for the user. The weight of the device will also be a factor in the comfort for the user should they need to carry it for extended periods of time. To measure this factor in comfortability, a measurement of the device’s weight in pounds can be obtained. The weight of the device should be similar to that of the average grease gun. The heaviest the gun can be is ten pounds while it would ideally be around six pounds. Along with a measurement of the device's weight, the team will also perform tests with five to ten pound weights to find out what weight is too much to comfortably carry around for extended periods of time. With the device being battery powered, we want it to have a lot of power to clean the fittings, but also not too much that its uses batteries at too high of a rate. A test will be performed to see how many volts the device needs to be effective and then record the amount of time the device can sustain that voltage before dying and needing a change of batteries. If the device can be used for six hours at a time, that would be a success. However, the goal is for the device to run for eight hours of constant cleaning before needing to change the batteries. Being able to clean for multiple hours at a time will save the user a lot of time that would be spent changing or charging batteries. To determine how durable the device is and its functional life span, a test will be performed to see how many hours the device can clean for without failure. The device is expected to least one hundred hours before failing and no longer maintaining its functionality. However, we are going to design the device to last as long as possible with the minimum goal being set at the one-hundred-hour mark. The requirements matrix used to organize all these requirements and performance measures can be viewed in Appendix A.

5 DESIGN

5.1 PRE-SENIOR DESIGN CONSIDERATIONS (DESIGN 1)

After the completion of pre-senior design, a conceptual design was selected that the team planned to work on upon the start of senior design. Several preliminary designs had been considered in pre-senior design and were worked with to determine which one would be the best starting point for the development of the grease zerk cleaning device. The first possibility was to utilize an existing grease gun like the one in Figure 4 and retrofit the body. This was going to be done by replacing the grease tube canister with a canister that could hold an aerosol solvent based cleaning solution like brake clean and using the existing pump to pressurize the cleaning solution propelling it to the end of the cleaning hose. There were several benefits to this design consideration such as the user being familiar with the device shape and function, a power source already attached that could be easily interchanged with devices of the same brand and voltage, and it is already known that the body could withstand heavy frequent abuse which is a project requirement. The biggest downside of this design was the future possibility of not having enough space to hold all the components that needed to be added for the cleaning function, as large companies have their products made extremely economical in terms of space and the smallest additions of components could affect this.

Figure 4: Existing Grease Gun

Another design iteration was to construct a device that was shaped like a long cylindrical tube so that it housed all components within it and could be attached somewhere on an existing grease gun frame. While this design would have utilized its own power source and motor for propelling the spray it was thought that the attachment to the existing grease gun could make the cleaning process much more convenient for the end user, and the all-in-one device would have made the time from having a dirty zerk to a clean and greased zerk much smaller. It was also thought that this idea could be cheaper to produce as much less of the structure would have to be constructed by the team. This design concept faced its own problems as all the commercially available grease guns are different shapes and sizes, and by creating a certain attachment system it could possibly eliminate some brands of grease guns from being able to use our product. Perhaps the biggest issue with this design was to violate the weight budget set for this project. A weight budget of ten pounds was set for this project to make it as practical as possible, as often grease guns must be held for extended periods of time while walking from grease zerk to grease zerk. It was found that most grease guns on the market range from seven to eight pounds which would hold this design to a weight requirement of two to three pounds.

A third design consideration was to eliminate the body portion of the product and just use a standard battery-operated drill for the rotational power source and attach the cleaning end which will be discussed later in the chuck end of the drill and hand spray cleaning solution on to the grease zerk before cleaning. While this idea would have been simple to construct with few failure points it led to the dependence of the end user also having a portable drill, and the possibility of uneven cleaning solution spray as well as over usage of cleaner. Initially it seemed that design one was going to be selected for the design of the body of the cleaning device however having little design done of the internal of the systems at the time of deselection the fear of not being able to fit all components into the body eliminated this design. The design that was selected instead was a combination of design one and two where the similar shape and parameters would be used from an existing grease gun, but the frame would be constructed by the group and the internal parts such as the pump, motor, and battery would be purchased separately and then assembled during the building phase. This final design seemed to be the best way to satisfy the requirements set forth by the group as well as market requirements created by potential users. The custom construction eliminates the tight weight budget, not being compatible with certain brands, possibility of previous internal parts not being compatible, and space issues while still offering the durability to withstand heavy abuse as the material could be selected later in the design phase. The final design also has the potential to be cheaper than designs one and three as it eliminates the power tools that would have to be bought to make both designs function.

For the end that would be used to clean the grease zerks there are no grease zerks cleaners on the market right rather than shop towels, so this would have to be created by the team. The idea for the cleaning end has stayed similar throughout the entire design phase. It would be a rotating end with bristles housed inside a plastic cylinder that would attach to the motor. The bristles would which serve as the abrasive force needed to be housed inside a plastic cylinder to follow OSHA Standard 1910 Subpart P regarding handheld and power tools. Which states "A safety guard is an enclosure designed to restrain the pieces of the grinding wheel and furnish all possible protection in the event that the wheel is broken in operation." [4]. The cylinder housing would ensure if a wire broke off it would be restrained inside and could not fly off hurting someone. The cleaning end is attached to the hose so that cleaning spray can be delivered from the device body to the end, and the bristle will do the actual cleaning. The inside of the cleaning end as well as the functionality will mimic the battery terminal cleaner in Figure 5.

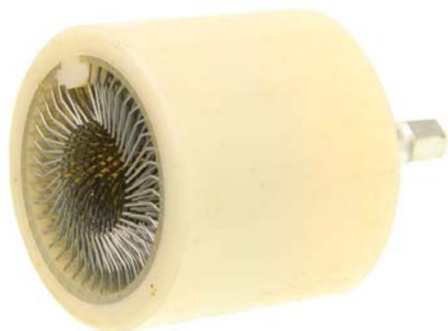


Figure 5: Battery Terminal Cleaner

5.2 DESIGN 2

After the first meeting with the senior design advisor for the semester, several fatal flaws were identified in the design that was planned to be used for the project. The most critical was the retrofitting of components into an existing device. To make the grease zerk cleaning device function the way it needed the device needed to have a pump, motor, and controls for these devices. The size of these components meant that more time would be spent focusing on how to fit these devices into the pre-existing body than the actual design of the device and would limit the full potential of design capability. This constraint was identified as too big of a problem to continue with, and the idea of retrofitting the components into an existing device was eliminated.

Another issue identified with the pre-senior design conceptual design was the cleaning end. Replicating the battery terminal cleaner seemed to be a faulty idea to continue with, as stainless-steel bristles had the possibility to damage the exterior of the zerk and continued use of the stainless bristles had the possibility to compromise the functionality of the zerk. The possibility of this and the manufacturing ability of a cleaning end that had sufficient stainless bristles to do the cleaning, was small enough to fit the grease zerk, and durable enough to handle repeated cleaning cycles proving to be very tedious caused this design to be set aside to find a better solution.

5.2.1 Exterior of the device

The critical errors in design one that were discussed in the previous section led to the start of the semester with a fresh design for the project. The first thing to be determined for the design was the exterior of the device. This component would serve as the housing for all the other components of the design which would hold them in place, as well as protect them from drops, exposure to grease, and other environmental effects. After considering the different types of designs that would satisfy the technical requirements of the project of being operable with one hand and comfortable to carry and use for extended periods of time it was determined that mimicking a cordless drill would be the starting point for the new design. To do this a CAD model was created that had an exterior similar to a cordless drill in terms of the shape and size, and the inside would be edited to fit and hold components as they were sized out and ordered. This design would also offer a device that a potential end-user would be familiar with in terms of handling and operating, which is one of the reasons the retrofitting of a grease gun was considered. The initial CAD model that was made to resemble a cordless drill and would be modified to become the housing for the device can be seen in Figure 6.

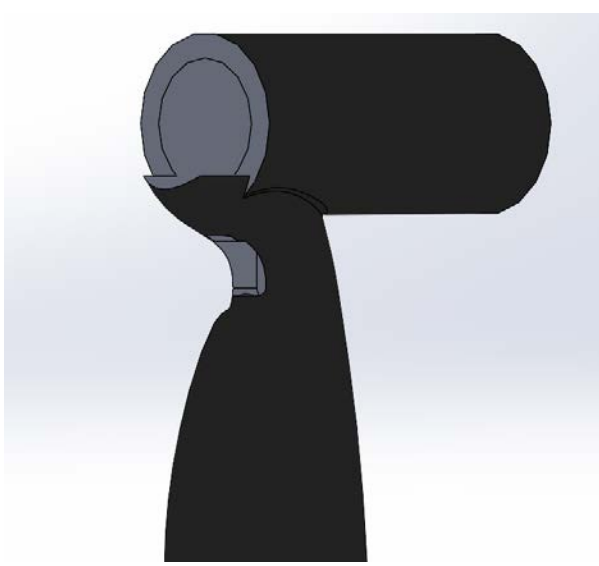


Figure 6: Initial CAD Model

To manufacture this part 3-D printing was chosen. By 3-D printing the part, the CAD model could be taken from modeling software, in this case, SolidWorks and put into a slicing application that takes the CAD model slices it into thin layers and exports the code to a 3-D printer. The 3-D printer then reads the code and produces a replica of the CAD model in the form of a 3-D printed model. There are several reasons 3-D printing was chosen to be the manufacturing process for creating the device exterior. The most significant reason it was chosen was the fact that it is one of the cheapest ways to create a part like this. USI already has several 3-D printers on campus that open for student use at any time so there was not upfront cost for purchasing a printer, and the 3-D printing process requires no operator once the code is uploaded and started, so there was no cost for manpower in manufacturing the print. This means the only cost for producing the exterior of the device was the material used to make it, for the print PLA was used which is one of the most common 3-D printer materials and only cost around 19 dollars for 1000 grams. The total amount of material used to make the housing was around 400 grams, making each device housing cost around 8 dollars.

5.2.2 Cleaning End

With a solution found for what would be used for the exterior of the device, the cleaning head issue was addressed next. As discussed above, stainless steel bristles could not be used as a material inside the cleaning end, as it would possibly damage the exterior of a grease zerk after several repeated cleaning cycles. The material inside the cleaning attachment that would be in contact with the zerk and whatever contaminants were present on the exterior of the zerks would have to be heavy duty enough to withstand the continuous rotational motion and efficient at cleaning dirty greasy surfaces. Steel wool was suggested to be used for the material. Steel wool is fine strands of steel matted into a mass, used as an abrasive. Knowing that steel wool is sometimes used to rub grease off metal surfaces, is cost effective and easily formed to fit any shape is one of the reasons it was chosen for the initial material to be used in the cleaning end. To test the steel wool ability to clean grease zerks several different steel wool grains and types were purchased and placed inside a 3-D printed cylinder. Once placed inside a 3-D printed cylinder the device would use a rotating motion to clean the grease zerks. The cylinders which contained the steel wool were placed inside a drill chuck, and the power of the drill was used to spin the cylinder and see how well the grease zerk was cleaned. The coarse grain steel wool tested inside the cylinder did an was most effective in cleaning the zerk removing all contaminants from the exterior of the grease zerk. The before and after results of a grease zerk cleaned in the Applied Engineering Center using the steel wool inside the 3-D printed cylinder and spinning the cleaning end with a Milwaukee drill can be seen in Figure 7.

Figure 7: Before (left) and After (right) of Initial Cleaning Test with the Steel Wool

As discussed above, the material inside the cleaning end would be interchangeable after it had reached the point of being saturated with grease and no longer perform as well as it should. Steel wool would allow this, as when the steel wool was no longer performing as well as it should be it can be removed, and the cleaning end could be refilled with new steel wool. In the initial testing discussed above the 3-D printed cylinder was filled with steel wool and compressed with a finger until the cylinder was full of steel wool. This initial compressive force, and the centrifugal force of the drill spinning kept the steel wool packed tightly inside the cylinder showing no signs of coming out as the grease zerk cleaning process took place. This was another good sign for the ability to change out the steel wool inside the cleaning end, as no attachment system must be used to keep the steel wool inside the cleaning but instead the forces used to pack the cleaning end could be relied on to keep the steel wool inside the cylinder during the cleaning process.

Due to how well the 3-D printed cylinder worked in the cleaning process in terms of holding the steel wool in place during the cleaning process, and the ability to have a very thin wall thickness which allowed the cleaning end to access grease zerks in recessed pockets the design was continued with. The shaft, which would be the part of the cleaning end that would attach to the motor of the device would have very little effect on the cleaning effectiveness of the cleaning end so it was left as a constant in the design process; however, this length could be very easily changed in the printing process. By changing this length, the grease zerk cleaning device would be effective in cleaning grease zerks in tight locations as the shaft could be made very long and would allow the cleaning end to be placed in tight places while keeping the body of the device outside of the tight area. The two parameters that were changed in the design of the cleaning end to find the optimal cleaning end was the diameter, and depth of the hole where the steel wool would be located. Having no way to calculate the optimal depth and diameter of a steel wool pocket to best clean a grease zerk multiple designs were printed out and tested. All of the different sizes of cleaning ends that were tested can be seen in Figure 8.

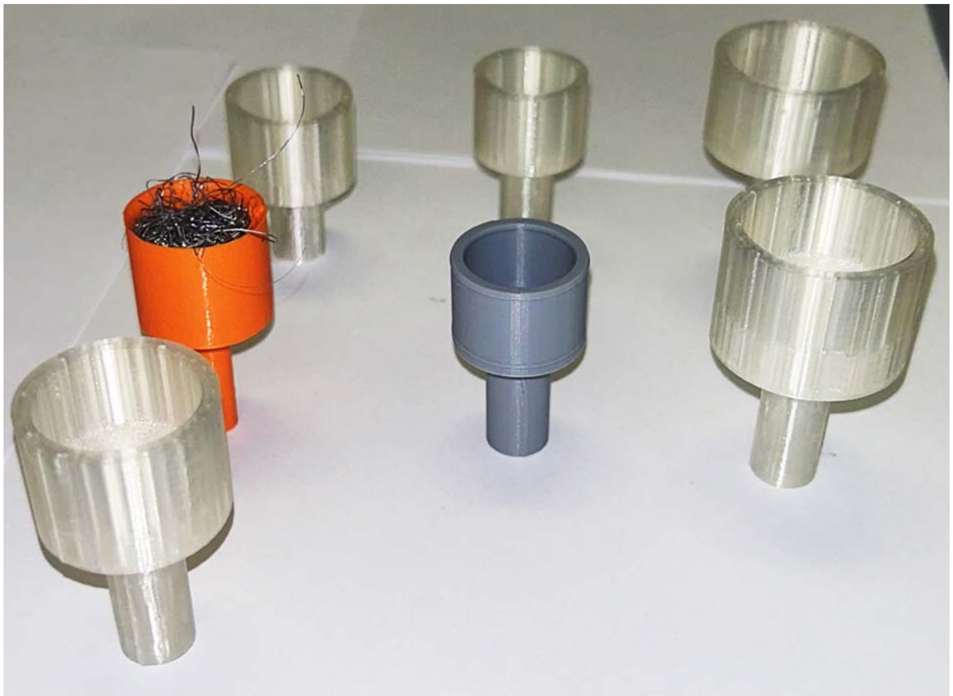


Figure 8: Cleaning Ends Tested to Find Optimal Dimensions

The testing of the different diameters and depth of the cleaning ends revealed that the depth of the cylinder did not have much effect on the ability of the cleaning end to clean the grease zerks as long as the depth was deep enough that the entire grease zerk could fit inside the cleaning end which meant the steel wool had complete contact with the entire grease zerk. Grease zerks are around 0.45 inches tall so to ensure the entire grease zerk would fit inside the cleaning end the final one selected would be 0.5 inches or taller. When testing the different diameters, the testing revealed that the largest diameter was the most optimal for cleaning the grease zerks. This was because the larger diameter led to more steel wool being able to be placed in the cleaning end, and as the cleaning end was used the steel wool shaped to the grease zerk and the grease being removed from the grease zerk was pulled to the edges by the rotational force. This meant that the bigger the diameter the more grease could be absorbed by the steel wool thus the more grease zerks could be cleaned with that bundle of steel wool. The best solution for the cleaning end would have been to make it as big as possible, but the constraint of keeping the cleaning small so it could clean grease zerks in recessed pockets eliminated this. When grease zerks are in recessed locations the hole that they are located in is not necessarily a standardized diameter so that could not be used to design with, so to find the best diameter that would satisfy both of the requirements talked about above the cleaning ends were worked through until the smallest diameter that would still do an effective job cleaning was found this diameter was found to be 1 inch . The final print for the cleaning end with a diameter of 1 inch, and depth of 0.5 inches which was selected as the optimal cleaning end dimensions

5.2.3 Motor

The initial testing of the steel wool inside the 3-D printed cylinders cleaned the exterior of the grease zerks so well that it was selected as the design that would be used for the cleaning attachment in the project. Having the cleaning end selected for the project allowed for the next step of the process of sizing out and selecting a motor. The first step to selecting the motor was finding the torque that would be needed to spin the cleaning end when it is first placed on a zerk that is covered in old, hardened dirt, and grease. To do this the same style of cleaning wool was placed inside of a 3-D printed cylinder with a lever arm on the side. This lever arm allowed us to place a force gauge on the lever and measure the input force required to spin the cylinder. This input force was converted to a torque and showed the minimum torque the motor would need to supply. The test showed that the minimum torque that would need to be supplied is 9.75 in-lbs. The full results from this testing can be seen in Table 1.

Table 1: Force Guage Test Results

Force Guage Test Results			
Test Number	Output force (lb.)	Lever Arm Length (in)	Output Torque (lb.-in)
1	7.5	1.5	11.25
2	6.0	1.5	9
3	5.0	1.5	7.5
4	7.5	1.5	11.25
5	6.5	1.5	9.75
		Average	9.75

The next step in sizing out the motor for the grease zerk cleaning device was determining the RPM the motor needed to operate at. To test this another cleaning end of the same diameter was printed with a hole so it could be attached to the shaft a small DC motor that was found in the AEC. The small DC motor did not spin fast enough to sufficiently clean the zerk. Knowing that the cleaning that was with the drill did operate at a high enough RPM to clean the dirty grease zerks, it was decided that a drill motor would be used to spin the cleaning attachment. The prototype cleaning attachment used in the drill chuck can be seen in Figure 9.

Figure 9: Prototype Cleaning End in the Drill Chuck

The drill that was used for this initial testing was a Milwaukee M18 that was located in the applied engineering center. Knowing that this drill motor did an exceptional job cleaning the grease zerks, it was decided that this would be the motor used to spin the cleaning attachment in the grease zerk cleaning device. However, when conducting online research trying to source one of these motors by itself it seemed very difficult to source this motor as the company did not want to sell a motor by itself as a replacement part. While conducting this research for the motor a similar drill motor was showing up on multiple Google searches. This motor was the HC785LP RS-785, a DC motor that could be powered with anything from a 12 volt to 20 volt power source. This motor supplies 10.34 in-lbs. of continuous output torque and has a maximum rpm of just above 18,000 RPM the full data sheet for this motor is in appendix B. Based on the requirements determined early that would be needed for the motor to clean the grease zerks this motor surpassed all of them and was selected to be the motor for the project. The motor can be seen in Figure 7.

Figure 10: HC785LP RS-785 Motor

The typical method for mounting this motor would be to mount a metal plate onto the front end of the device using the screw holes on the front face, and then attach the steel plate to another fixed rigid member that would eliminate the reaction forces of the motor twisting, and the vibrations produced from the motor running. This mounting system would not work for the grease zerk cleaning device, as there would be no way to attach the metal plate to the PLA body. Having eliminated the typical method for mounting the motor a new design had to be made. With the motor and the top of the device both being circular shaped the easiest way to incorporate, a mounting system that could be fixed to both the motor and the frame would be using a mounting system with round circular geometry. It was decided to test a collar that would slip around the outside of the motor and then have a tab that would fit inside the frame and one of the bolt holes would be used to secure it. To keep the project as light as possible, it was chosen to make the mounting system out of PLA instead of metal. By making it out of PLA the device could be made using the same 3-D printing system talked about above in the section about the making the exterior of the device. To secure the motor inside the 3-D printed mounting system the ring would be pressed onto fit on the motor. To determine the best way to design a press fit for a system like this faculty member Dr. Nelson was consulted. His advice for designing a press fit where one component would be 3-D printed and the other would be metal was to measure the diameter of the motor subtract the three to four diameters off the motor diameter and use that for the inside diameter of the mounting system to help with getting the collar on to the motor a small fillet should be added on the inside. With the information provided a collar was designed on SolidWorks, and printed using the 3-D printer this ring can be seen in Figure 11.

Figure 11: Motor Mount

To mount the motor inside the ring the motor was placed inside of bench vise in the AEC, and a rubber mallet was used to press the ring on to the motor. Once the ring was on the motor the fitment was very tight, and the motor was hooked to a power source to make sure the torque provided by the motor or vibration would not cause the motor to rattle inside the mounting system. Due to the collar tight tolerance even with the motor running at 13,500 RPM it did not move or rattle inside the mounting system. The rest of the geometry including the outer diameter of the ring, the mounting tab size, tab thickness, and hole were chosen based on the constraints of the size device body. This was done in an effort to keep the device from getting any larger. To test if these dimensions could handle the forces from the motor running during the grease zerk cleaning process a SolidWorks stress simulation was run on the motor mount. The top of the device had fixed constraints set on it just like it would function in the device, and a torque of 12 in-lbs. was placed on the inner ring face which would be a conservative design of the motor running. This conservative test revealed that the maximum stress in the motor mount was around 1800 PSI, and the yield strength of PLA is 6700 PSI according to the datasheet from the provider of the PLA which can be seen in appendix C. The results from the SolidWorks simulation can be seen in Figure 12

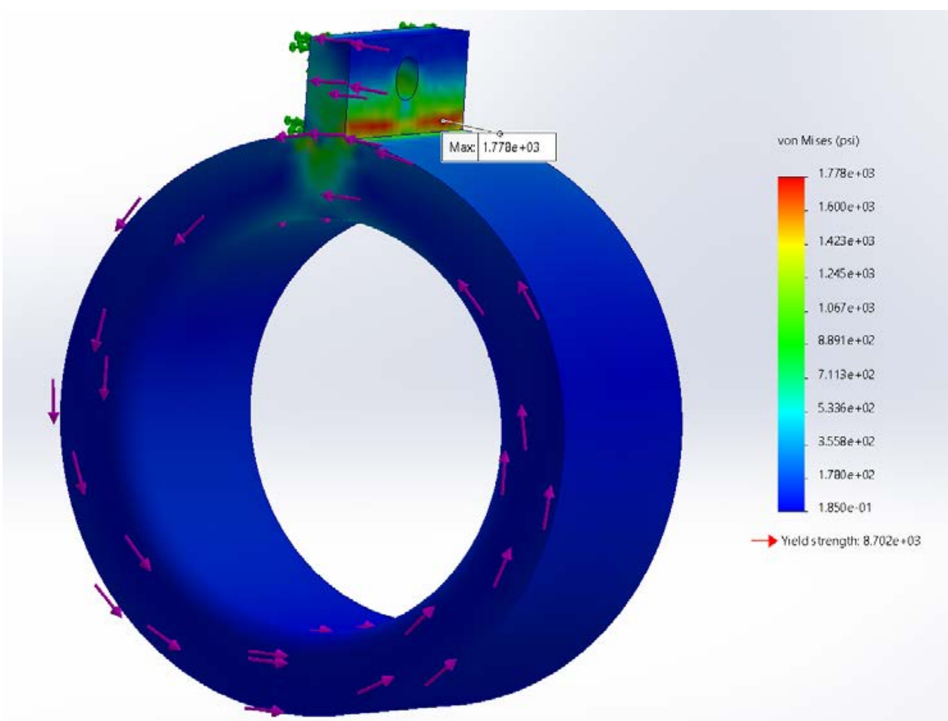


Figure 12: SolidWorks Simulation on Motor Mount

5.2.4 Battery

Having selected the motor that would be used for the project, the next component that needed to be determined was the power source for the device. In order to make the device comfortable to use and carry for extended periods of time, and work for six hours continuously which were technical requirements set at the beginning of the project it was determined that a lithium-ion battery would be the best power source to do this with. Lithium batteries are the lightest out of the four rechargeable batteries and high specific capacity and specific energy compared to the other battery materials. While lithium-ion batteries are more expensive in comparison to the rechargeable batteries, the performance gains are enough to offset the extra cost **[4]**. The next thing to determine for the power source was the voltage as many of the popular lithium-ion batteries available on the market that are used in other cordless power tools come in 12 volt and 18-volt options. The motor that was previously chosen could be powered by either of the voltage sources and the only difference is when powered by 12 volts the motor reaches a maximum RPM of 13,500 and when powered by 18 volts it reaches a maximum RPM of 18,300. The operating speed of 13,500 RPM was not a constraint in this design as this speed was still more than sufficient for cleaning the exterior of the grease zerks, so the two things that were considered when selecting the battery were weight and cost. To start the deselection process it was decided that the battery would be sourced from the power tool company Milwaukee. The two main factors that caused this battery to be selected was that Milwaukee is a popular brand in the United States which means that if a potential end user were to use the grease zerk cleaning device they may not have to buy a battery and charger to run the device as they may already have one in their shop, and Milwaukee is the brand used in applied engineering center so for the project only the battery would need to be purchased saving expense on the charger. Similar to many power tool companies, the shape between the 12 volt and 18 volt battery platforms are quite different for Milwaukee. The 18 volts are rectangular and slide on to the bottom of the drill handle while the 12 volt are more stick like and slide inside the handle of the power tool. In addition, the 18-volt battery ranges in weigh from 1.48 pounds to 3.4 pounds while the 12 volt only ranges from 0.35 pounds to 0.9 pounds depending on the amp hour. The significant weight savings and the ability to conceal the battery inside the handle led to the 12volt battery to be chosen. A comparison of the 20 volt on the left side and the 12 volt battery on the right side can be seen in Figure 13 below, the 12 volt battery that was chosen is the battery on the right side.

Figure 13: M18 Battery (left) and M12 Battery (right)

After determining that the 12-volt Milwaukee battery would be the power source for the device, it had to be determined what would be used to hook to the battery connections. Like most cordless drill batteries, Milwaukee uses a prong system that makes their batteries only work with the connections on their devices. Due to this being the only component from Milwaukee being used, the device would not have the needed prongs to make the battery usable, so a solution had to be sought after to fix this. The first possibility was trying to find the schematic for the batteries output and hook the wires from the other components directly to the prongs on the battery. The second option was to order an adapter that connected to the battery and had a positive and negative wire coming out of the top that could be wired to the components in the device. These adapters were widely available on various online retailers, and cost around 15 dollars. The second option was selected for several reasons; firstly, it eliminated the possibility of loose connections that could potentially lead to the device not properly functioning. Additionally, the adapter allowed the battery to function just like a regular battery powered tool where the battery could be easily removed, placed on the charger, and then reinserted into the device without having tp go inside the device to remove any connections. The battery adapter that was selected can be seen in Figure 14.

Figure 14: M12 Battery Adapter

5.2.5 Cleaning Solution

Often when it comes time to clean a grease zerk the contaminants on the exterior of the grease zerk such as dirt, dust, old grease, etc… can be come dried on the surface and become hard to remove with a paper towel. To ensure the grease zerk cleaning device could remove the dried on grease a cleaning solution would be added to the device. The cleaning solution would be sprayed on the zerk prior to using the rotating end to soften the grease and make the removal process easier for the rotating end. In the pre-senior design consideration, it was determined that the cleaning solution used on the device would be an aerosol solvent base degreasing solution such as brake clean. When researching the properties of solvent-based degreaser to complete the integration of the cleaning solution it seemed that the risk associated with using a solvent based degreaser were too great to offset the benefits. One of the main goals of the grease zerk cleaning device is too great a more environmentally and user-friendly solution to cleaning grease zerks. Solvent based degreasers contain “Volatile Organic Compounds or VOCs. VOCs are materials that readily evaporate and turn into the gaseous state at normal room temperatures, and their ability to contribute to smog formation and the environmental and personal health impacts associated with them.” **[6]**. Utilizing a solvent based degreaser would release unnecessary VOCs into the atmosphere which would offset any postive environmental impact gained from the elimination of paper towels in the grease zerk cleaning process. This along with the fact that solvent based degreaser can also degrade PLA 3-D printer filament which is what is going to be used to manufacture the frame of the device will not create an environmentally and user-friendly solution to cleaning grease zerks so the solvent based degreaser was eliminated from the design.

Knowing that a cleaning system still needed to be implemented into the grease zerk cleaning device, to aid in the removal of contaminants that are dried on to exterior of a zerk the team sought out a new solution. After identifying the issue addressed in the previous section the projects advisor suggested that a water-based degreaser was investigated as a possible solution. Water based degreaser operate by dissolving contaminates, and chemically reacting with contaminates to make them more readily dissolvable in water without the VOCs the solvent-based degreaser contains **[6]**. Water based degreasers are sold in gallon jugs as a liquid, so a storage system and propulsion system needed to be designed to transport the liquid from the storage system to the cleaning end. A tank from a paint spray gun was selected to be the storage system for the cleaning solution. These tanks hold around a quart of liquid so there would be more than enough storage capacity for the cleaning solution when cleaning zerks and are made from stainless steel creating a very durable corrosion resistant storage solution. The cleaning solution tank can be seen in Figure 15.

Figure 15: Cleaning Solution Tank

Having determined the storage system for the cleaning solution, the next component that needed to be designed was the propulsion system. This component needed to be able to deliver the cleaning solution from the tank to the cleaning end and control the flow. In an effort to meet the technical requirements that were previously set forth of the device being completely operable with one hand. The device that was selected to do this was an electric solenoid valve. The solenoid valve would turn the flow on and off with an electric switch that would be implemented somewhere in the handle of the CAD model so it could be toggled on and off with the same hand that was holding the device. To deliver the cleaning solution from the tank to the cleaning end the elevation difference between the cleaning solution in the tank and the solenoid valve would be used to push the cleaning solution through the system. While the solution of using the solenoid valve to control the flow seemed rather simple several constraints arose when it came to sizing out and the ordering process. Most of the available solenoid valves are rather large compared to the room that was available in the model, and the ones that are small in scale were outside of the price range of this project to stay within the budget. At this point of the process that motor had already been selected, and the CAD model was edited to fit the motor. As components were being added to the device the dimensions continued to grow, so in an effort to keep the device from growing any larger it was determined the solenoid valve height, and width needed to be smaller than the diameter of the motor. After determining this size constraint, and shopping for solenoids that were the most budget-friendly options a ¼'' electric solenoid value was selected which can be seen in Figure 16.

Figure 16: Solenoid Valve

5.2.6 Assembly

The first step in the assembly process was to update the interior of the model to fit the components that had been previously selected for design two. To speed up the assembly process as the components that were discussed in the sections above were still in the shipping process, the interior of the model was edited using the dimensions that were listed in the item descriptions from the retailers the parts were sourced from. As discussed above the size of the motor was used as the baseline for what size the top part of the model should be, so the first thing done to the CAD model would be to update the top housing to hold the motor. The motor had a diameter of 1.65 inches to allow room for proper fitment of the motor and the mounting system that would be later determined a section of the top cylinder was removed from the model with a diameter of 2.5 inches and 2.75 inches long. The length of the 2.75 inches would allow for the motor which was 2.65 inches long to fit inside and still have room from the electrical connections which would connect to the leads on the backside of the motor and connect to the battery wires.

The next component that needed to be placed inside the model was the electric solenoid valve. The solenoid valve needed to be placed somewhere where the tank could be connected to the inlet side of the solenoid valve, and a hose could be routed from the outlet to the cleaning end. In order to utilize the elevation difference from the cleaning solution tank to the solenoid to push the cleaning solution through the system the tank needed to be placed on top of the device. The best location on the model for this to be located was behind the motor so a rectangle with the same dimensions as the solenoid value was removed from behind the motor area was removed from the model. The wires for the solenoid valve were located in the middle of the device so by removing an area with the same dimensions as the solenoid valve the cavity would securely hold the component and the wires could easily run through the same path the motor wires were running through. Two holes were added on both sides of the solenoid that would serve as the inlet and outlet where tubing would run from the tank into the solenoid and from the solenoid to the cleaning end. To account for the changes in the model of the two additional components being added in the top cylindrical section dimensions needed to be edited. The outer diameter of the top cylinder was updated to 3.35 inches. This would allow for a wall thickness 0.42 inches, which should be a sufficient amount of PLA to absorb the impacts that the top cylinder would potentially take if it were dropped during use and protect the components inside of it. The total length was changed to 6 inches which would allow for the motor and solenoid to be placed inside, and the electrical connections needed to power them while keeping the excess length to a minimum to reduce the total footprint of the device.

When the CAD model of the initial device was designed there was already an area for a trigger included and it was not edited for design two. The next component that needed to be added to the device was an area for the battery and battery adapter. As discussed above by choosing the 12-volt Milwaukee battery, it could be concealed in the handle of the device, so the first step in editing the model was to reshape and size the handle of the original CAD model to fit the battery and adapter. Knowing that the design process would contain multiple iterations to refine the fitment of components and performance of the device the battery adapter could not be glued or permanently attached to the inside of design two, so to fix the battery adapter inside the handle a cavity of the same size would be inserted inside the model and the force used to hold the device together would be used to also hold the battery adapter inside. To ensure that this method would work to hold the adapter securely the tolerances between the cavity and the adapter had to be very tight. To start this step the dimensions and geometry changes were recorded and then incorporated into a sketch on the CAD model; however, needing the tight fitment talked about above this method did not seem to accurately model the correct shape of the adapter. To solve this problem there was a CAD-Grab file available of the battery adapter, so that was inserted into the model, and used to cut the cavity that would hold the battery adapter, and the batter would slide inside of it. The battery releases from the battery adapter using prongs that are pressure released by squeezing the sides so the battery adapter was placed in the model so that most of it was concealed within the handle, but these squeeze points could still be accessed from the outside. To allow for room for the wires on the components to be connected to the leads coming off of the battery adapter a 0.5-inch hole was placed in the model that runs all the way from the battery adapter to the top cylinder. Finally, to connect the two halves together several M4 hex head bolt holes were placed on the model that would allow the device to firmly secure together holding all components but easily taken apart if work needed to be done on the inside of the device.

Once these changes had been incorporated into the model, it was printed in the Applied Engineering Center using the Prusa original printer. For this design a 15 percent infill was selected, infill is a “method that fills the inside of an object with a sparse supporting structure.

Infill provides internal support for top layers, which would otherwise have to bridge over empty space." **[7].** While it would have been ideal to go with a much higher infill for the added structural integrity the model was already large for the Prusa 3-D printer which led to a total print time of around 30 hours to print both sides, so increasing the density of the print would have made the print time, and material usage increase even more. After the 3-D printing had been finished and the components had arrived from various online retailers the second design was able to be assembled. The 3-D exterior of the device for design two can be seen in Figure 17. The removed material on the top and bottom section on the left of the print was not a printing defect, and was material removed after some initial fitment to test fit the solenoid after it was

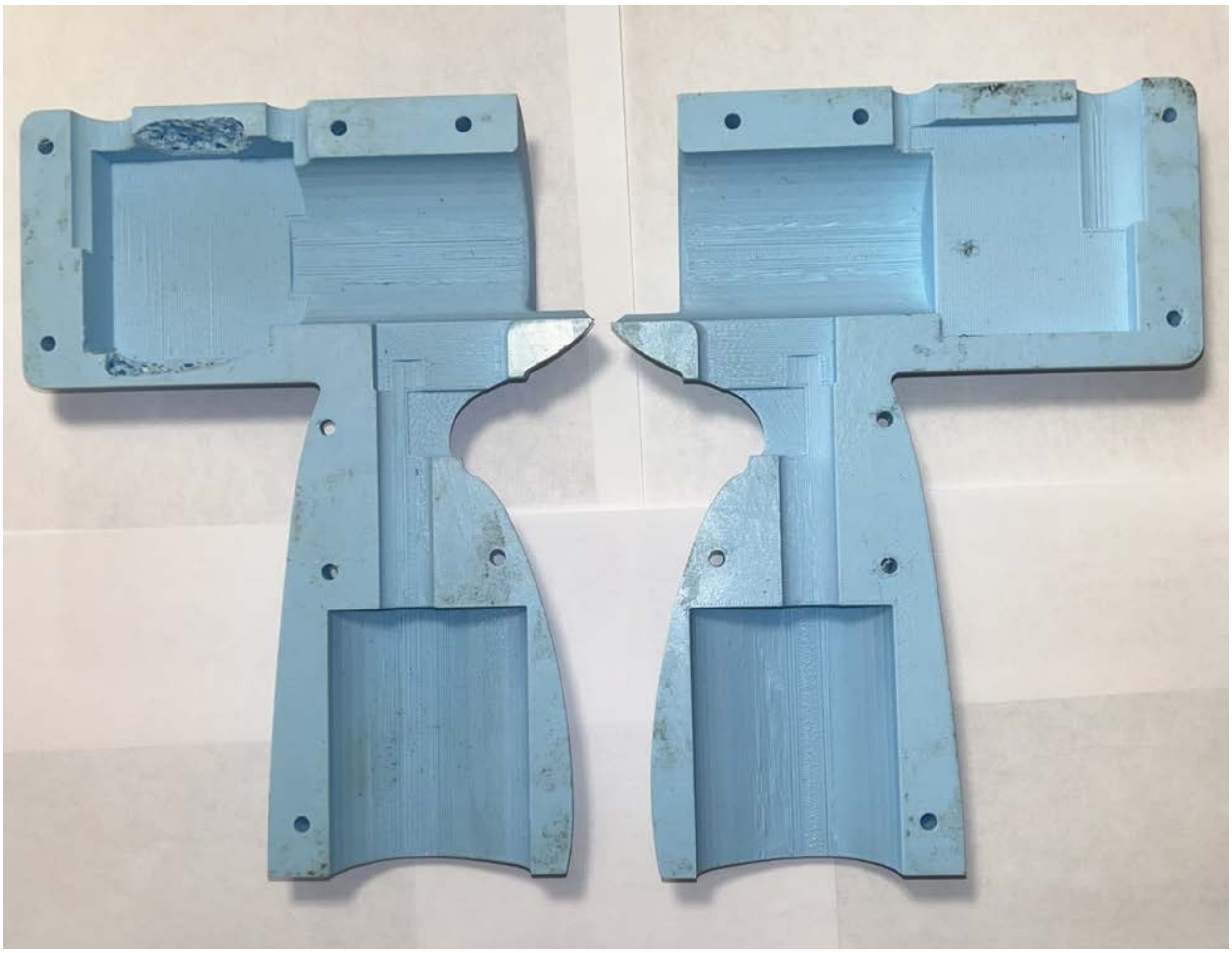


Figure 17: 3-D Printed Exterior of the Device for Design Two

larger than the dimensions listed on the online product description.

The first component that arrived was the motor and with its arrival, a cleaning end could attach to it. As discussed in the cleaning end section the cleaning end needed to be able to be removed and replaced from the shaft of the motor whenever necessary, due to this and the fact that the press fitting method that was used to mount the motor worked so well the same approach was used to attach the cleaning end to the motor shaft. The motor was then hooked to a power source and tested to see if the calculations earlier performed in the motor section could be verified. When hooked to a 12-volt power source, which is what is being used in the design, the motor performed exactly how expected and thoroughly cleaned the exterior of the grease zerks. After testing the motor and verifying it performed as expected it could be placed into the body of the device. As talked about in the top of the section the CAD model was designed as parts where still in the shipping process, so design two did not include the tab that was being use for the motor mount, as at the time the frame for design two was printed the motor mount had not been designed yet. This meant that including the motor mount would be one of the updates that would have to be accounted for in the redesign.

The next two components that arrived were the battery adapter and battery. The process of incorporating them into the model was very simple the battery was placed inside the adapter, and a multimeter was used to measure the voltage coming from the wires. This measured 12 volts, so the battery and battery adapter were working successfully. The battery adapter was then placed inside of its respective cavities and the frame was temporarily bolted together to make sure everything fit correctly. The battery adapter fit securely inside the cavity and when bolted together the adapter caused no fitment issues and was held securely in place even in the process of inserting and removing the battery. This means that the process of inserting the CAD-Grab sketch into the CAD model worked successfully and the lower section could be kept the same in the change from design two to design three.

The last component that came in was the solenoid valve and tank. These two components presented the most issues in the design two assembly. The first issue was when trying to connect the tank and the solenoid valve. Per the item description on Amazon the paint tank end selected was supposed to be a 3/8’’ NPT threaded male, and the solenoid valve was a ¼’’ NPT thread female end. To make these components connect a 3/8’’ female to ¼’’ 90-degree elbow was ordered to connect the tank and solenoid. When using the adapter the ¼’’ side threaded to the solenoid adequately, but would not connect to the tank after measuring the threads with a thread gauge in AEC it turned out the threads were metric. To keep the assembly process moving a new paint tank of the same size and dimensions was sourced from a local Harbor Freight that had the correct end to connect to the 3/8-inch adapter. Having the tank connected to the solenoid these components were placed in their respective places in the 3-D printed frame to test the flow of the cleaning solution through the solenoid valve. However, after trying to insert the solenoid into its respective location, it would not fit, after analyzing the dimensions on the CAD Model and the dimensions on Amazon it was determined that the knob on top of the solenoid was not included so some of the 3-D printed frame was removed with a Dremel tool to fit the solenoid. The tank was filled up with cleaning solution and the solenoid valve was opened by connecting its electrical leads to the battery. This test revealed that gravitational difference between the solenoid valve and the tank, accompanied by the flow restriction of the solenoid valve was to great to push the cleaning solution through the system. After determining this the idea of using a solenoid valve to control the flow of cleaning solution was discontinued, and a new component to push the cleaning solution through the system would have to be found. Having tested all components involved with design two and determining what could be kept and what needed to be fixed design three was started. Design two can be seen in Figure 18 with all components in their respective places, and the two halves laid next to each other before it was bolted together.

5.3 DESIGN 3

5.3.1 Pump

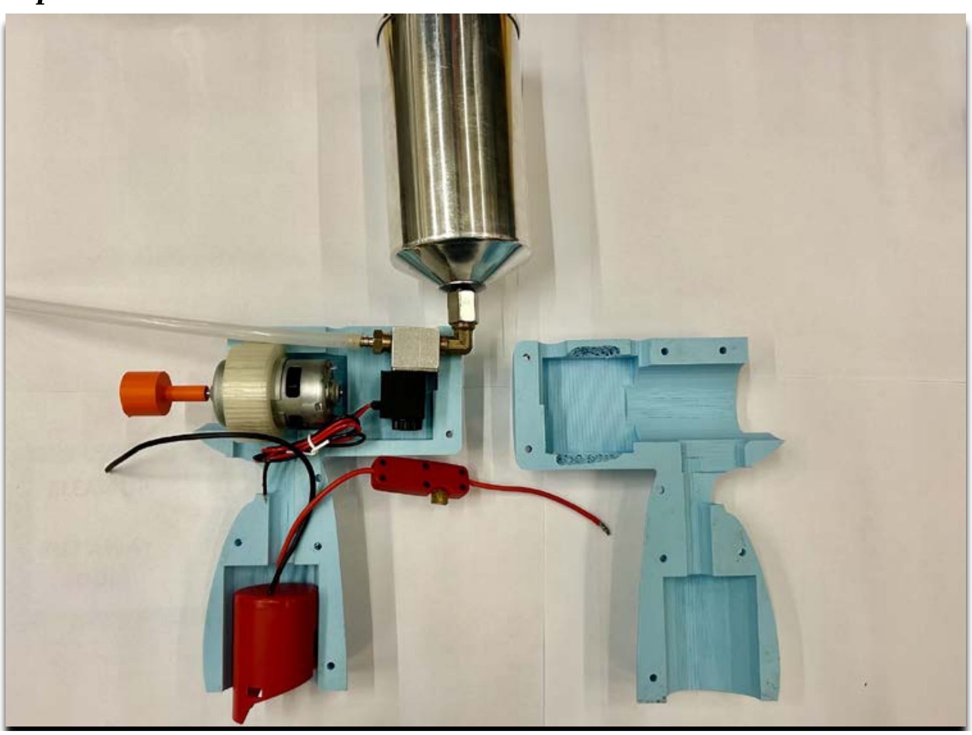


Figure 18: Design Two with all the Components Inside

The first task in design three was to fix the issues that arose in the assembly of design two, and to replace the components that were faulty in the second design. The largest issue in design two that needed to be addressed was finding a component to replace the solenoid. Based on the fact that the elevation change was too much for the flow to overcome the replacement for the solenoid needed to be something that could push the fluid through the system and switch it on and off as the same control that was talked about in the solenoid section was still applicable. The best solution for this problem seemed to be a 12 volt pump that could overcome the distance the solution would need to travel from the pump to the cleaning end. More specifically a diaphragm pump that has a check valve inside of the pump that allows the cleaning solution only to flow when it is turned on. Once again, it was desired that the component being added would not make the exterior of the device any larger so the limiting constraint when searching for a pump was the price and size. The pump that was selected can be seen in Figure 19 this pump has a diameter of 1 inch and a length of 2.6 inches.

Figure 19: 12 Volt Diaphragm Pump

That meant it could fit easily inside the location previously designated for the solenoid valve by changing that rectangular cut out to a continuous circle that was the same size as the motor. This simplified the geometry inside the model and allowed plenty of room inside the model for the component placement and wiring. To ensure that the pump functioned correctly, and that it would provide enough power to push the cleaning solution through the system it was hooked to a temporary voltage source and placed in the location of the solenoid of the second design. The outlet hose was routed out from the back of the device to the top of the cleaning end, and the inlet hose was inserted into a water bottle just for the initial testing. The pump worked very well in this initial testing and would deliver an ample amount of cleaning solution to the cleaning end in about two seconds once the pumped was prime which would help make the grease zerk cleaning device a quick effective solution for cleaning grease zerks which was one of the projects technical requirements.

5.3.2 CAD Model Changes

Due to the mistakes that were encountered with design two in terms of dimensions being listed online not being the same as the actual products, the design of the third frame was not started until the pump arrived. Upon the pumps arrival it was determined that the same tank could be used for the cleaning solution by exchanging the 3/8 inch to ¼ inch adapter for a 3/8inch female to ¼ inch male tube stem adapter this would allow a piece of tubing to be attached from the pump inlet to tank exit. Another change that needed to be made in the third design that was left out from the second design was how the tank was going to be held in the device. The adapter being used had a hexagon base that was located in between the pump and the tank, so to hold the tank a hexagon shape was cut out from the CAD model that was the size of the adapter and was placed in the middle of the sketch. By placing this hexagon hole in the middle of the sketch the force of the bolts that was used to hold the device together could be used to hold the tank in place. To hold the pump in place the same mounting system that was used for the motor was used. A cylinder ring with a mounting tab was press fit on the pump by using the same dimensioning system as with the motor mount, and then tapping it on with a rubber mallet. While the pump would not be creating any forces when it was operating the weight of the tank and the cleaning solution would be pushing down on the pump so it was important that it would be held securely in place while the device was used. The outlet was located on the backside of the pump in the way it was orientated when laying everything out so a hole was made on the backside of the model so that ¼ inch flexible tubing could be routed from the backside of the pump to the cleaning end so the cleaning solution could be applied to grease zerks. Having determined how the pump would be mounted and plumbed into the system the final step was determining how it would be controlled. As discussed above the cleaning solution and cleaning end should function independently of each other, so it was known that the motor and pump would have two different control solutions. The most intuitive way to control the flow of the solution seemed to be using an on/ off switch that would control the pump. Knowing that the device must be controllable with one hand the old model was used with an on/off switch found in the AEC to determine the most comfortable location to operate with on hand. After some testing by just placing it in different locations and turning it on and off it was determined that placing the thumb switch by the operators thumb if they were using their right hand was the best location for the device to still be comfortable to use, and turn the pump on and off. The switch that was picked already had flexures on the top and bottom that would deflect when placed in a rectangular cut out to hold it in place, so a rectangle the size of the switch was cut out of the model in the location discussed earlier and would be the location of the switch. By implementing this switch into the handle of the device, the device is compliant with ASTM A380/A380M-17. This standard states that when using degreasing solutions to clean metal surfaces in places that do not require extreme caution when using chemicals such as surgical, aerospace, or nuclear applications that amount of fluid used should be no more than the minimum amount to clean the surface. This switch easily allows the user to control the flow of the degreasing solution and use as little or as much as deemed necessary. Some zerks will not require any solution while others will require a lot. However, by implementing the switch, the user is given complete control of this function.

The next change that needed to be made to the design was removing the tabs that would be used to hold the mounting tabs for the motor and pump mounts in place. To do this a rectangle was removed from the middle of the CAD model one on the top side which is where the motor would mount and one on the bottom side which is where the pump would mount. The areas that were removed were the same size as the tabs of the motor mount. This was done for two reasons, the first being by making everything the same size the two halves should fit together nicely and there wouldn’t be a gap in the seam when assembled. The second reason is that by removing as little interior material as possible it would make the exterior of the device as strong as possible.

These changes covered all of the notes of items that needed to be fixed when assembling design two and made the changes needed to house the new components that were added with this done the third design iteration for the handle could be printed. The updated CAD model that contains all the modifications for design three can be seen in Figure 20.

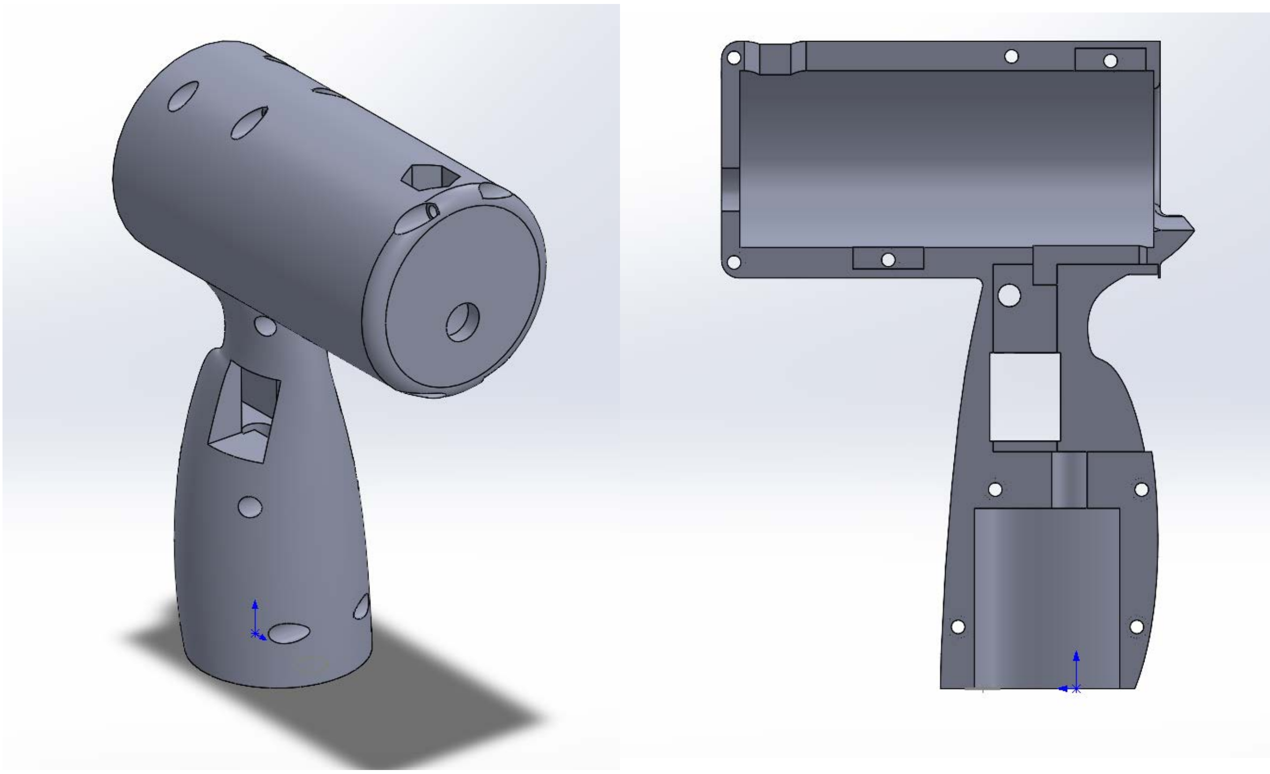


Figure 20: Design Three Cad Model

5.3.3 Assembly

After the device was printed using the same process that was used to print the second one it was removed from the printer and the components could begin to be inserted into the device. The first component that was inserted was the motor and motor mount. These components fit very well into their respective spots and the motor mount fit inside the mounting tab slot. The tank was next connected to the pump, and they were placed in their respective spots once again they fit very well and the pump mount fit well in its slot. The final piece was the battery and adapter as discussed above. The battery and battery adapter were sufficient in design two so nothing was changed, thus meaning it fit very well into design two. Having all the components in their respective places and fitting inside the model meant that the wiring process could begin. Still not having a control mechanism for the motor, a variable speed drill trigger was ordered from Amazon. This would allow the operator to run the grease zerk cleaning head at whatever RPM they deemed fit to remove the contamination on the greasy zerk and would also fit in the trigger slot that was already in the design by making the width and height of the slot slightly smaller. Once the motor came in one set of leads were soldered to the motor leads, and the other to the wires to the battery adapter. After this was complete the switch was wired in by soldering wires from the battery adapter wires to the switch and from the switch to the pump. Once this was complete, the battery was inserted into the battery adapter to test the switch and trigger. The trigger and pump both functioned properly and could be operated independently or at the same time meaning the wiring had been done correctly. The left half of the assembled design three

Figure 21: Design Three Assembled

which is the side that housed all the components can be seen in Figure 21.

While this seemed to mean everything was functioning properly and the testing could begin to see how the device function problems arose when it came time to assemble the two halves of the device. To assemble the two halves the process is very simple the second half is laid on top of the first half and the M4 hex bolts are placed through the bolt holes on the device ensuring that the motor and pump mount holes are aligned so that the bolt in that hole is also holding the mount secure, and then place a nut on the backside of the bolt and tighten until they are snug. When doing this all the bolt holes lined up, but it would not tighten down probably so that there was no gap. The fitment issue was due to multiple reasons the first being the switch was recessed in the handle and the depth of the switch once the wires were attached to the leads coming off the back was not accounted for in the initial CAD design, so the wires hit the other half of the model causing a gap there. Also, the six wires which included the battery adapter, pump, and trigger wires were too bulky and would not fit inside the designated hole that was made for them in the middle of the handle. Besides wiring the tabs, which were used to mount the motor and the pump being the exact size of the cut out caused some interference where the two halves met due to there being no room for error and the 3-D printer not having amazing tolerances. While this interference was small between the two tab slots, it still caused a gap at the bottom and top where the two halves should be bolted together. These issues would not let the model be assembled, creating the need for a fourth the design.

5.4 FINAL DESIGN (DESIGN 4)

5.4.1 CAD Model Changes

The components that were used for design three all worked independently, and function together properly to make the grease zerk cleaning device work, so no new components needed to be added. The only changes that needed to be made in the fourth design was the exterior of the device. The first change that was made in the fourth design was changing how the switch for the pump was mounted in the handle. In design three the area which the switch was made was simply cut out of the handle so it would mount flush with the outside of the handle, as previously said this did not leave enough room for the wired connections from the battery, and to the pump. To fix this a small box that protruded out of the handle was placed were the switch was previously located, and the dimensions of the switch were cut out from the inside of that box all the way through the handle. Due to the shape of the handle, and the location of the box it did not make it any less comfortable to be held with one hand as it was in the smallest part of the handle and would fit in a gap that would be made by the operator’s hand when they were holding the handle. By placing this switch inside the box, it offset the switch enough on the inside so that the wires could be connected to the leads on the backside and still be routed to their respective locations. The next change that was made was enlarging the cylindrical hole that ran from the battery cavity to the top of the device so there was plenty of rooms for all of the wires of the device and their connections. Lastly, the tab cut outs on the device handle that held the motor and pump mount were oversized by a factor of 1.25 so that there would be plenty of area for the tabs to sit in their cutouts but still held tightly in place by the bolts that ran through the holes. These changes were the only ones noted when assembling the third design, so the CAD model was ready to be printed again on the 3-D printer, this final CAD model can be seen in Figure 22.

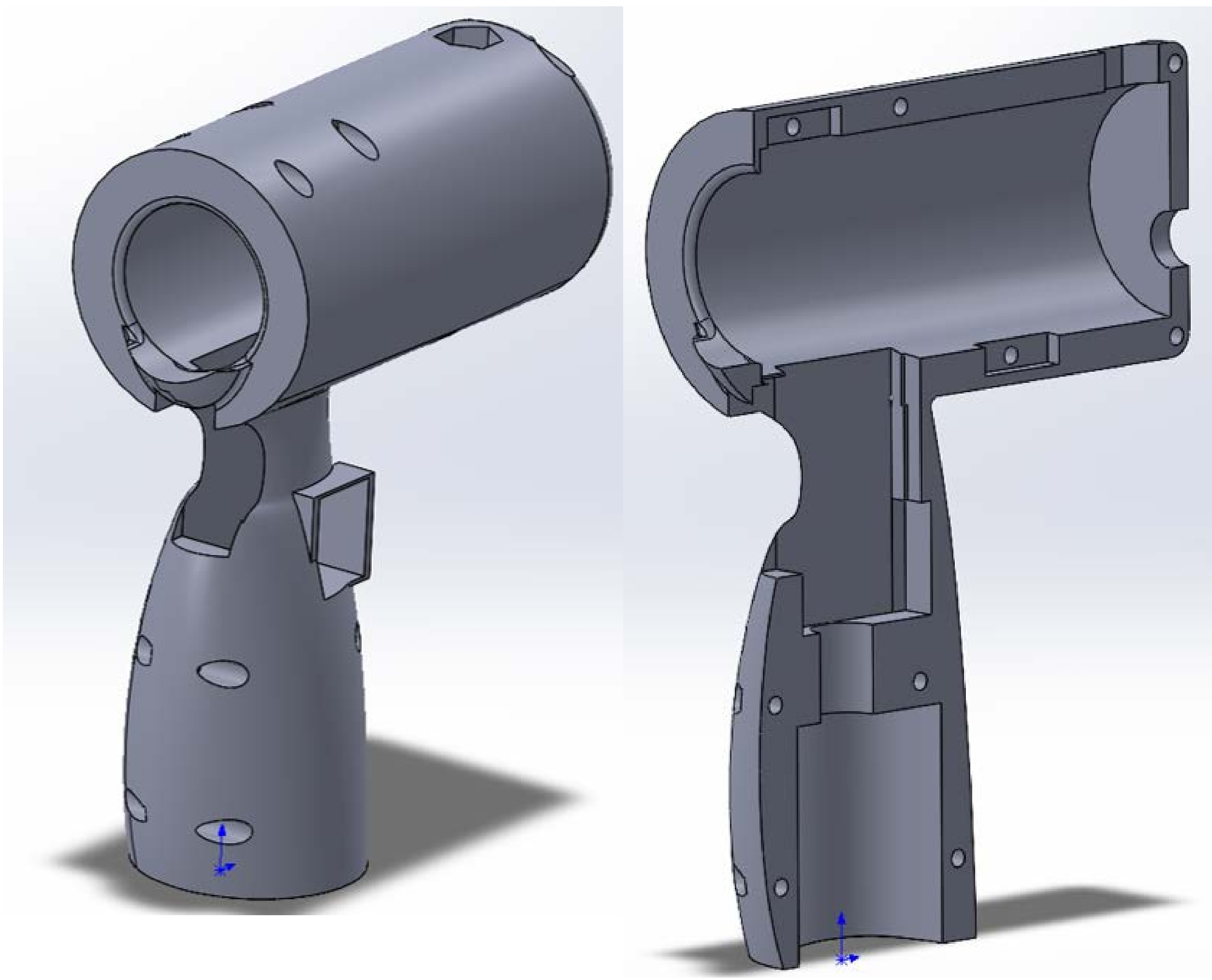


Figure 22: Design Four CAD Model

5.4.2 Assembly

Once the print was completed and removed from the 3-D printer the components could be placed in their correct locations. The components for the device were placed in the model using the same procedure that was used for the third design. All the wires that were solder on the motor, pump, switch, and trigger were left on the device. However, this time the wires connecting the switch were not soldered directly on to the positive and negative wires of the pump and battery like in the previous model. Instead Wago wire connectors were used to connect the wires. A Wago wire connector is a wire nut with a lever on it that holds the wires firmly crimped in place when engaged, but the lever can be disengaged to allow the wires to be removed from the connection, this was done so that the switch could be removed from the device once assembled. In design three these connections were soldered which meant once the device was assembled and the wires were connected, it could not be disassembled without melting the solder of the wires connected to the pump. While this was a small change it would now allow the device to be easily dissembled and any component that failed could be replaced by just loosening the bolts and working on that component instead of first having to addressing the wires connected to the switch. Having all the components placed in the model, secured and wired to the power source the other half of the model could be placed over top, and bolted down. This time once the two halves were together, and the bolts were tightened down there was no gap between the two seams, and all the components were held securely in place which meant that the initial design worked, and the grease zerk cleaning device was complete. The last component that needed to be added to the exterior of the device was an attachment that held the cleaning hose in the correct place during the cleaning process. To do this a CAD model was made of a half ring with the same diameter as the exterior of the device. Then a small circle and ring were added to the top of the CAD model that would route the hose for the cleaning solution in the correct direction, and make sure the hose is held in the correct place to apply the cleaning solution to the dirty grease zerk. The CAD model was then printed out on the 3-D printer and snapped into place on the exterior of the device. The final design can be seen in Figure 23. The picture on the left shows one half of the device with all the components inside of it, and the picture on the right shows the final product once assembled. This meant that the initial design of the device was done and the testing and refinement of how the device could begin.

Figure 23: Design Four with Components Inside (left) and Assembled (right)

6 RESULTS

After choosing a final design and completing the assembly process, the device was tested. The main focus during the testing process was to determine if the device could clean grease zerks quickly and effectively as that was the most important goal for this project. The first tests were completed in the Applied Engineering Center at USI as there are many grease zerks on the machinery throughout the shop. The device cleaned very well in the first trials and some of those were even completed without the use of the degreasing solution. The team found that if a zerk had been recently greased, the cleaning process was much easier and required little to no degreasing solution. However, zerks that had not been greased in a while and had built up grease and debris needed the solution to help agitate the debris and allow the device to clean. This result justifies why the team chose to have the pump and motor operate independently from each other. This allows the user to assess each zerk and use as little or as much degreasing solution as deemed necessary. Shown below are before and after images taken during the testing process. The first set of images is from the AEC and this trial was completed without degreasing solution. The second set of images was taken by a team member at work where the device was used in a real work setting. This trial was completed using the degreasing solution as there was a lot of built up grease and debris. The device cleaned the zerk without issue and the before and after show how effective the device is.

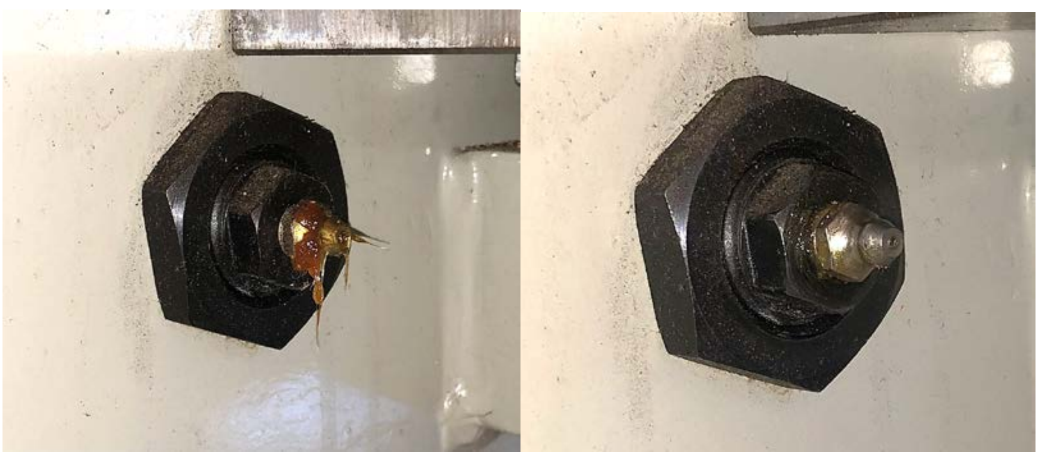


Figure 24: Before (left) and After (right) Images Without Using Degreasing Solution

Figure 25: Before (left) and After (right) Images Using Degreasing Solution

Another key point to address along with the device's quickness and effectiveness is how many zerks the device can clean before the steel wool in the attachment needs to be changed due to grease and debris build up. While the team did not have access to hundreds or thousands of dirty zerks to record a large dataset, through the testing done in the AEC, a sample of steel wool was able to effectively clean around 28 grease zerks before it stopped cleaning as well as it previously had been and needed to be changed out multiple times. This depends on the amount of grease and debris on each zerk which can vary largely from zerk to zerk, but on average, the team believes 20 to 30 uses is a number that could be regularly achieved in any testing environment. It should also be noted that even when the steel wool needs to be changed from the cleaning attachment, that process takes only seconds to complete. The user simply pulls the ball of wool from the attachment and inserts another ball of similar size. Even if this process needs to be done regularly, it costs the user a negligible amount of time. The cost to change the steel wool is also negligible as the amount of steel wool needed to fill up the cleaning end is around 2 ounces. The cost of 2 ounces of coarse grain steel wool that was used for the testing cost around half of a cent and can be easily sourced from any hardware or grocery store.

After experimenting with the device's cleaning ability, other aspects of the device were tested. Other requirements such as the size, weight, and durability of the device were important to the team. The weight of the device was measured to be 3.7 pounds which was well under the 10 pound maximum that had been previously set. This low weight of the device made it very comfortable to use and carry without issue for extended periods of time during use. This was very important to the team as it should make the device much more appealing to future users. Along with the low weight of the device, it was also easy to handle and use in terms of its size. The handle fits in the hand very well and allows the user to get the device into many different areas to clean any zerks that may need cleaning. However, while the weight of the device and its handle allow for easy use, the overall size of the device including the solution storage tank ended up being a little bit larger than the team expected. While this measurement does slightly limit the device, it is still very effective. Further discussion of this overall size can be found in the Key Insights and Challenges section of the report.

As previously mentioned, the weight of the device was kept low. While this is good for the comfortability of the device, the durability was decreased. By decreasing the weight of the device and trying to keep it small enough to fit in the average user's hand, the durability of the device was noticeably lessened. Before completing any durability testing, the team was not optimistic that the device could withstand many drop tests or anything of that sort. In order to keep the final design intact, previously 3D-printed models of designs two and three were used to get a good estimate of the durability of the final design. The device bodies printed for designs two and three were assembled just as before, except filled with rocks and scrap metal to make the test model 3.7 pounds which matched the weight of the final design. After assembly, the test models were dropped from various heights and positions. The test models produced similar results. The first test model survived three drops from two feet off the ground and one drop from four feet. On the second drop from four feet, the device handle completely failed and left the device in two pieces. The second test model was dropped from a height of about 7 feet. This single drop produced the same results as multiple lower drops did. The handle completely failed in the same location as before and the device was left in two pieces. This was not a surprise to the team. Further discussion of the decisions made regarding this issue can be found below in the Key Insights and Challenges section of the report. The image shown below is after the completion of the drop test. The failure can be clearly identified across the handle and the device would no longer be usable after a failure of this magnitude.

Figure 26: Results from the Drop Test

The last aspect of the device that the team tested was the battery life. The team had previously set a goal of six hours of continuous run time for the device. While an exact number of hours was not obtained for the run time of the device, the team concluded that this number was not within reach given the battery is supplying power to the motor and pump. However, after several hours of testing, the battery being used was never depleted. This leads the team to believe that the device could reach six hours of total run time that includes stoppage in between uses which is more practical for use in the field anyway. While there was not sufficient time to get an exact value for the run time, the team firmly believes that users in the field could easily use the device for six total hours before needing to replace or recharge the battery powering the device. This is another value that can vary depending on how often the pump and motor are used for each zerk that is cleaned.

7 SAVINGS

While the grease zerk cleaning device was made to be a more efficient and environmentally friendly solution to cleaning grease zerks, it was also a goal to create a device that would save the end user money. As discussed above, the previous method of cleaning grease zerks with paper towels required a large amount of paper towels over time, and this reoccurring cost of buying paper towels becomes expensive over time. For the return on investment calculations the total number of greases zerks on a farm from Appendix A will be used. As estimated Appendix A, the total number of greases zerks cleaned on a farm in a calendar year is around 5200 zerks. Due to the exposure to dust, dirt, and water these grease zerks are often very dirty and usually only five zerks can be cleaned with one paper towel. This means that around 1,000 paper towels are used every year to clean grease zerks alone. The towels this farmer uses cost 14 dollars for 200 towels, this means he spends around 80 dollars on shop towels in a year.

The grease zerk cleaning device could be reproduced for around 120 dollars if the end-user did not already have a Milwaukee battery on hand, and 100 dollars if they did have the battery. The price breakdown of the components inside the device, and the total cost of the device can be seen in Appendix D. The cost to fill the cleaning end with steel wool is around a half of penny, and that amount can clean 28 zerks, so to clean 5200 zerks it would cost around a dollar in steel wool. This means that after about a year and a half of use the end-user would break even on the cost of paper towels, and any time after that would be saving the operator money.

8 KEY INSIGHTS AND CHALLENGES

The first challenge the team encountered with the building portion of this project was inaccurate dimensions for parts and components ordered online. This challenge played an important role in the design decision that was made to switch from the solenoid to a small pump which is now in the final design. The online specification sheet for the solenoid led the team to believe that it was small and could be easily incorporated into the device body to control the flow of the degreasing solution. However, upon arrival, the team realized that the solenoid was much larger than expected and would require the body to be made noticeably larger which was not an option due to previously listed design constraints. This, along with some other issues regarding the solenoid, led to choosing the pump to control the flow of solution. There were several other instances that measurements caused problems for the team. Trying to match threads for the storage tank installation, print parts for press fit onto the pump and motor, and many other things all became difficult as the team quickly realized that many online retailers are not always accurate regarding measurements. However, the team overcame these challenges well as they appeared and learned a lot in the process.

After completing this project there were several key points that the team would like to address regarding the device that has been created. The first point being the total cost of this device and how economically friendly it will be to future users. The entire device was produced for around $120. However, the focal point of this device that the team would like to point out is the 3D-printed body. The body of the device was printed for less than $10 and can be made very easily. The team believes this is important to future users because if the device gets dropped, cracked, broken, etc. it will most likely be the body of the device that takes most of the damage. If the body of the device can successfully protect all the internal parts, which it did during the previous drop tests, this will allow users to replace that part easily if needed. A lot of power tools on the market are becoming very expensive and are not easily replaced. This is why the team believes this is a great characteristic of this device. Future users would be able to purchase this device for much less than many other power tools and be able to replace broken parts if needed with very little additional cost.

Another key point the team would like to address is the overall size of the device. The problem with designing this device was trying to add all the necessary components while still having the device remain handheld. It was very important to the team that future users could easily grab this device and clean zerks effectively and efficiently using only one hand. Several problems were caused by this constraint throughout the design process for the device. The first problem encountered was the overall height of the device which was previously mentioned in the results section. In order to have a place to store the degreasing solution, the team felt that a tank needed to be installed somewhere on the device to store the solution. The best place to attach this tank was on the top of the device. Not having much time, the team ordered a standard paint storage tank and added it into the design. As the project progressed, it was clear that this tank could be an issue due to its large size. However, the team had already made the design decision and made it work as well as possible. It should be noted that while the device is still very much operable with one hand, the storage tank can make it awkward to use depending on the positioning of the device to reach zerks that need cleaning. If there was more time to change the design, the team feels that a horizontal tank would distribute the weight much better across the top of the device and make for easier use. However, with the current design, the team advises that any future users should not fill the storage tank completely full. This extra weight so high up on the device creates a larger moment arm that makes the device harder to use and control. If the storage tank is kept at half capacity or less, it is much easier to use and more convenient for the user.

The next part of the device size that the team would like to address is the size of the handle on the device. There were a lot of components to be incorporated into the handle while ensuring that the average person could fit their hand around it and use the device using only that one hand. In order to have the switch, trigger, and several wires fit into the handle while not increasing the overall diameter, the team made a design decision to remove a lot of the wall material inside the handle making it extremely thin in some areas. While this was a success regarding the handle size, a design tradeoff was made involving the durability of the device which is the next point the team would like to address.

By decreasing the wall thickness so much in some areas around the handle to fit all components inside, the durability of the device was greatly reduced. As mentioned previously, drop tests for the device were completed during the testing phase of the project. These drop tests quickly showed the team that the durability of the device was not going to meet requirements. The device cannot withstand many drops from above two to three feet before completely failing.

However, the team believed that keeping the device handheld was much more important than the durability for this project. This is why the team decided to make the design tradeoff for this specific problem. It should be noted that some of the durability could be recovered if a different material was used in the 3D-printing of the device body. The most readily available material for this project was PLA which is not the strongest 3D-printing material.

REFERENCES

[1]Mowry, M. (2011b, Spring). The true cost of bearing lubrication - igus.

[2]Koulocheris, D., et al. "Experimental study of the impact of grease particle contaminants on wear and fatigue life of ball bearings." *Engineering Failure Analysis* 39 (2014): 164-180.

[3] Holdmeyer, D. (2022). Regrease properly. Tribology & Lubrication Technology, 78(4), 22-24.

[4] OSHA. (1978, October 24). *29 CFR § 1910.241 - definitions.* Legal Information Institute. https://www.law.cornell.edu/cfr/text/29/1910.241

[5] Morris, M., & Tosunoglu, S. (2012). Comparison of rechargeable battery technologies. ASME early career technical journal, 11, 148-155.

[6] Techspray. (2018, August 3). *Chemtronics*. Techspray. https://www.techspray.com/a-thorough-comparison-of-water-based-cleaners-and-solvent-cleaners?

[7] Kočí, J. (2021, January 22). *Everything you need to know about infills*. Original Prusa 3D Printers. https://blog.prusa3d.com/everything-you-need-to-know-about-infills_43579/

APPENDIX

Appendix A: Total Grease Zerks on a Farm

Number of Grease Zerks on 1000-acre farm			
Equipment	Number of Zerks	Estimated times they are greased in a calendar year	Total Grease Zerks
1770nt 16 row Corn Planter	132	10	1320
1795 Split Row 31 Bean Planter	140	10	1400
Wheat Drill	54	4	216
Tractors (x6)	144	8	1152
Combine	40	8	320
Disc	24	10	240
BlueJet Liquid Sidedress Bar	42	4	168
Salford	64	6	384
		Total:	5200

Appendix B : HC785LP RS-785 Motor Data Sheet

HC785LP-012 — Low Voltage DC Motors

Characteristics:

High Power DC motor

Specifications:

Dimensions	: Ø 42.3 X 67.0 mm
Shaft Diameter	: Ø 5.005 mm
Input Voltage	: 18.0 V DC
No Load Speed	: 20950 rpm
No Load Current	: 2.90 A
Stall Torque	: 1175.03 mNm
Stall Current	: 138.64 A
Maximum Output Power	: 644.74 W
Maximum Efficiency	: 78 %
Speed at Maximum Efficiency	: 18300 rpm
Life (typical)	: 18 hr
Weight	: 380 g
Operation Temperature	: -10 to 55 °C
Storage Temperature	: -20 to 80 °C
Electrical Connection	: Terminal

Performance Data:

	No Load	Stall	Max Efficiency	Max Power
Current (A)	2.90	138.64	19.99	70.76
Efficiency (%)	-	-	78	50
Output Power (W)	-	-	-	644.74
Speed (rpm)	20950	-	18310	10475
Torque (mNm)	-	1175.03	148.10	587.51

Application Examples:

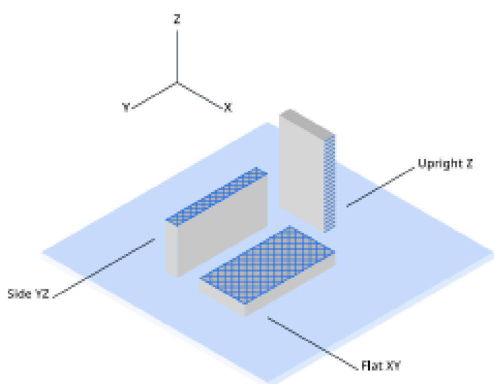
Drills, Power Equipment

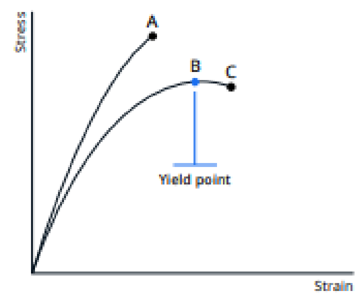
Appendix C : PLA Datasheet

Mechanical properties

All samples were 3D printed. See 'Notes' section for details.

	Test method	Typical value		
		XY (Flat)	YZ (Side)	Z (Up)
Tensile (Young's) modulus	ASTM D3039 (1 mm / min)	3250 ± 119 MPa	3292 ± 101 MPa	3071 ± 181 MPa
Tensile stress at yield	ASTM D3039 (5 mm / min)	52.5 ± 0.9 MPa	59.0 ± 0.7 MPa	No yield
Tensile stress at break	ASTM D3039 (5 mm / min)	45.5 ± 1.1 Mpa	56.0 ± 1.5 MPa	33.1 ± 2.8 MPa
Elongation at yield	ASTM D3039 (5 mm / min)	3.4 ± 0.0%	3.4 ± 0.1%	No yield
Elongation at break	ASTM D3039 (5 mm / min)	7.8 ± 1.2%	4.2 ± 0.7%	2.0 ± 0.2%
Flexural modulus	ISO 178 (1 mm / min)	3019 ± 87 MPa	2894 ± 53 MPa	2740 ± 47 MPa
Flexural strength	ISO 178 (5 mm / min)	96.8 MPa at 2.5% strain	101.3 MPa at 1.1% strain	52.0 MPa at 4.4% strain
Flexural strain at break	ISO 178 (5 mm / min)	4.8 ± 0.2%	No break (>10%)	1.9 ± 0.2%
Charpy impact strength (at 23 °C)	ISO 179-1 / 1eB (notched)	3.9 ± 0.4 kJ/m²	-	-
Hardness	ISO 7619-1 (Durometer, Shore D)	84 Shore D	-	-





A. Tensile stress at break, elongation at break (no yield point)
B. Tensile stress at yield, elongation at yield
C. Tensile stress at break, elongation at break

Print orientation

As the FFF process produces part in a layered structure, mechanical properties of the part vary depending on orientation of the part. In-plane there are differences between walls (following the contours of the part) and infill (layer of 45° lines). These differences can be seen in the the data for XY (printed flat on the build plate - mostly infill) and YZ (printed on its side - mostly walls). Additionally, the upright samples (Z direction) give information on the strength of the interlayer adhesion of the material. Typically the interlayer strength (Z) has the lowest strength in FFF.

Note: All samples are printed with 100% infill - blue lines in the ilustration indicate typical directionality of infill and walls in a printed part.

Tensile properties

Printed parts can yield before they break, where the material is deforming (necking) before it breaks completely. When this is the case, both the yield and break points will be reported. Typical materials that yield before breaking are materials with high toughness like Tough PLA, Nylon and CPE+.

If the material simply breaks without yielding, only the break point will be reported. This is the case for brittle materials like PLA and PC Transparant, as well as elastomers (like TPU).

Appendix D: Budget

Budget	
Item	**Cost**
Motor	$46.18
Solution Canister	$15.99
Battery	$18.88
Battery Adapter	$12.99
Pump	$17.77
PLA	$8.50
Total	**$120.31**

Appendix E: ABET Outcome 2, Design Factor Considerations

ABET Outcome 2 states "*An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health safety, and welfare, as well as global, cultural, social, environmental, and economic factors.*"

ABET also requires that design projects reference appropriate professional standards, such as IEEE, ATSM, etc.

For each of the factors in Table N.1, indicate the page number(s) of your report where the item is addressed, or provide a statement regarding why the factor is not applicable for this project.

Table N.1, Design Factors Considered

Design Factor	Page number, or reason not applicable
Public health, safety, and welfare	12, 24
Global	3,24,25
Cultural	All information that was gathered on the grease zerk cleaning process, waste produced, and solutions were gathered with information inside the United States. Due to the lack of knowledge about other culture practices it is unknown how this will affect cultures.
Social	Grease zerks are not necessarily a social topic, so therefore a process for cleaning them does not have any social effects.
Environmental	3,24,25
Economic	3,45

Ethical & Professional	24,25
Reference for Standards	12, 34