Product design of an automatic spice crusher

Design, manufacture, analysis

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Abstract:

This thesis aims to design, manufacture and analyze an automatic spice crusher. The thesis describes the work done towards achieving the goal of manufacturing a functional automatic spice crusher following the guidance of product design principle. After the initial idea to convert a traditional spice crusher into an automatic one, a sketch was made. Through constant design iteration and 3D printing the parts, necessary design changes were made in the SolidWorks environment for better results. All objectives of thesis, i.e., to design an automatic spice crusher, 3D printing and prototyping the intended product, assembly of parts and analysis of the developed prototype was achieved and is discussed in the thesis. While improvements could still be made in the future regarding automatic spice crusher, this thesis provides a benchmark for anybody aiming to design their own product or updating an existing one.

Keywords: Desing, product design, analysis, mechanics

Acknowledgments

I would like to use this opportunity to express my gratitude towards my teachers, starting with my thesis supervisor, Rizwan Ullah, who has constantly supported me throughout my thesis, and provided invaluable guidance. Similarly, I would like to express my gratitude towards my teachers, Harri Anukka and Silas Gebrehiwot, who have constantly provided me with much needed guidance and their valuable expertise towards completing my thesis. I would like to take this opportunity to thank my friends and family, especially my mom and my sisters for believing in me. Finally, I would like to thank my wife, Nicole Lamichane, for constantly motivating me and encouraging me.

Contents

1 Introduction

With the rapid advancements in technology across various fields, automation has increasingly simplified our daily tasks, enhancing the convenience of our routine activities. One such task is the manual crushing of spices in the kitchen. The electric spice grinder offers making a paste with the use of rotary blades. Choosing the fineness of the spice mix is not possible in the modern grinder that uses blades, and the cleaning process is rather difficult. This thesis addresses the challenge of studying the functional requirements of a more effective spice crusher, emphasizing the integration of 3D printing and product development principles. The need to study this topic arises from the desire to design, manufacture, and analyse a spice crusher.

1.1 Background

Spices have long been used in culinary arts, dating back to ancient societies when they were prized for both their flavor and therapeutic qualities. In the past, simple implements like stones, wooden or metal mortars and pestles (Figure 1) were used to grind spices. Even while these manual techniques worked well, they took a lot of time and labor. Instruments for crushing spices have developed in parallel with human civilization, and during the industrial revolution, when mechanized grinding instruments were introduced, notable developments were made (How spices changed the ancient world, 2019).

The equipment used in the processing of spices has advanced greatly from basic manual grinders to complex automated systems. Stone mills and manual spice grinders were among the first tools used; around the middle of the 20th century, however, as time passed, electric spice grinders took their place (The Role of Technology in Modern Kitchen Design, 2024). Users were able to swiftly and consistently grind spices thanks to the efficiency and convenience that these electric grinders offered (The Art Of Indian Spice Grinding: Mortar And Pestle, 2023). The electric grinder, however, does not provide user an option to choose the level of fineness of the spices. Consumers often use mortar and pestle to crush their spice, due to their specific need, that electric grinders cannot provide.

Figure 1 Traditional spice crusher

1.2 Objectives of research

Electric grinder uses set of blades to make a paste of the mixture. The level of fineness cannot be determined by the user. Despite having electric grinders, consumer still use traditional mortar and pestle to crush their spice mix according to their needs. This thesis aims to fill that gap by designing and manufacturing an electric spice pounder that can crush spice with different level of fineness, instead of making it into a paste. This thesis also aims to study and investigate the process of designing and prototyping a product from scratch. We will design, simulate, design and optimize the product. The following are the main objectives of this thesis project.

- **Design an automatic spice crusher**: To design an automatic spice crusher
- **Prototype development**: Make the intended parts using 3D printing technology.
- **Assembly and testing**: Put the printed parts together to create a working prototype, and carrying out functional assessments.
- **Performance Analysis**: Assess the automatic spice crusher's functionality, effectiveness, and user-friendliness.

1.3 Compliance with degree program

The fundamental ideas of mechanical design and materials processing that aligns with the degree program are supported by this thesis. To complete this thesis, knowledge of material selection, CAD (computer aided design) will be utilized. Important mechanical design concepts like motion control, stress analysis, and prototyping are also incorporated into the project.

By illustrating the use of contemporary design and manufacturing techniques in the creation of a useful kitchen appliance, the project advances practical knowledge. It provides a thorough case study on the use of 3D printing to product development, the iterative design process, and the incorporation of automation into culinary tools.

1.4 Relevance to existing knowledge

The study done in this thesis not only deals with mechanics and manufacturing, but also investigates the basics of innovation to make our lives easier. It is not new to come up with a new product from traditional ideas. Almost all automatic machine we use today are optimized design of some sort of traditional simple machine.

Similarly, it is a common practice nowadays to 3D print a product to minimize manufacturing costs. In addition to minimizing the manufacturing costs, 3D printing also helps engineers check the feasibility/functionality of the product, optimize the potential errors, and make the product optimal before moving onto mass production stage.

A similar thesis about designing and manufacturing a functional product was written by Bijaya Poudel "How to make Portable Homemade Filament Extruder" (Poudel, 2015), where the author described designing and manufacturing a filament extruder using homemade and 3D printed parts. Another similar thesis written by Suman Thapa "3D Printing of Automobile Power Transmission System Using Tough PLA" (Thapa, 2020) also describes the use of SolidWorks to design automotive gear transmission and use of 3D printer to additive manufacture the PLA parts. In review with the above thesis's, this thesis aims to study the designing process of an automatic spice grinder and use it for its intended use. Moreover, it also describes the mechanism behind a functional product, and design optimization for an optimal product. The results of this thesis will help students to perform their own project and

troubleshoot design and manufacturing errors that may arise during a new product development.

2 Literature review

2.1 Simple machine

Any equipment that transforms the applied force through a medium is simple machine (Engineering: Simple machine, 2022). Simple machine has been used since ancient times to make our daily lives easier. Simple machines are rudimentary mechanical devices that change the direction or force of an applied force to facilitate work.

$$Mechanical\ advantage(\ M.A) = \frac{Load\ (F_0)}{Effort(F_i)} \qquad (1)$$

(FORMULAS RELATING TO MECHANICAL ADVANTAGE, 2010)

In basic machines, mechanical advantage is essential because it makes it possible to produce a bigger output force with a smaller input force, improving task performance, lowering effort levels, and making it easier to handle heavier loads. These basic machines are essential to comprehending the operation of many commonplace gadgets, and they can be combined to create more complicated machines (Augustyn, 2024).

Among such simple machines, mortar and pestle is the simple machine, from which our thesis is derived. The mortar is a bowl made up of hard materials and the pestle is a hard tool used to crush the spice. We will be attempting to convert a traditional mortar and pestle in an automatic one.

2.2 Motor

An apparatus that transforms electrical energy into mechanical energy is a motor (Motor, n.d.). It generates motion by applying the electromagnetic principle. While there are many different kinds of motors, the electric motor is the most often used. It consists of a revolving rotor fastened to the motor shaft and a stationary stator with wire coils. Rotation is produced via an electromagnetic interaction between the rotor's field and the stator's magnetic field. In DC

motors, a commutator and brushes reverse the direction of the current while preserving spin, producing mechanical energy for a variety of uses.

$$Power(P) = torque(\tau) * angular\ velocity(\omega) \quad (2)$$

(Angular Motion, 2024)

In motors, torque, power, and angular velocity are essential since they define motor's operation. Together, these three parameters ascertain the motor's work capacity, rotational force, and speed of rotation. Because of their effectiveness, dependability, and versatility, electric motors are widely employed in many different applications. Large motors used in industrial machinery and vehicles and small motors used in domestic appliances are only two examples of the various sizes and configurations available for them. (Slemon, 2024)

2.3 Machine design

The methodical process of building or enhancing machinery to carry out particular duties effectively and dependably is known as machine design (Design, Technilogy, 2023). It is used in a broad range of fields, including as manufacturing technology, computer-aided design (CAD), materials science, and mechanical engineering. Despite the difference in industry in which machine design is used, the machine design follows a similar pattern, that is described as follows (Design, Technilogy, 2023);

2.3.1 Problem identification and requirements analysis

The first step in the process is determining whether a new machine is necessary, or whether an existing one can be improved. Understanding the intended use, user demands, performance expectations, environmental variables, safety laws, and financial restrictions helps engineers gather requirements (Matale, 2022).

2.3.2 Conceptualization and brainstorming

To solve the specified problem, engineers come up with ideas and concepts. They investigate several design options while taking ergonomics, manufacturability, aesthetics,

and utility into account. Idea refinement and concept selection are aided by brainstorming sessions and concept sketching.

2.3.3 Design specifications and constraints

Following the selection of a concept, engineers set forth particular design requirements and limitations. This include specifying the machine's required dimensions, tolerances, material qualities, operating environment, and performance standards.

2.3.4 Analysis and simulation

To assess the viability and performance of the suggested design, engineers do analyses and conduct simulations. Structural integrity, thermal behavior, fluid flow, and other important factors can be evaluated using finite element analysis (FEA), computational fluid dynamics (CFD), and other computational tools.

2.3.5 Detailed design and engineering drawings

After the design concept has been approved, engineers use CAD software to produce detailed designs and engineering drawings. The geometric measurements, part configurations, assembly guidelines, and material specifications required for manufacturing are all included in these drawings.

2.3.6 Development and testing of the product

The machine's design and functionality are confirmed through the construction of a prototype. Through iterative testing and refining, engineers can use prototyping to find and fix any design faults, performance issues, or usability concerns.

2.3.7 Materials selection and procurement

Mechanical characteristics, durability, corrosion resistance, and cost-effectiveness etc are among the factors that engineers consider when choosing the right materials. To get the supplies and parts needed for production, they collaborate closely with suppliers.

2.3.8 Manufacturing and assembly

After the design is complete, the individual components can be manufactured using a variety of manufacturing techniques, including but not limited to welding, casting, forging, and additive manufacturing. These parts are assembled into the finished product/s by knowledgeable technicians who adhere to thorough assembly instructions.

2.3.9 Quality assurance and control

Strict quality control procedures are followed all the way through the manufacturing process to guarantee that the product satisfies performance and design requirements. The machine's compliance with industry norms and regulations may be verified via inspections, testing, and certifications.

2.3.10 Documentation and user manuals

To assist users in efficiently running, maintaining, and troubleshooting the equipment, a wealth of paperwork is developed, including operation manuals, maintenance guidelines, and catalogues of spare parts.

2.3.11 Deployment, training, and support

After the machine is finished, it is put to use for its intended purpose and users receive training on how to operate and maintain it. To guarantee peak performance and longevity, regular updates, maintenance services, and ongoing technical support could be offered.

In order to translate concepts into workable, dependable machines that satisfy users' and stakeholders' needs, cross-functional teams must collaborate during the machine design process. Innovation and constant improvement are key factors that propel machine design improvements in a variety of industries. (Design, Technilogy, 2023)

2.4 Product design

The process of developing new products or enhancing current ones to satisfy consumer demands and preferences while taking technical, financial, and aesthetic considerations into account is known as product design (what is product design, 2019). It entails a methodical

process that combines user experience, engineering, marketing, and design thinking components (what is product design, 2019).

Similar like machine design, designers produce CAD models and prototypes, generate and assess concepts, and write comprehensive specifications. These prototypes go through extensive testing to ensure that they work, are usable, and perform well. Iterative development makes sure the finished product satisfies every requirement. Cost, quality, and sustainability are considered while choosing materials and production techniques. Branding and packaging communicate the worth of the goods. Following debut, customer input and market data inform ongoing enhancements and upcoming changes (Your Complete Guide to Product Design (2023 Guide), 2023).

2.5 3D Modelling

The technique of utilizing specialist software to create digital representations of three-dimensional objects or scenes is known as 3D modelling (What is 3D Modeling?, 2024). These models can be applied to animation, manufacturing, simulation, and visualization, among other things. The salient features of 3D modelling are broken down as follows:

2.5.1 Geometry creation

Forming the fundamental geometric shapes that serve as the basis for the 3D model is the first step in the process. Primitive forms like cubes, spheres, cylinders, and cones can be used for this, while more sophisticated formations can be created by extruding, lofting, sweeping, or rotating 2D objects (What is 3D Modeling?, 2024).

2.5.2 Mesh Modelling

Mesh modelling is the process of shaping a polygonal mesh into the required shape by adjusting its faces, edges, and vertices. Tools like extrusion, beveling, chamfering, smoothing, and subdivision surface modelling can be used for this. Creating organic shapes, figures, and objects with fine details is a popular application for mesh modelling.

2.5.3 Surface Modelling

Surface modelling is the process of applying spline curves or mathematical formulae to create continuous, smooth surfaces. This method is frequently used to create intricate and accurate shapes for things like consumer goods, architectural structures, and car bodies. With the aid of surface modelling tools, designers can manipulate the surfaces' topology, curvature, and continuity to provide the required visual appeal and functional characteristics.

2.5.4 Parametric modelling

Using constraints and parameters, parametric modelling entails specifying a 3D model's geometric attributes. This saves designers the trouble of manually adjusting each individual component and makes it simple to update and modify the model by just changing the parameter values. In engineering and product design applications where design iterations and changes are prevalent, parametric modelling is frequently employed.

2.5.5 Texture Mapping

Texture mapping is the process of adding 2D patterns or images to a 3D model's surface in order to improve its visual appeal. Diffuse textures can be used to create color and pattern, normal maps can be used to give surface detail, displacement maps can simulate surface geometry, and specular maps can regulate surface reflection. For the purpose of creating realistic and immersive settings, texture mapping is frequently utilized in animation, gaming, and visualization applications.

2.5.6 Animation and rigging

To enable a 3D model to be animated and posed, rigging entails building a digital skeleton or armature. Keyframes are created and motion paths—which might include movements, transformations, deformations, and simulations—are defined for the model during the animation process (What is 3D modelling and what is it used for?, 2022). For 3D objects and characters to come to life in motion pictures, video games, and interactive media, rigging and animation are necessary.

2.5.7 Rendering

Rendering is the process of taking a 3D model and using it to create 2D visuals or animations by mimicking the way that materials and light behave in a virtual setting. In order to create realistic visuals with precise lighting, shadows, reflections, and textures, rendering software computes the interaction between light sources, surfaces, and cameras (What is 3D Modeling?, 2024). The process of 3D modelling frequently ends with rendering, which produces photorealistic representations for publications or presentations.

In general, 3D modelling is a flexible and effective technique that helps engineers, architects, designers, and artists to conceptualize, create, and convey their ideas in three dimensions. 3D modelling fosters creativity and innovation in a wide range of fields and sectors, whether it is utilized for concept sketches, engineering prototypes, architectural renderings, or animated characters (Zorana Jeli, 2016).

2.6 Design iteration

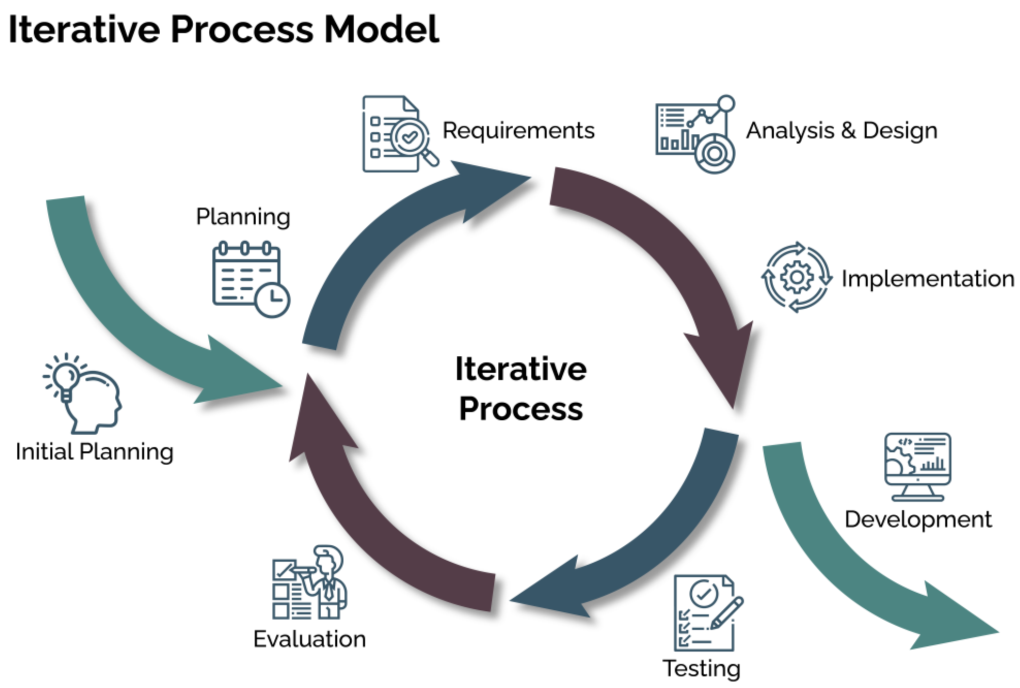


Figure 2 Iterative process model (What is iterative design, 2024)

A design iteration is a methodical, cyclical process that involves multiple cycles of testing, feedback, and improvement with the goal of improving a system or product (Figure 2). This process is essential to agile development and design thinking since it encourages creativity

and makes sure the product closely matches user expectations and demands (An Introduction to the Design Iteration Process, 2024).

Making the first iteration of the design, or prototype, is the first step in the process. After that, users or stakeholders test this prototype in order to get insightful input on its overall efficacy, usability, and functionality (An Introduction to the Design Iteration Process, 2024). The gathered feedback is examined to determine what needs to be changed or improved.

The required adjustments are made by designers and developers in the following stage, and the prototype is improved in light of the new knowledge (The iterative design process: a full guide for UX designers, 2023). The cycle is continued by subjecting this updated version to additional testing and user feedback. With each iteration, the design gets closer to its intended result and improves customer satisfaction, performance, and usability over time.

A primary benefit of design iteration is its capacity to promptly detect and address problems, hence reducing the likelihood of significant defects in the completed product. More flexibility is also made possible by it, allowing for the addition of fresh concepts and adjustments as they come up. Iterating continuously makes the design process more user-responsive and adaptable, which eventually produces a more successful and user-centered solution (Adams, 2002).

3 Methodology

In this section, detail of steps taken to achieve the objectives are mentioned. This include description of software, hardware and process flow with detailed description so that this work can be validated and verified, if needed. The principles of product development will be used as guidance to develop our spice crusher.

The automatic spice grinder needs to ground different spices effectively and consistently finely, with user-friendly features that make cleaning, disassembly, and installation simple. It should be strong, made of sturdy materials, and have speed settings that may be changed to accommodate various textures. For ordinary kitchens, safety features and a small, attractive design are crucial. The product must also be economical, maximizing the use of materials and manufacturing techniques to preserve high quality while lowering production costs.

The project started with an idea to motorize the traditional mortar and pestle. We will be discussing the different stages of product design including sketch of the initial idea, design in SolidWorks, 3D printing of the designed parts and finally the assembly of the prototype.

3.1 Different stages of sketch of automatic spice crusher

After the idea to motorize the traditional mortar and pestle arose, we began to sketch the first sketch of the design of the automatic spice crusher as shown in figure 3. The idea was that a bowl would be situated on a plate. A pestle would be connected by a pin to a shaft that pivots in a stationary support. A Z like rod, as shown in figure 3 would be connected to a motor. As the motor spins, the rod will lift the pestle, after attaining the maximum height, the pestle will drop to crush the spice.

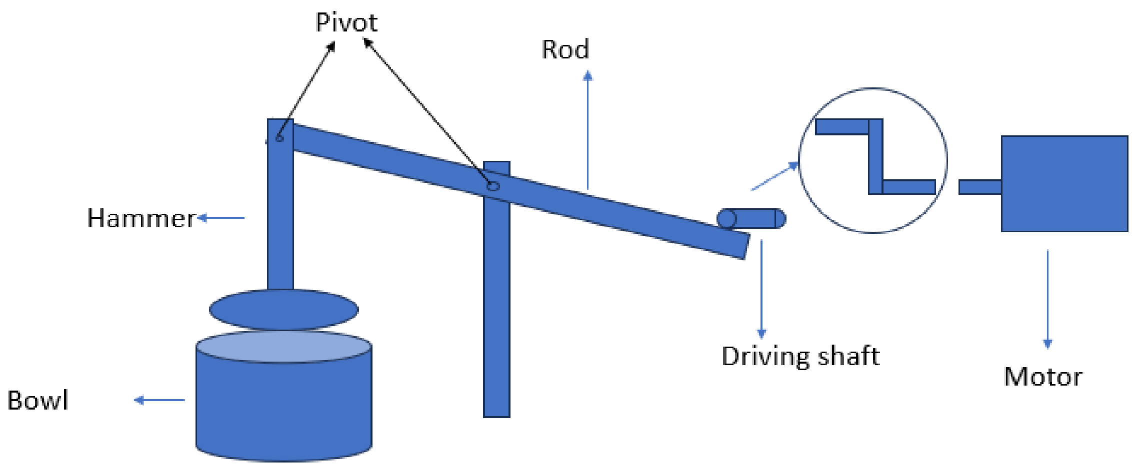


Figure 3 Design concept sketch

After discussing the idea with the supervisor, we modified the sketch to use a slider crank mechanism, as shown in figure 4. After basic mechanism of the product was outlined, we started to design the product in SolidWorks, while keeping in mind, the different parts required design a functional automatic spice crusher. The design process is described below.

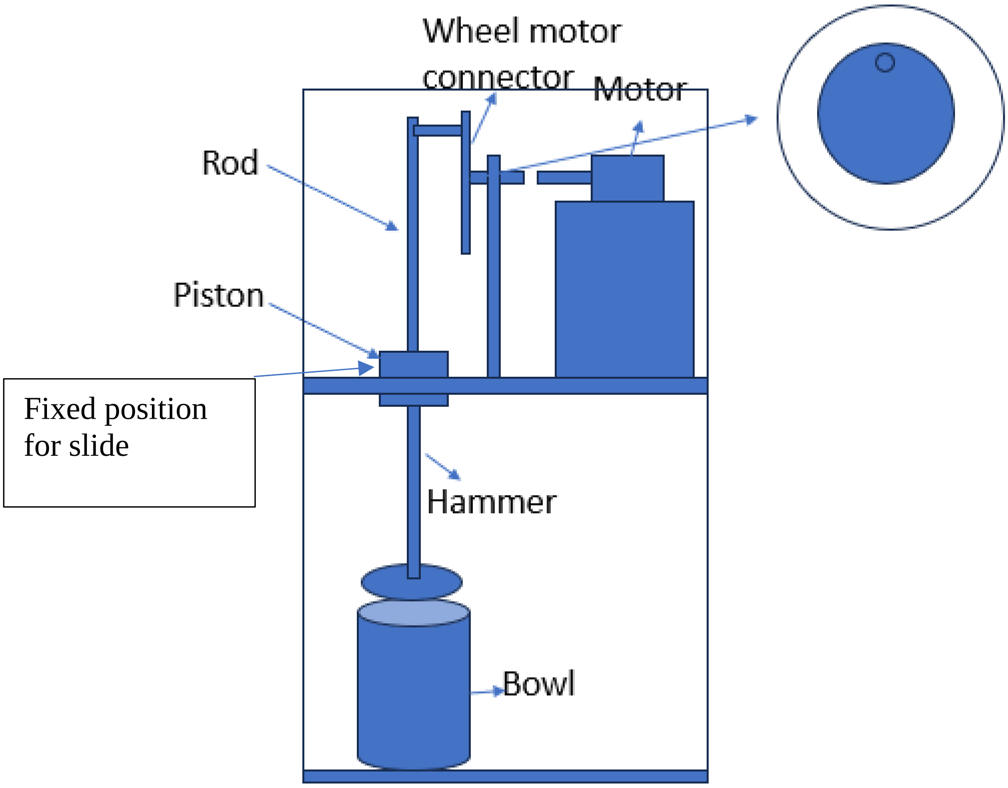


Figure 4 Sketch 2 of design

3.2 Design process in SolidWorks

The initial design process in SolidWorks started with a sturdy stand. The stand was a whole structure that included a square shaped hollow space for a piston, a locking mechanism for bowl, and space for shaft, as shown in figure 5.

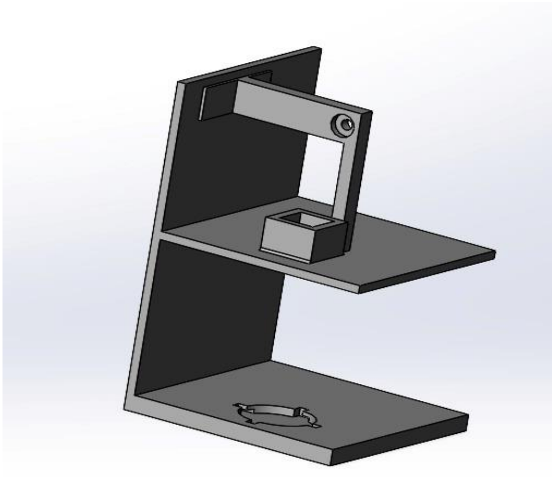


Figure 5 Stand frame

The next part we designed for the automatic spice crusher was a piston, as shown in figure 6. The piston consisted of a hollow shape for a rod, and a hollow space for a pin that will securely lock the rod and the piston.

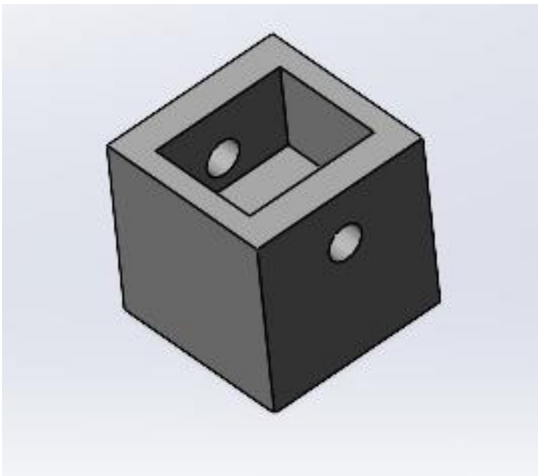


Figure 6 Piston design in SolidWorks

We the designed a rod that will be connected to the piston with a pin. The rods consisted of two circled hollow space for the bearings, as shown in figure 7. The bearing was bought first, after which the size to the hollow cavity in the rod was dimensioned to fit the bearing perfectly.

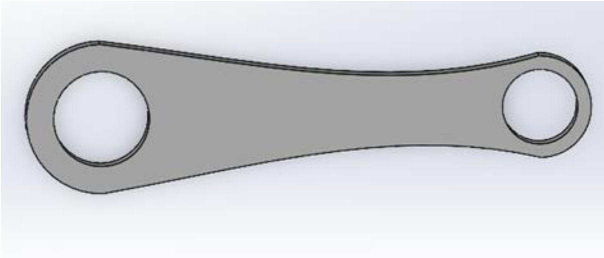


Figure 7 Rod design in SolidWorks

A wheel motor connector was designed to connect to the rod. The wheel motor connector consisted of a driving shaft that is going to be connected to a motor and an extruded part that connected with the rod, as shown in figure 8.

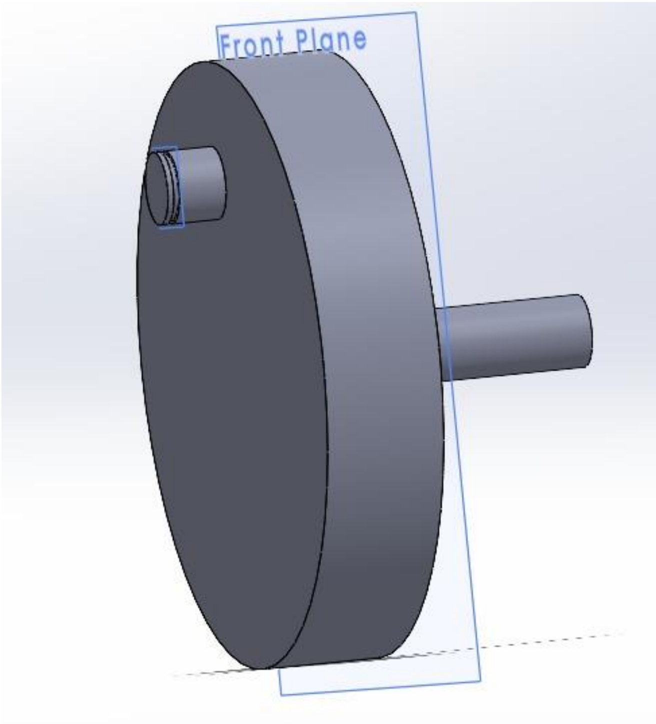


Figure 8 Wheel motor connector design in SolidWorks

The next part then designed was a hammer head. The hammer head consisted of an extruded part that locked into the piston, as shown in figure 9.

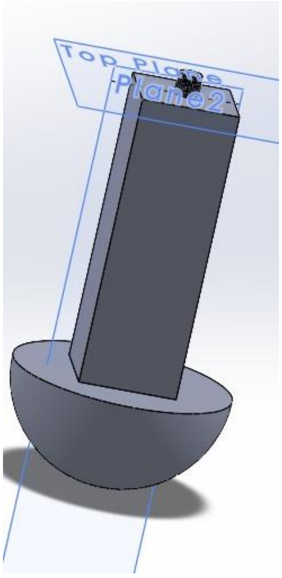


Figure 9 Hammer head design in SolidWorks

After designing the bowl (Figure 10), we started to assemble the parts in SolidWorks environment. Then, we started 3D printing our smaller parts and iterated the designs along the way.

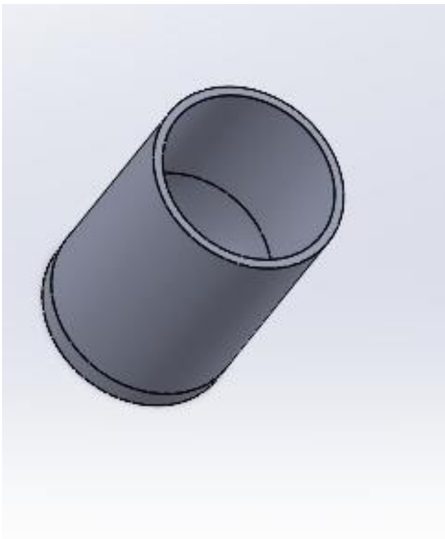


Figure 10 Bowl design in SolidWorks

3.3 3D printing, assembly and design iteration

The SolidWorks file we designed was uploaded in CURA (UltiMaker Cura, 2024),a slicing software, to generate g-code required to 3D print the parts using Creality ender 3 pro (Ender 3 Pro, 2024) (PLA (Polylacticacid), 2024). We used Polylactic acid (PLA) as our printing

material. We choose PLA because of its availability and cheap cost. The first part we printed was piston. The print settings we used, and the printed parts are shown in figure 11 and 12 respectively.

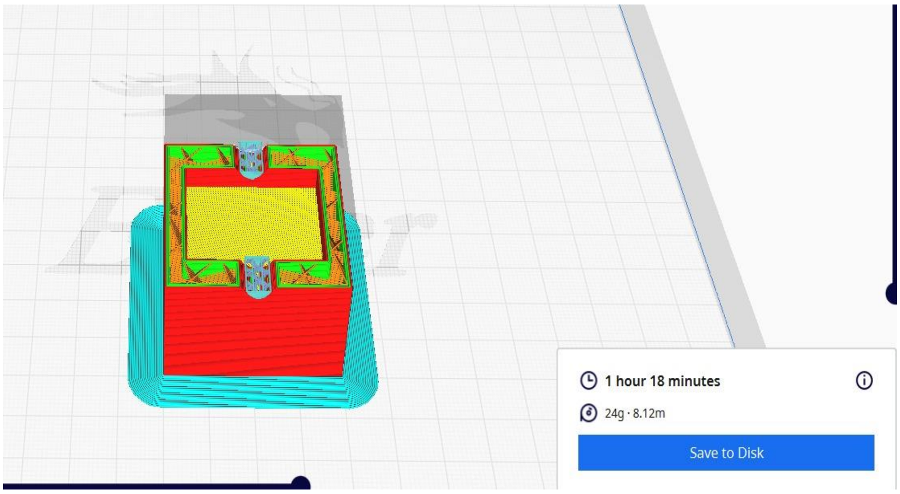


Figure 11 Piston in CURA

Figure 12 3D Printed piston and rod

After printing the piston and the rod, it came to our attention that the part did not function as initially thought. The end section of the rod did not fit inside the hollow cavity of the piston, hence, we had to iterate the design of the piston to fit the rod, as shown in Figure 13 and figure

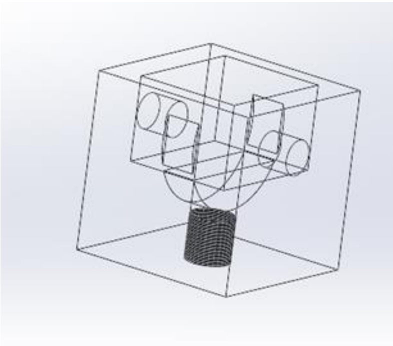


Figure 13 Piston hidden line view

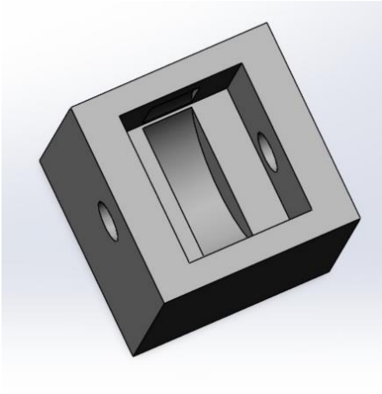


Figure 14 Piston iterated design

14. After 3D printing the piston again, the rod and the piston was secured together with a piston pin, as shown in Figure 15 and 16.

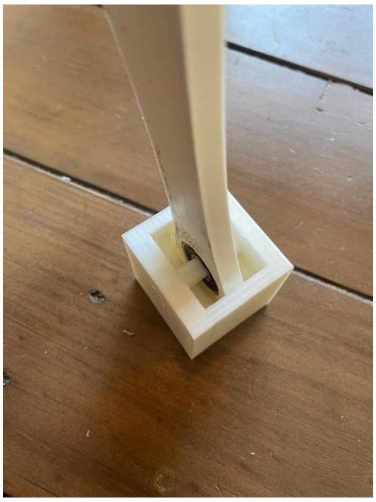


Figure 15 Rod, pin connected by piston pin

Figure 16 Iterated piston pin

The wheel motor connector was our next part to be printed. The print orientation of the wheel motor connector is shown below (Figure 17). After printing the part, it came to our attention, that the extruded part did not have the strength required to fulfil its purpose of transferring motion from the motor to the rod. The extruded part snapped from the joints (Figure 18). Hence, we divided the existing design into three smaller parts, i.e., a driving shaft (Figure 20), a wheel (Figure 19), and a dowel for the rod, as shown in figure below.

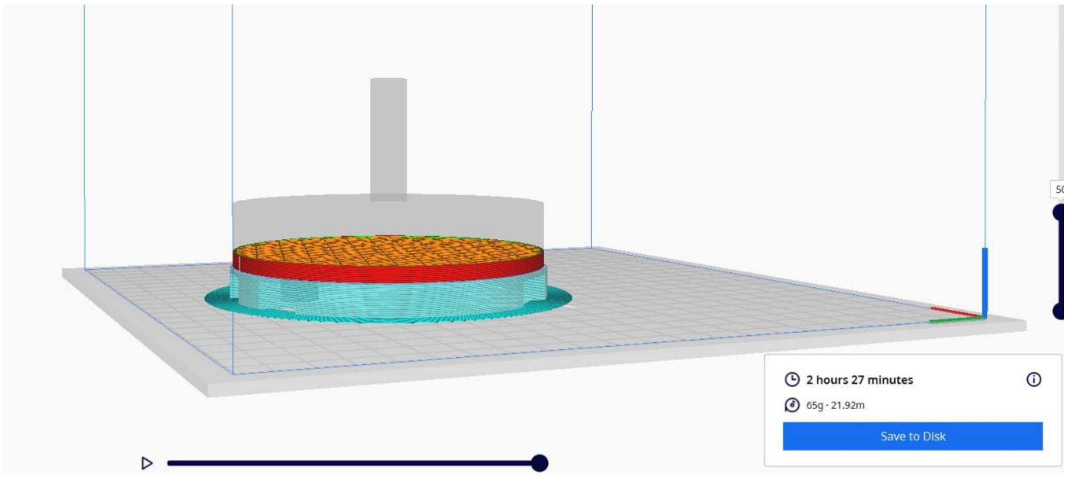


Figure 17 Initial wheel in CURA

Figure 18 Extruded part snapped off

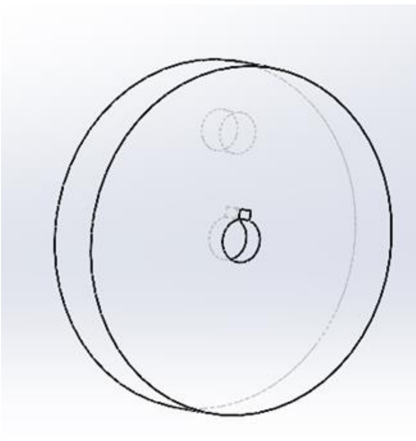


Figure 19 Wheel

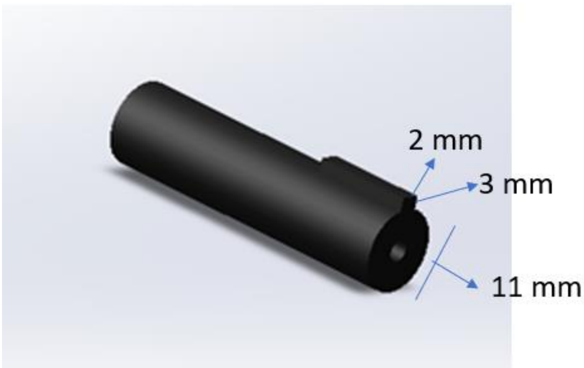


Figure 20 Driving shaft

After the small parts for the circular motion to linear motion was printed, the next big part to print was stand frame. After importing the stand frame file to the CURA (Figure 21) slicing

software, we noticed that the part did not fit inside the printing area, hence, was too big to print, as shown in figure below.

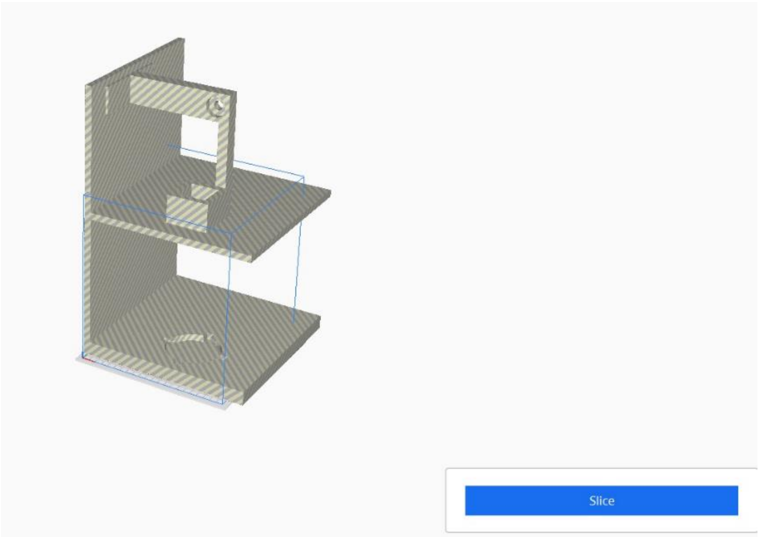


Figure 21 Stand frame initial design in CURA

We then divided the stand frame into two different parts, i.e., upper stand frame and a lower stand frame. The iterated design of the stand frame is shown in figure 22 and 23.

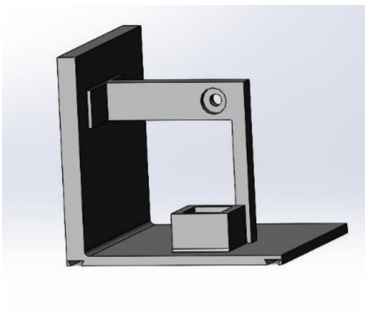


Figure 22 Upper stand frame

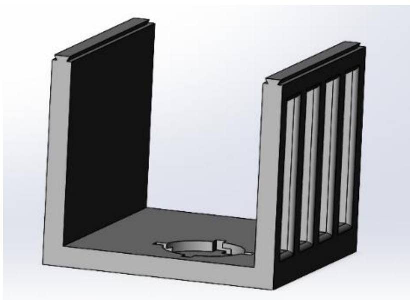


Figure 23 Lower stand frame

The new assembly looked like in figure 24. The upper stand frame consisted of a female locking mechanism, whereas, the lower stand frame consisted to male locking mechanism, that would interlock to complete a whole structure. Upon further discussion, it came to our attention that

the locking mechanism would not work in such a huge structure, with very thin walls. Hence, we further iterated the design, which we will cover later in the thesis.

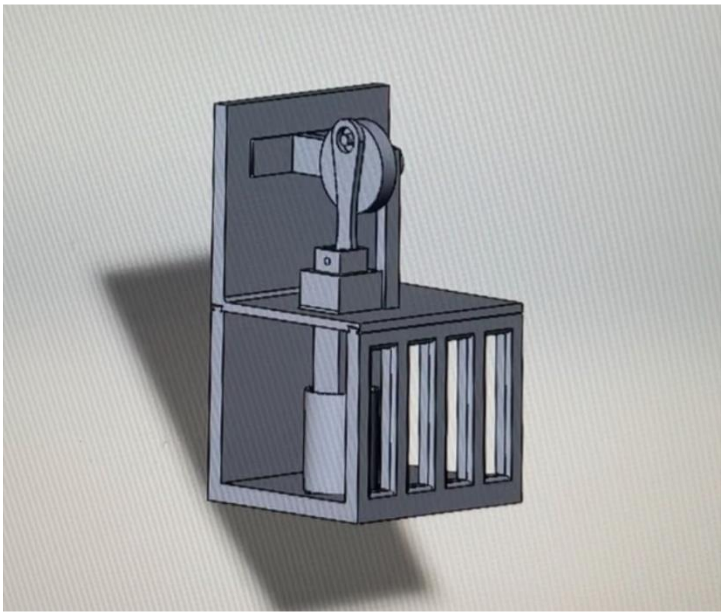


Figure 24 Iterated assembly

3.3.1 Lower stand frame

The original design was construction made up of top and bottom part. It was later divided into two parts to minimize printing time and material volume. Arch like faces, as in figure 25, were added instead of horizontal line to avoid using supports. It acts as the foundation for the entire design and has a bowl locking mechanism. The base consists of a locking mechanism for bowl, where the pounding of the spice will take place. To cut down the printing cost and printing time, a lot of material were removed from the initial design. The final design that went through for printing is shown below.

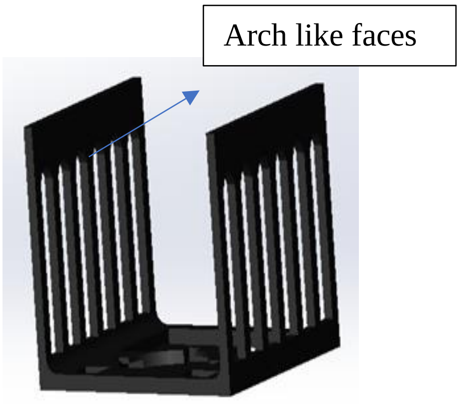


Figure 25 Lower stand frame design

3.3.2 Upper stand frame:

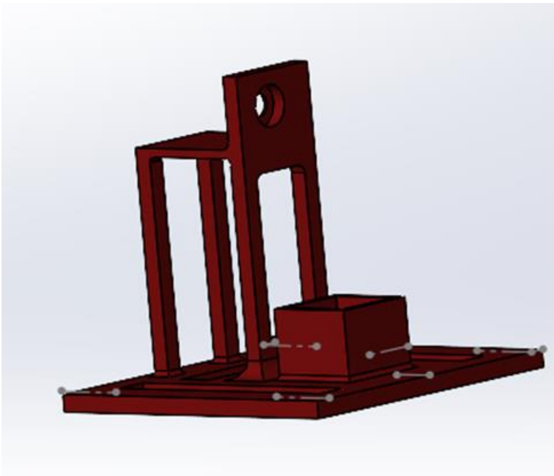


Figure 26 Upper stand frame

The original design was whole structure made up of both upper and lower stand frame that was later divided into two separate parts to minimize printing time and material volume. Most of the moving parts are assembled into the upper stand frame (Figure 26) to complete a functional product.

3.3.3 Hammer head

Figure 27 Iterated hammer head design

After printing the first design of hammer head, we noticed that due to the extruded part, the hammer head took long time to print, and the print failed in the middle. After discussion, we iterated the hammer head into two part, consisting of a hammer and a dowel that connected to the piston (Figure 27).

3.4 3D Printing

During the 3D printing of the parts, many factors had to be considered. Constant design iterations were made during the product development process to ease the 3D printing process and to ensure that the print would succeed. Different aspects like the size of the product, the overhang support, providing fillets to improve the strength of the part, making the parts easy to assemble, and using as less material as possible were immediate concerns before starting the print of the product. A detailed description of parts with photos, the problems faced during the printing, and solutions to overcome the challenges are given below. We used PLA filament as printing material, as it is cheap and is easily available. We used Creality Ender 3-pro printer (Ender 3-pro, 2024)to print the parts, due to its availability at Arcada. Similarly, CURA slicing software was used to generate the g-code i.e., the language of the 3D printer.

3.4.1 Driving shaft

Driving shaft was printed with the locking mechanism touching the build plate (Figure 28). This orientation was chosen to maximize the accuracy of the print. By doing so, we did not

need to use any support structures. We also added brim as adhesion between the part and the build plate, so the part would be stuck in the build plate, and the print would proceed accurately.

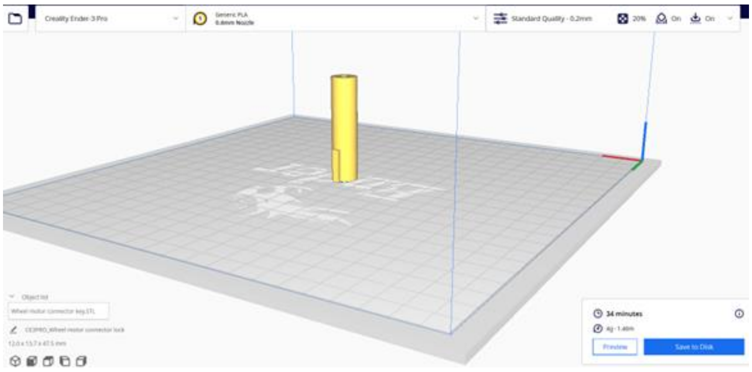


Figure 28 Driving shaft in CURA

3.4.2 Dowel

The dowel was initially a part of the wheel motor connector. However, the part snapped off upon pressure during the trial. Hence, the part was designed separately as male and female part to maximize the strength. Independently, the dowel snapped even after the part was made to assemble and disassemble, so a hollow space was added to increase the strength. Overall, the dowel was one of the easiest and quickest part to be printed.

3.4.3 Lower stand frame

Lower stand frame was one of the most difficult part to print, due to its size and complexity. Only the part with overhang was printed initially to confirm if the part required support. After printing partial part, it came to our attention that it was not necessary to print support, which would have added an additional of at least 4 hours to print. Brim was added as adhesion between the part and the buildplate to ensure that the part did not bulk during the print (Figure 29).

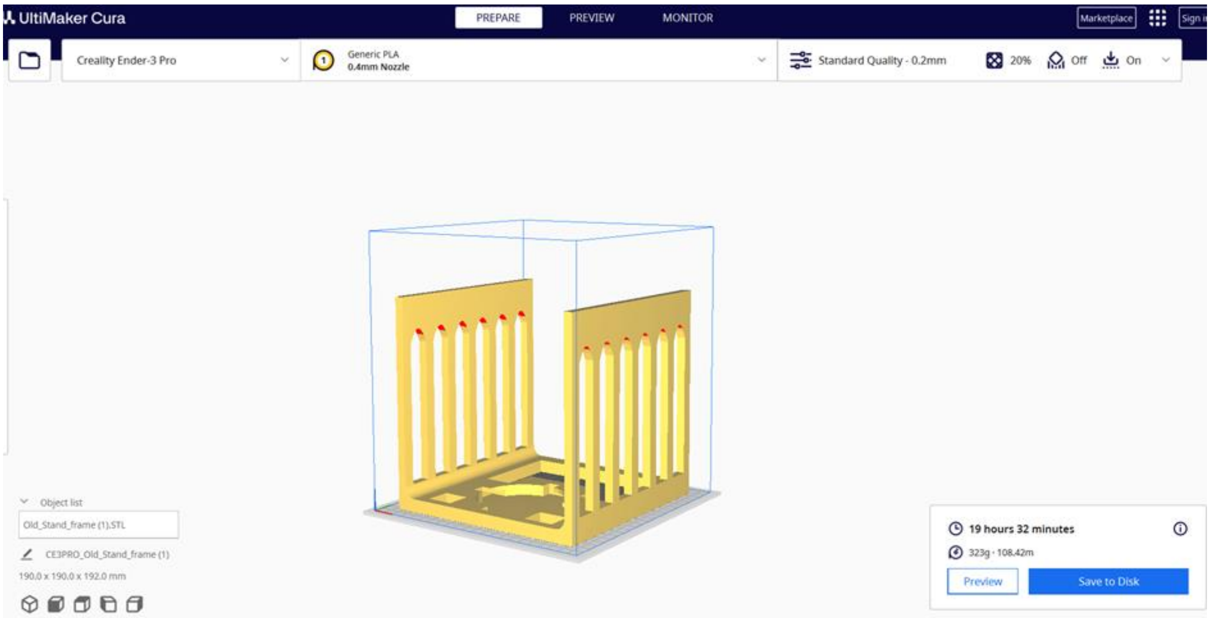


Figure 29 Lower stand frame in CURA

3.4.4 Stand frame upper

Like lower stand frame, upper stand frame (Figure 30) also seemed very difficult to print. Unlike lower stand frame, it was necessary to print support to for the part, as it had overhanging parts. Brim was used as an adhesion between the part and the build plate to ensure that the part would not warp. A lot of material needed to be cut off from the original design, to decrease the printing time and materials.

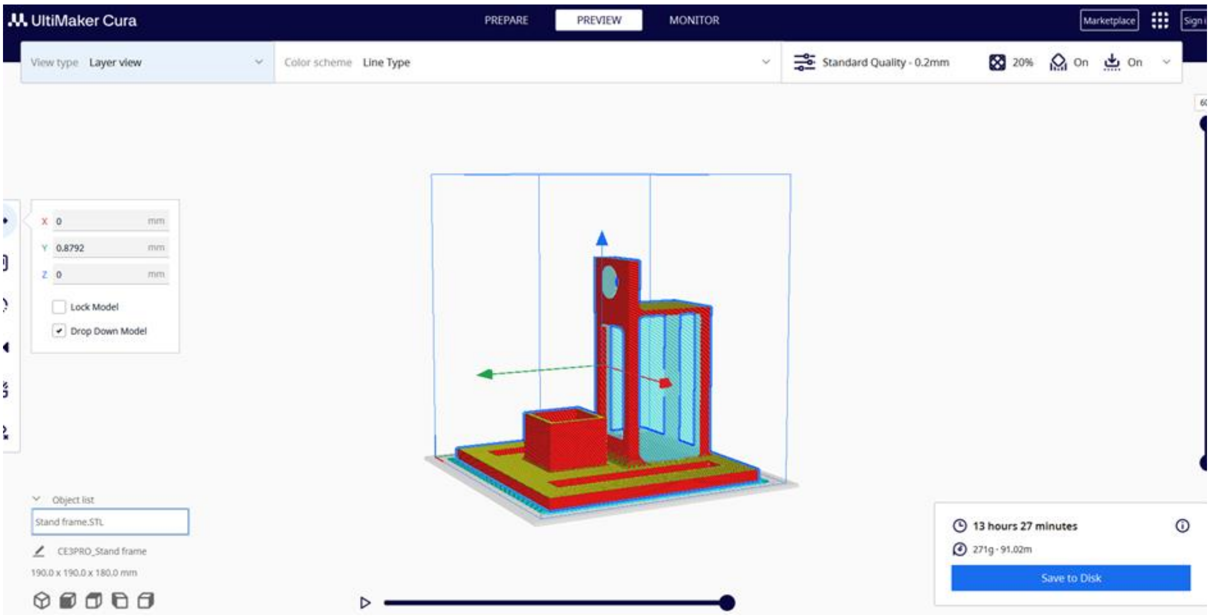


Figure 30 Upper stand frame CURA

3.4.5 Hammer head

Hammer head was printer vertically, with hammer head facing upwards (Figure 31). This orientation was chosen so no support would be needed for printing the part. Brim was used as adhesion between the part and the buildplate to ensure that the part would be stuck to the buildplate during the printing process.

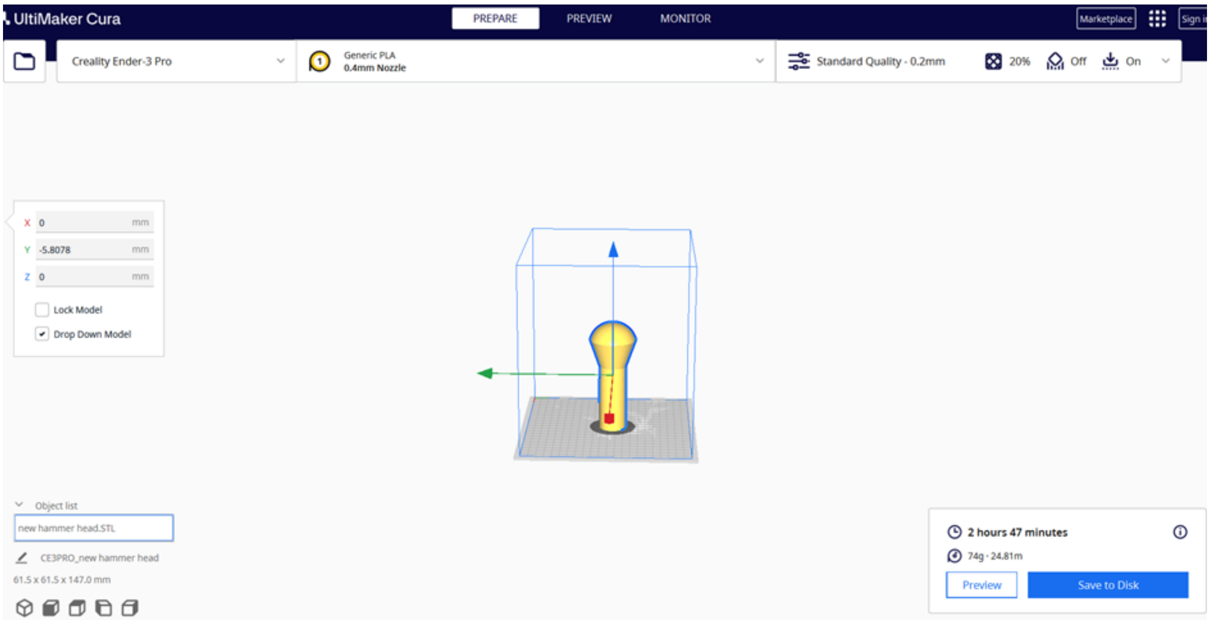
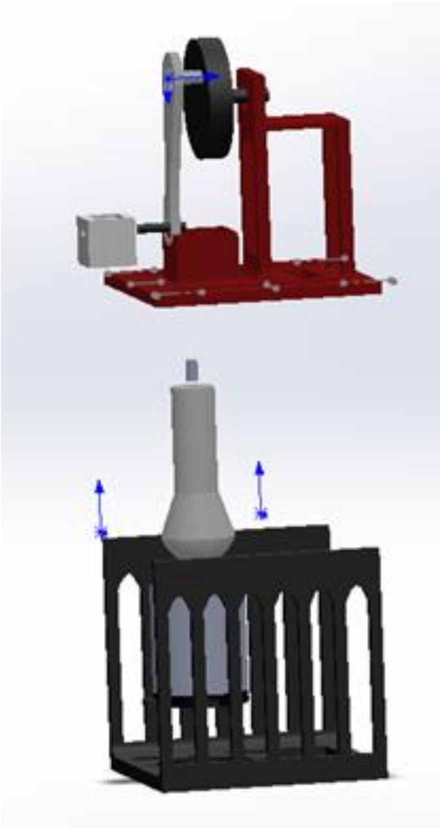


Figure 31 Hammer head in CURA

3.5 Assembly of components

The assembly of consists of fixed structures and moving components. The different steps of assembly in SolidWorks are described below. An exploded view (Figure 32) and a described picture (Figure 33) of the spice crusher is given below. The mates used in SolidWorks are coincident, concentric, distance, and lock.



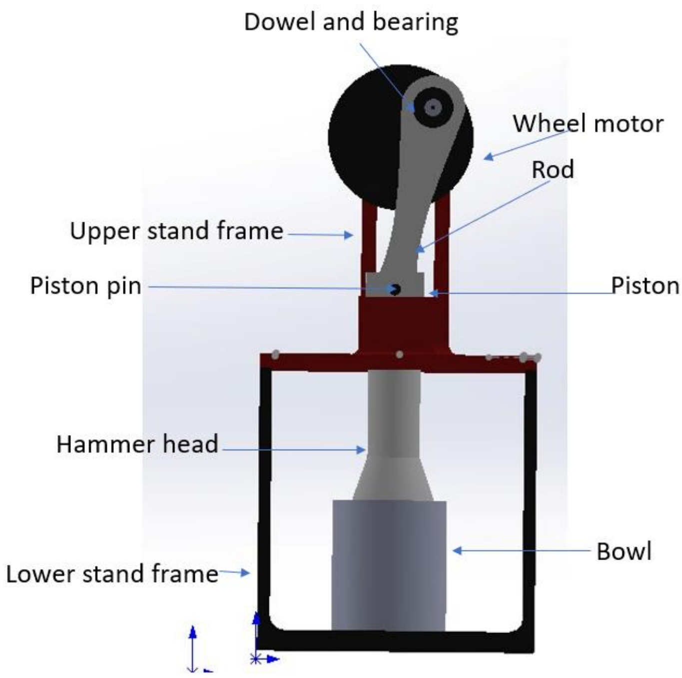


Figure 33 Spice crusher labled

Figure 32 Final assembly exploded

3.6 Motion study

A motion study is an organized examination of movement with the goal of maximizing an object's performance, safety, and efficiency. The research visualizes and forecasts motion using modelling and simulation tools in order to automate training and remodel surroundings, machinery, and processes. Common uses include improving athletic performance, designing ergonomic tools for manufacturing, and producing realistic animation. These applications offer important insights into the mechanics of movement in a variety of contexts (Abdul Talib Bon, 2010).

In our case, we will be looking into a motion study including a power transfer from a motor to the shaft which will be the main driver for the machine (Figure 34). We have provided a rotary movement of 500RPM to the driving shaft. The provided 500 RPM is to calculate the strikes of the hammer head and can be changed. By providing the RPM of 500 to the driver shaft, the hammer head will pound up to 120 strikes in a minute. The study was performed to determine

the number of strikes the hammer head would perform, so we can code the rpm for the motor accordingly.

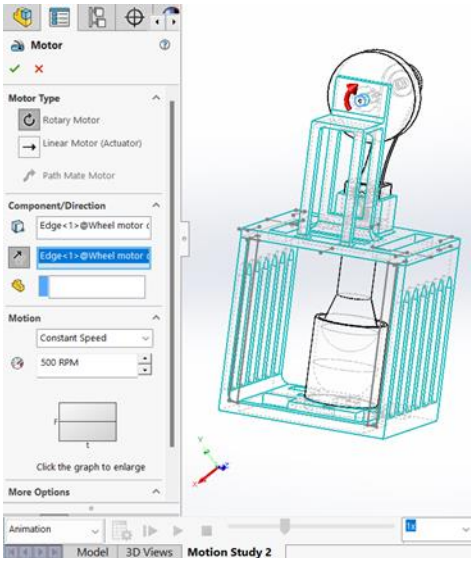


Figure 34 Motion study of assembly

4 Results and Discussion

4.1 Design outcomes

The automatic spice crusher was designed and prototyped through a thorough and iterative process that yielded an efficient tool that satisfied the original goals. The objectives of designing, 3D printing the required parts, and assemble to build a functional automatic spice crusher was achieved. The next section discusses the main results of the design and prototyping process.

4.2 3D printed parts

Several essential parts of the final design were successfully 3D printed using PLA material. The structural integrity and printing efficiency of these parts were optimized. Below are the main components that were 3D printed for assembly.

4.2.1 Lower stand frame

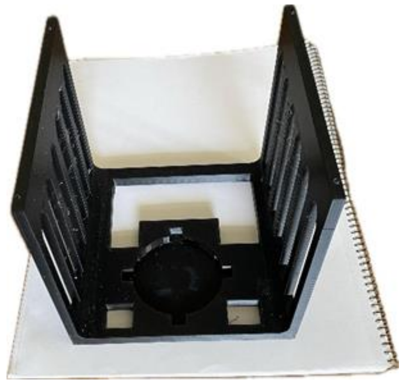


Figure 35 3D Printed lower stand frame

Figure 36 Lower stand frame

The lower stand frame's (Figure 35&36) careful design ensures efficiency and cost-effectiveness by reducing material consumption and printing time. The frame keeps its structural integrity without using too much material by optimizing the geometry and implementing carefully planned cuts. This method provides a practical and strong basis for the entire construction of the automatic spice crusher since it lowers production costs and expedites the 3D printing process.

4.2.2 Upper Stand Frame

Figure 37 3D Printed upper stand frame

To make the overall construction simpler and assembly process easier, the upper stand frame (Figure 37) was built as a distinct component from the lower frame. The construction process is made simpler by using this modular method, which makes it easier to align and attach moving pieces. The frames are separated to improve accessibility during assembly. This allows each section to be independently managed and integrated, resulting in increased efficiency and user-friendliness.

4.2.3 Driving shaft

Figure 38 Driving shaft current view

Figure 39 Driving shaft top view

The driving shaft and wheel motor connector were originally intended to be printed as a single item, but this proved to be difficult to print and structurally weak. Subsequently, it was strengthened and made more printable by adding a distinct locking mechanism, and a hollow cavity. This revision made sure that the connection remained strong and made 3D printing simpler and more effective.

Figure 40 Wheel motor connector

4.2.4 Wheel motor connector

A locking mechanism was added to the revised wheel motor coupling, greatly increasing its endurance. By addressing prior brittleness issues and guaranteeing a strong, secure connection, this enhancement increased the component's overall longevity and reliability in the spice crusher assembly (Figure 40).

4.2.5 Piston rod, piston pin, and rod

Figure 41 Piston, pin and rod

Throughout numerous design modifications, the piston rod and pin (Figure 41) remained durable and functional. The dependable performance and longevity of the automatic spice crusher were enhanced by each version's assurance that these parts fulfilled the necessary strength and operational requirements.

4.2.6 Hammer head

Figure 42 Hammer head

The hammer head (Figure 42) fulfilled the initial objective of fitting together with the rest of the parts to complete a functional spice crusher.

Figure 43 Final assembly of spice crusher

4.3 Assembly

The automatic spice crusher assembled perfectly (Figure 43) with the help of few screws, and clamps. After constant design iteration, every part was made to blend in with the others, making assembly simple and easy. All parts have their own SolidWorks files and .stl file so individual parts may be printed and replaced when it wears down. The motor used in the spice crusher is a Creality 40-42 stepper (Creality 3D 42-40 Stepper Motor, 2024) motor, as shown in figure 44. The assembled spice crusher's overall structural integrity is enhanced by the finely engineered, precisely fitted 3D-printed pieces. Even with constant usage, the built crusher retained its stability and durability.

Figure 44 Creality stepper motor (CREALITY STEPPERI 42-40, 2024)

During development, one of the main priorities for the automatic spice crusher was making sure it operated smoothly. The motor-driven driving system effectively transmitted motion to the hammer head. The hammer head was able to execute the hammering action to a certain level. However, it lacked the power needed to crush the spices finely. The motor transferred motion well, but it was unable to exert enough force to grind the spices to the appropriate fineness. This restriction shows that in order to completely accomplish the project's goals, a stronger motor and additional crushing mechanism improvement are required.

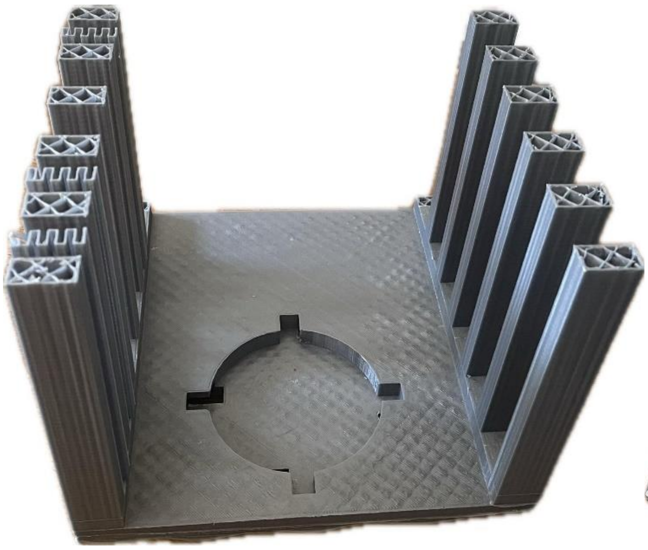
4.4 Challenges and solution

The challenges faced and solutions used during the product design of an automatic spice crusher are described below.

4.4.1 Print Failure

Print failures were a major problem, particularly when dealing with intricate pieces like the lower stand frame. Due of the large design and unsupported overhangs, early attempts produced prints were either partial or defective. Support structures were introduced to give stability throughout the printing process. To improve adherence to the print bed and lower the risk of

failure, the part orientation was also improved. The success rate of printing complex components was considerably increased by these modifications. Below are some of the failed attempts of the 3D printing, as shown in figure 45 and 46.



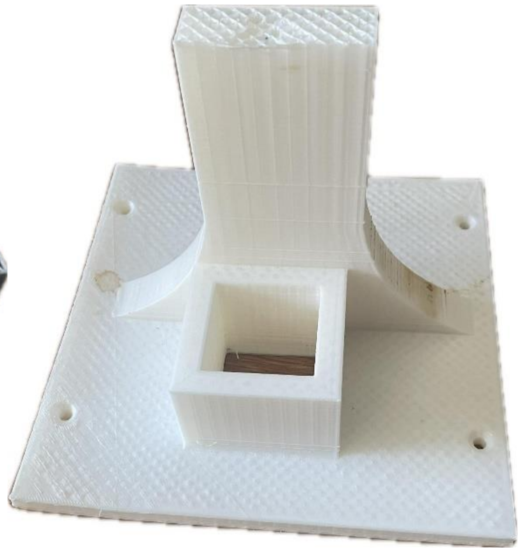


Figure 46 Upper stand failed print

Figure 45 Lower stand failed print

4.4.2 Motor coding

Coding the stepper motor was one of the challenges faced during the product design of the spice crusher. Initially, the plan was to incorporate a potentiometer in the machine so that the user could choose from a grind setting. However, due to insufficient time, and expertise, we were unable to incorporate such feature in the spice crusher. Hence, we coded the stepper motor to have a simple on/off function and predetermined the rpm of the motor. The code used in the stepper motor is in the figure 47.

motor_copy_20240703183949.ino

```
// Include the Arduino Stepper Library
#include <Stepper.h>

// Number of steps per output rotation
const int stepsPerRevolution = 200;

// Create an instance of the Stepper class
Stepper myStepper(stepsPerRevolution, 8, 9, 10, 11);

void setup() {
  // Set the speed at 60 RPM
  myStepper.setSpeed(350);

  // Initialize the serial port for debugging
  Serial.begin(9600);
}

void loop() {


  // Step one revolution in the other direction
  Serial.println("counterclockwise");
  myStepper.step(-stepsPerRevolution);
  delay(0);
}
```

Figure 47 Stepper motor code

4.4.3 Strength of Material

The weak points in several of the parts, such the piston pin, were another big problem. Because the first designs lacked the requisite toughness, they broke under high stress. In order to improve structural integrity, hollow spaces were added, and the geometry of these pieces were modified to address this challenge. Because of these modifications, the components' stress was distributed more evenly, making the parts stronger and more dependable and able to resist the demands of the spice crusher's operation. Figures 48 and 49 shows the parts that were printed but failed when used for its intended purpose.

Figure 48 Broken hammer head upon use *Figure 49 Broken wheel motor upon use*

The hammer head design was not changed. The hammer broke while dismantling the machine and not during the crushing, so the design remained as it is. The strength in the driving shaft was increased by adding a hollow cavity, as seen in figure, 38 and 39. Below are the analysis of piston pin with and without the hollow cavity (Figure 50 and 51).

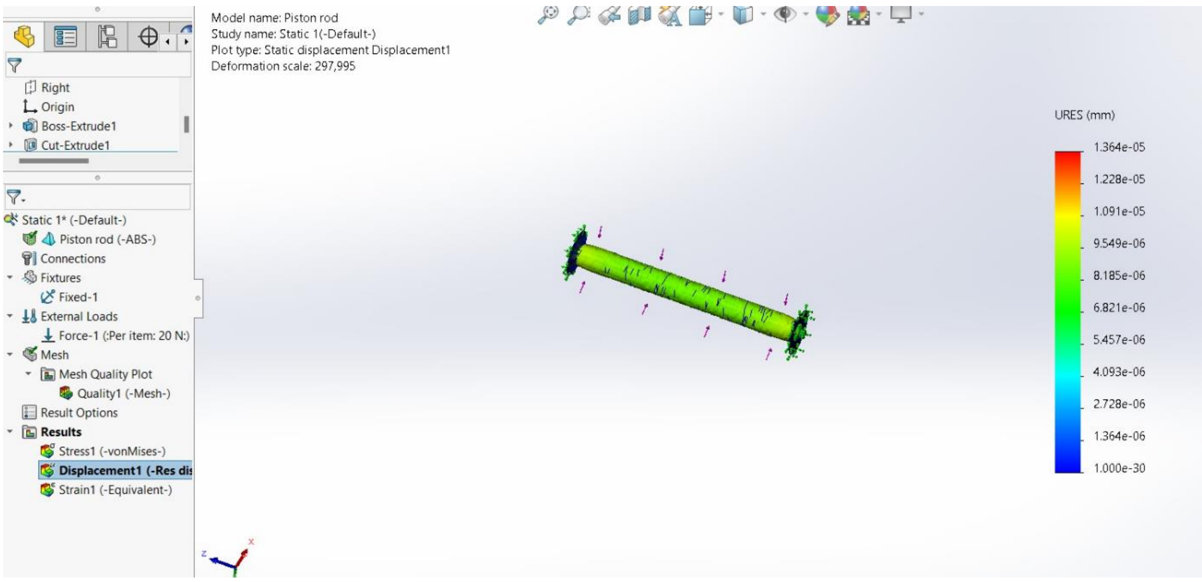


Figure 50 Hollo cavity piston pin static displacement

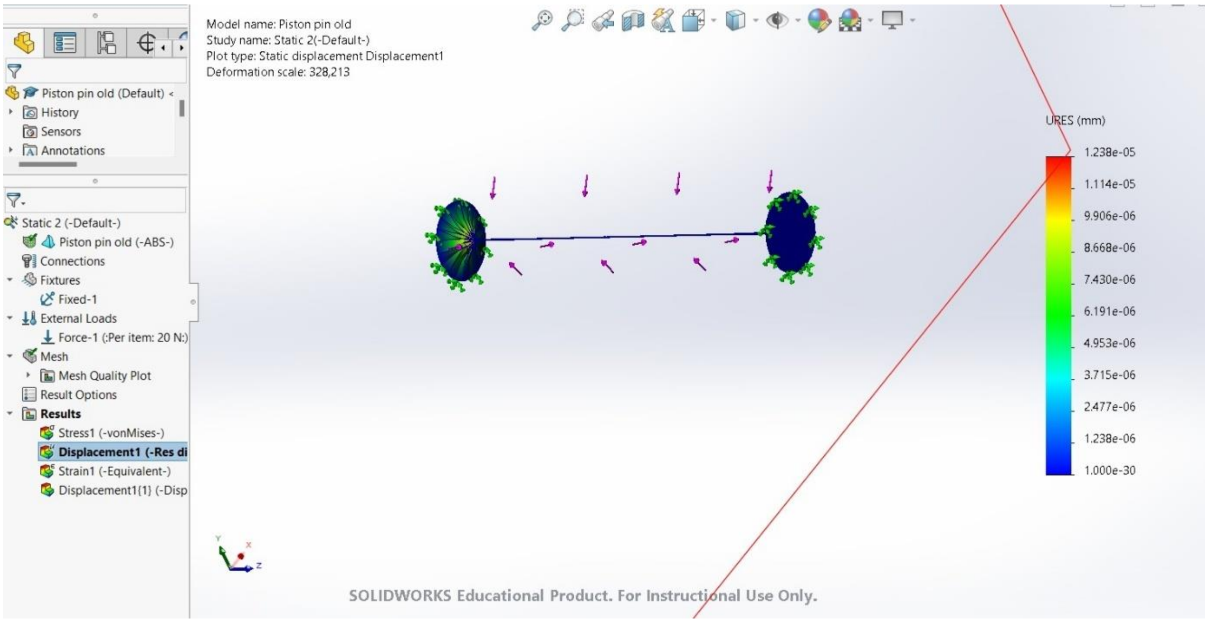


Figure 51 Piston pin no hollo cavity static displacement

4.4.4 Performance analysis

Various criteria were used to assess the automatic spice crusher's performance, exposing both its advantages and disadvantages. Different spices crushed by the automatic spice crusher is shown below.

Corriander Whole cumin Cloves

Figure 52 Spices grinded by machine

Figure 53 Spices grinded by hand

The spices in figure 52 are the spices grinded by the automatic spice crusher that we developed. The spices in figure 53 are the spices crushed by hand, using the 3D printed hammer head and the bowl. The above figures suggests that the hammer head and the bowl are not of sufficient hardness needed to crush the spice.

4.4.5 Reliability

The spice crusher proved dependable upon assembly. The spice crusher has been used for about 60 minutes over the course of two weeks. The automatic spice crusher has worked without any issue until now. Due to insufficient time, the motor was mounted with zip ties, as shown in figure 54, and the driving shaft has been directly connected to the motor shaft with a manual drill of 5 mm. Hence, the driving shaft has shown signs of wearing, as shown in figure 54. For future improvements, a coupling part to connect the driving shaft to the motor shaft could be 3D printed, so power transfer could occur without hinderance.

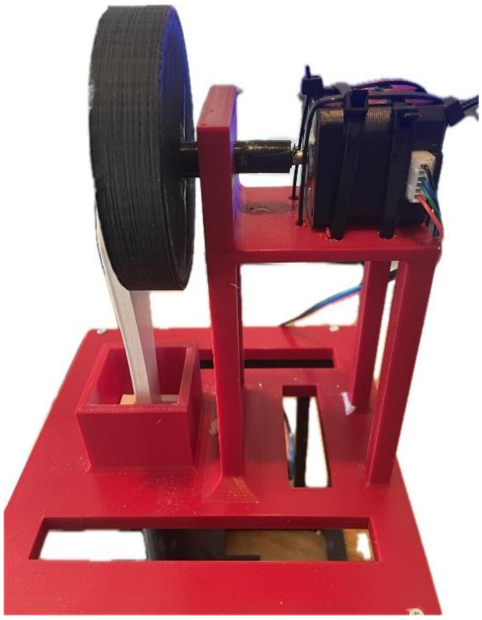


Figure 54 Driving shaft wear

4.4.6 Efficiency, Implications and Future Work

The crushing mechanism ground spices to a certain degree, but it was not strong enough to continuously grind them to the required fineness, as shown in figure 52. Even though the motor and overall design were effective at transferring motion and pounding, they were insufficient to produce a fine and consistent grind. Since the spice were grinded both manually and by the machine using the same bowl and the hammer head, it suggests that the machine is exerting enough power to function as a spice crusher. The hammer head and the bowl are not hard enough to crush the spice. By replacing the hammer head and the bowl with a hard metal part, the level of fineness of the spice crusher could be improved. On the other hand, heavier hammer head would mean that the machine would require to exert more power to lift the hammer head properly. Hence, a transition to a heavier motor may be needed along with heavier hammer head and bowl.

Despite its power restrictions, the automatic spice crusher's design and prototyping provide insightful information with multiple implications for future study and development. The automatic spice crusher has the required structural integrity, as it has been used repeatedly through the course of days. The 3D printed hammer head was used by hand to test it, but the tool did not crush the spice even with a human labor. This proves that due to lack of heaviness of the pestle replacement i.e., the hammer head, the proper crushing of the spices couldn't be achieved. For future work, even though most of the parts can be 3D printed with PLA,

important parts like pestle and bowl could be made up of hard materials. For heavier loads, a heavier motor and a better power transfer system would be needed.

5 Conclusion

The automatic spice crusher's design and development showed important progress toward creating a dependable and user-friendly product. Because the 3D-printed parts all retained their structural integrity, the assembly is strong and long-lasting, however, the crusher did not have enough crushing power to consistently ground spices finely. By crushing the spices by hand using the same hammer head and the bowl did not achieve satisfactory results, this suggests that the crushing mechanism needs to be further optimized by replacing the parts with materials with more hardness. Since the machine will need to exert enough power to move the heavy hammer head, the motor should also be replaced to a more powerful motor. To fully fulfil user expectations and achieve optimal performance, future development should concentrate on improving motor power, scalability, customization choices, and implementing advanced automation technologies, such as speed control. The knowledge acquired from this project lays a strong basis for further study and creation in product design topic for anybody looking to build a new product or updating an existing one.

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