

Grater Product/Service System

Ben Chapman and Ndungu Muturi



Introduction

For eight semesters now, the goal of the ADE Ghana Team has been to improve the livelihood of Gari producing women. We have done so by providing tools to ease their physical burden and increase their gari production efficiency, both of which ultimately contribute to a larger income. One of these tools is an electric cassava grater that renders the process 7x faster than the current method of hand grating.

This venture has been in the deployment stage for some time now (with four graters currently in the field), and we are looking to scale up the business and deliver one hundred graters across Ghana in the next 18 months and tens of thousands of graters over the next 5 years. To do so, we have been working to improve the durability and affordability of our grater this semester. In conjunction, we have been addressing performance/interaction problems, so that we can more comfortably manage larger quantities in the field, and ensure the highest quality products for our users.

Description

The ADE Mini grater is a portable, off-the-shelf cassava grater designed to be owned, operated, and maintained by individual gari producing women. Listed here are the specifications of the product

Small & transportable

- Size: 19.5" wide x 25.4" tall x 20.9" long
- Weight: 38 pounds
- U-shaped handle allows various modes of carrying and repositioning
- Grater disassembles into 3 parts for easy packing and transportation

Motorized & runs on electricity

- Electricity Requirements: 240v 50 Hz
- Power Consumption: 370 W
- Motor Speed: 1500 RPM
- Throughput: 148.76 kg/hr cassava – 85% time savings over traditional hand grater.

Easy to install & maintain

- Only steps after purchase are to attach the legs and to plug into the electric grid
- Grater heads are easy to remove & replace
- Clean, durable & food safe
- Components touching the cassava are made of food safe stainless steel
- No rusting or paint chips falling into the cassava

Adjustable grate size

- Adjustability with anvil allows gari producers to perform small size adjustments
- Grating-head is replaceable in seconds, offering the option of different heads for different coarse or fine grating.

Parts of the Grater

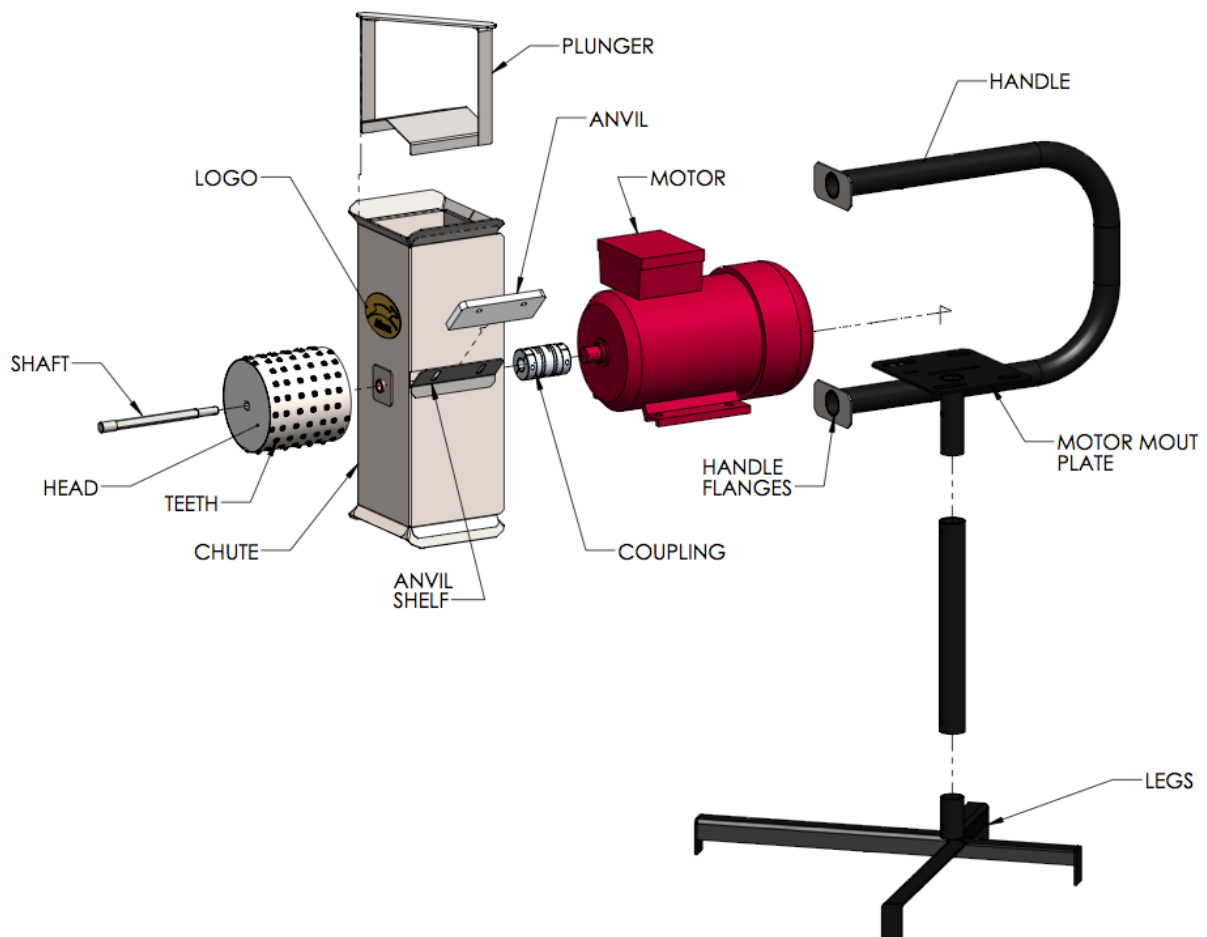


FIGURE: Exploded View of the Fall 2014 Production Prototype Grater

Chute

Chunks of cassava are pushed through the stainless steel chute with a plunger and are grated between a stainless steel teeth sheet wrapped around a cylindrical head and a plastic anvil. The anvil is adjustable by loosening the restraining bolts and sliding it in or out to change the gap distance between the head and the anvil. This allows the woman to use each machine for longer, since the anvil can easily be adjusted or replaced as it becomes worn down.

The stainless steel plunger allows for safe operation preventing users from using their hands to push the cassava into the chute. The handle of the plunger contacts the top of the chute at the bottom of the grating stroke to prevent the user from pushing the plunger too far down and again running it into the head.

Handle Frame

The handle frame consists of the motor mount plate, the handle, and the attachment tube for the leg as well as two handle flanges. The handle is a 1.25" OD plain steel, 0.060" wall tube bent in a U-shape that allows gari producers to hold, lift, and reposition the grater in a variety of different ways.

Legs

The legs are also detachable for ease of packing and transport. The vertical leg is constructed from the same tube as the handle and the horizontal legs from plain steel angle iron.

Head

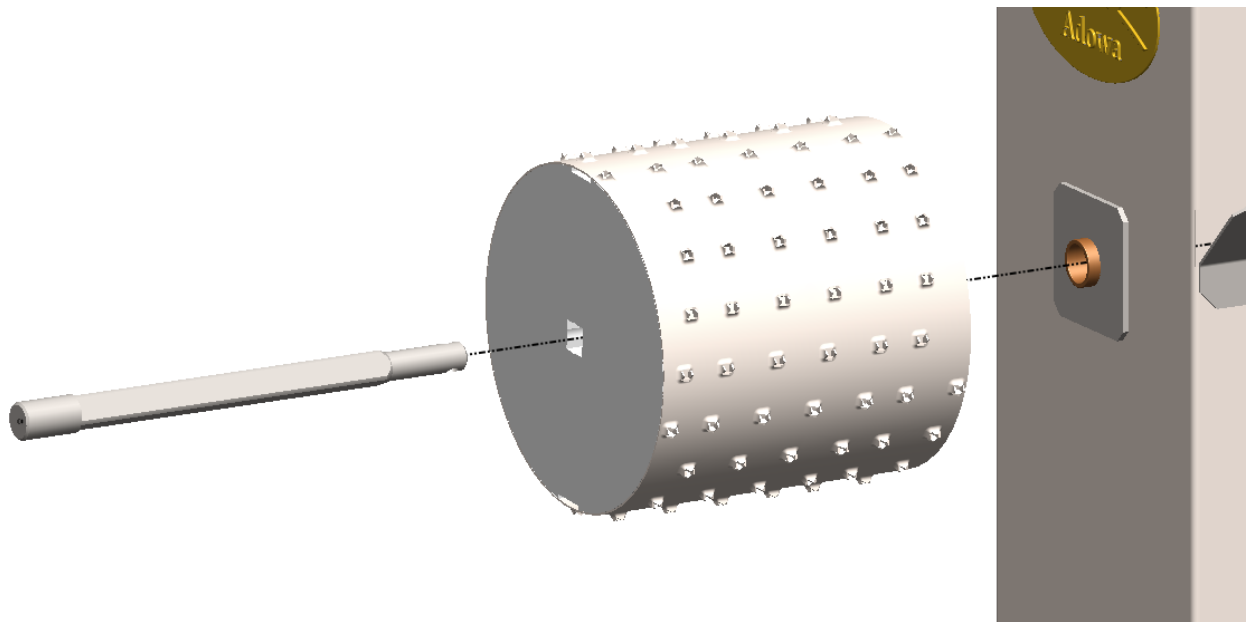


FIGURE: Detail of head and shaft

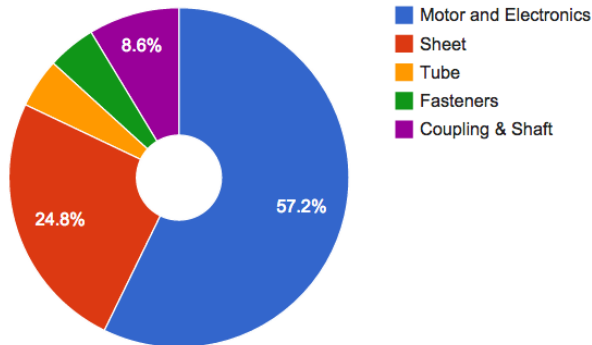
The spinning cylindrical head has the teeth which actually grate the cassava. It is spun by the square shaft. The head is currently machined from a solid cylinder of HDPE. Teeth are made by piercing a sheet of .025" SS316. Torque is transmitted from the HDPE drum to the teeth using two metal strips welded to the teeth, positioned in slots in the drum.

Manufacturing and Operational Costs

The estimated material cost of the grater is \$75 at quantity 100-1000. The largest portion comes from the motor, which costs \$42. The Yachan 8024 motors that we are currently piloting appear to meet all of the requirements and if the durability is sufficient we

recommending ordering more. The only operational cost for owning the Mini Grater is the cost of electricity, which is small. To grate 30 kg of cassava, the cost of electricity is \$0.002 USD.

Fall 2014 Production Grater Cost

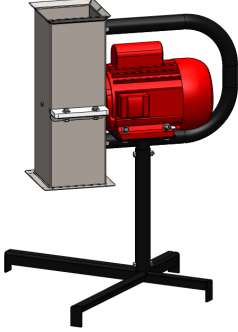
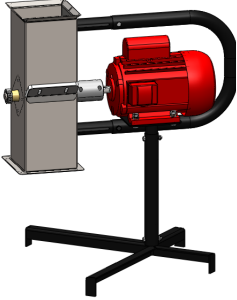



Process

Many improvements were made on the previous models to increase rigidity, mitigate grater vibration, and standardize materials and processes for scaling (see spring 2014 grater product service systems report for more information). However, on the trip it became apparent that we still had issues with the design. During operation, the grater experienced runaway vibration caused by the head's imbalance and by its deteriorating interaction with the shaft. Vibration is a serious problem because it leads to accelerated wear of the motor and decreased grater lifetime. The creation of our grater also largely depends on the ample resources provided by the Olin College machine shop. Large scale production with our current methods would turn out unfeasibly expensive, so we re-examined our design to prepare it outside manufacture.

Premature, vibration-driven failure and Ghanaian manufacturability are the leading concerns that we tackled this semester. After several tests and discussions on our current grater, we made design decisions to optimize for the 10-100 scale. We then created a prototype to test our assumptions, and used our results to inform a second iteration akin to the model we plan to field. Below is a table of our design's progression throughout the semester. In this report, we highlight the changes.

TABLE: 3-grater comparison of major changes.

				
	<u>Spring 2014</u>	<u>Design Prototype</u> <u>Fall 2014</u>	<u>Production</u> <u>Prototype</u> <u>Fall 2014</u>	<u>Future</u> <u>Suggestions</u>
<u>Head</u> <u>Mounting</u>	Cantilevered on keyed motor shaft	$\frac{5}{8}$ - $\frac{1}{2}$ Stainless Double-D independent shaft	$\frac{1}{2}$ " - $\frac{3}{8}$ " Stainless 303 Square Shaft	$\frac{1}{2}$ " - $\frac{3}{8}$ " Stainless 303 Square Shaft
<u>Anvil Angle</u>	90°	45°	45°	45°
<u>Head</u> <u>Structure</u>	Metal tube with spot-welded, keyed stock	Metal tube with spot-welded, Double D plates	Solid HDPE with 10mm broached square hole	Solid Cast foam head or 2-part injection-molded head.
<u>Motor</u>	Zhaoqing YC-DW	Zhaoqing YC-DW	Dually compatible with Leeson 110086 and Yachan YC8024	Yachan YC8024
<u>Coupling</u>	N.A. No coupling	Lovejoy Brand	Helical Style	Custom coupling with cast-rubber flexible inserts

Assumption Testing

Chute

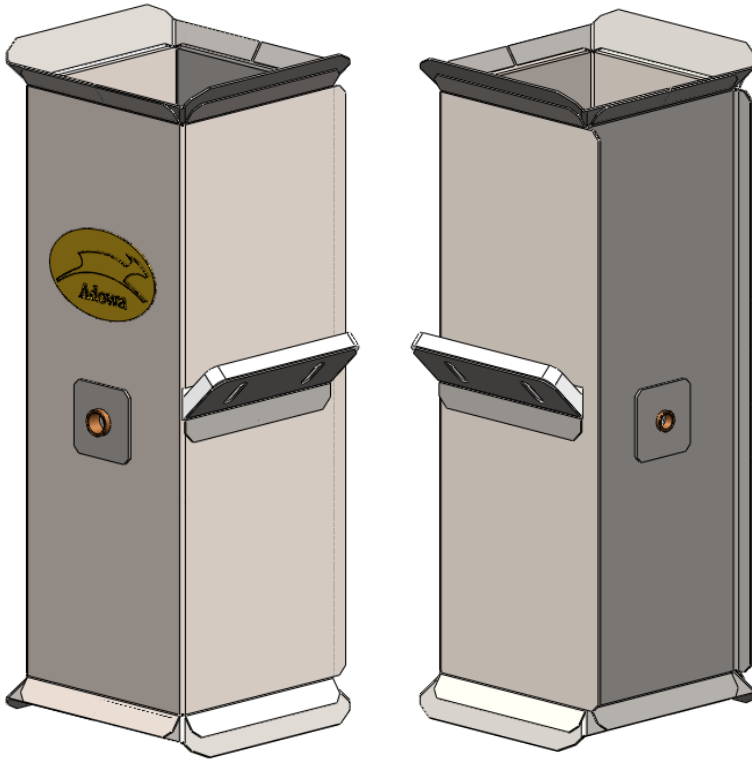
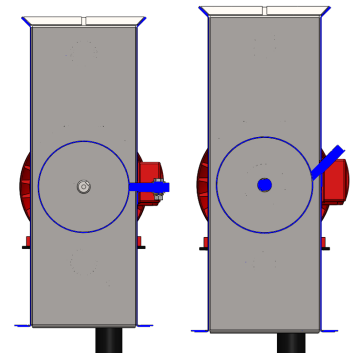


FIGURE: Production Prototype Chute

Design Prototype

- In the spring '14 grater, the cantilevered mounting of head on the motor shaft led to runaway vibration and failure (of the head key and/or motor bearings) after moderate to heavy use.
 - Switched to an independent jackshaft supported by self lubricated bronze bushings on both ends. This has the added advantage of reducing the stress on the motor-facing side of the chute so we reduced its thickness from 1.5mm to the 1mm sheet that the rest of the chute is made out of. Bushings are press-fit into 2mm thick stainless flanges, which are spot welded to the chute.
- Having the mild steel motor shaft directly inside the chute accelerated shaft corrosion and accelerated corrosion and failure of the motor's internal bearings due to starchy liquid traveling down the shaft back into the motor bearings.
 - Switched to independent jackshaft attached to the motor with a shock-absorbing coupling, which isolates the motor components from vibration and cassava moisture.
- 90-degree anvil shelf causing cassava to jam in the chute,
 - switched to 45-degree angle anvil shelf



- Chute “Outer U” piece with 4 90-degree bends was difficult to manufacture and led to unsatisfactory tolerance stackups for trying to keep the front and back faces very parallel (to use with plain flange bushings on a shaft).
 - Switched to a nested-U design with a deep front U and shallow back U. This can be jigged and welded very parallel even if the bend locations are not extremely exact.
- 1-piece Chute Rim Reinforcement had inefficient nesting and used lots of metal
 - switched top and bottom to 2-piece 45-degree angle reinforcement flanges

-Results and Implications from Design Prototype Test

- Independent shaft with bushings was manufacturable with satisfactory tolerances, good shaft alignment and minimal friction on the shaft (even with plain bushings instead of self-aligning bushings).
- Removing the shaft and head had excellent interaction. The shaft slides out easily and the head falls into the bowl of cassava.
- Installing the shaft and head has poor interaction. It requires reaching in and holding the head in position from below and inserting the shaft with near-perfect alignment without being able to see where it's going. See the Shaft section for more details.
- The chute reaches a resonant mode of vibration when running and produces a quite loud and periodic ringing sound. It's unclear the cause of the loudness, but it is significantly loud even without the head. See the assumption test on Grater Vibration for more details.
- 45 degree Anvil shelf works well, though quantitative tests have not been done.

Production Prototype

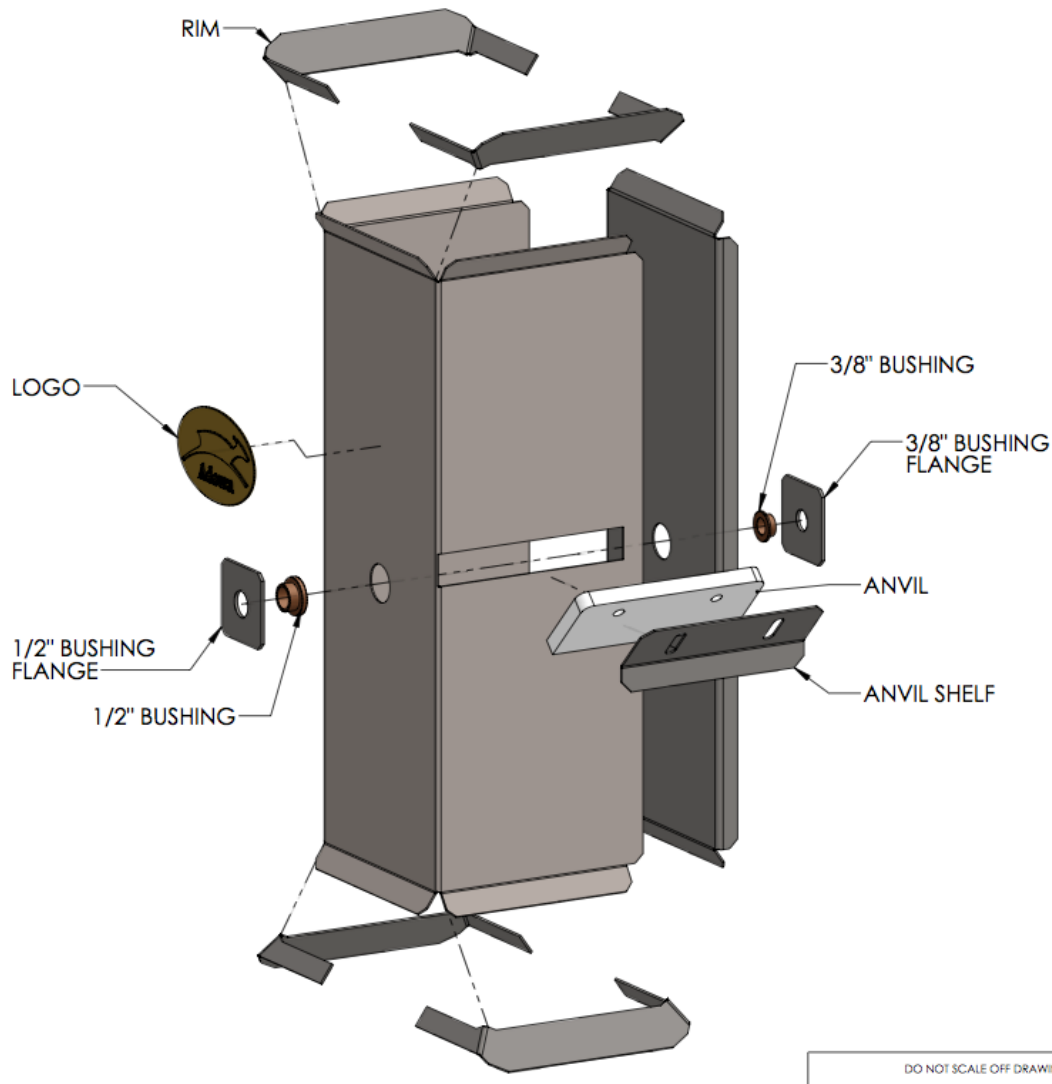


FIGURE: Exploded View of Production Prototype Chute

The production chute is very similar to the Design Prototype. The clearances for the bushing flanges will be made smaller to aid manufacturing. The shape of the flanges for the bushings and the handle-mount have been switched from round to rectangular for better material efficiency and spot-welder clearance. The shape of the rim has changed to improve material efficiency. Since the front and back edges have the same profile, the new rim shape can be “sheared” from a wide strip using a specialized cutter, with almost zero waste.

Head

Design Prototype

As stated earlier, last semester’s grater suffered from vibration, because the head’s mass—although reduced from previous models—was still too imbalanced. For the initial

prototype we used a modified version of our retroactive balancing solution discovered on the Ghana trip. After finding the radial point of least mass, we inserted a rod there to compensate and balance the head. Also we moved away from a thick, keyed plate, because it would have been too expensive to manufacture. Instead thinner keyed plates of a harder strength material were spot welded onto the two endplates.

After being welded together, the head was severely imbalanced. Although able to recover concentricity, we were convinced to explore very different options for head manufacture rather than building the tooling to optimize this current method. The number and nature of processes makes this a very expensive part currently. Also, we could easily spot weld the thinner plates, and they performed well enough for consideration in our next prototype.

Production Prototype

We created a design matrix comparing our head production method to different ones, and it greatly underperformed. Consequently, for the production prototype we planned to make and test the heads listed below:

TABLE: Head Construction Options

Head	Description
2-Part Injection Molded	Interlocking injection molded parts, similar to Grandma Anne’s potato grater.
Solid Polyurethane foam	Castable polyurethane foam poured and hardened inside jig, centered around an extruded polycarbonate square tube
Solid Plastic	Solid food-safe plastic cylinder with broached square hole, with milled slots for torque transmission
Plastic with caps? (might not happen)	Plastic tube epoxied to metal endcaps with hardened torque-transmission plates
Plates in Tube? (might not happen)	Rolled Sheet Metal cylinder with stamped flanged sheet metal disks. Optional square inner tube

We tested the polyurethane foam, 2-part 3D-printed, and solid plastic heads. All had more consistent balance than previous techniques. Foam and solid plastic heads were all within 2 grams of balanced. We had more confidence in the durability and food safety of the solid plastic head so we decided to use it for the production prototype, but it still is too costly and requires a prohibitive amount of precision machining to be a long-term solution. Cast foam looks like a viable option if we can increase our confidence in it’s durability and food safety.

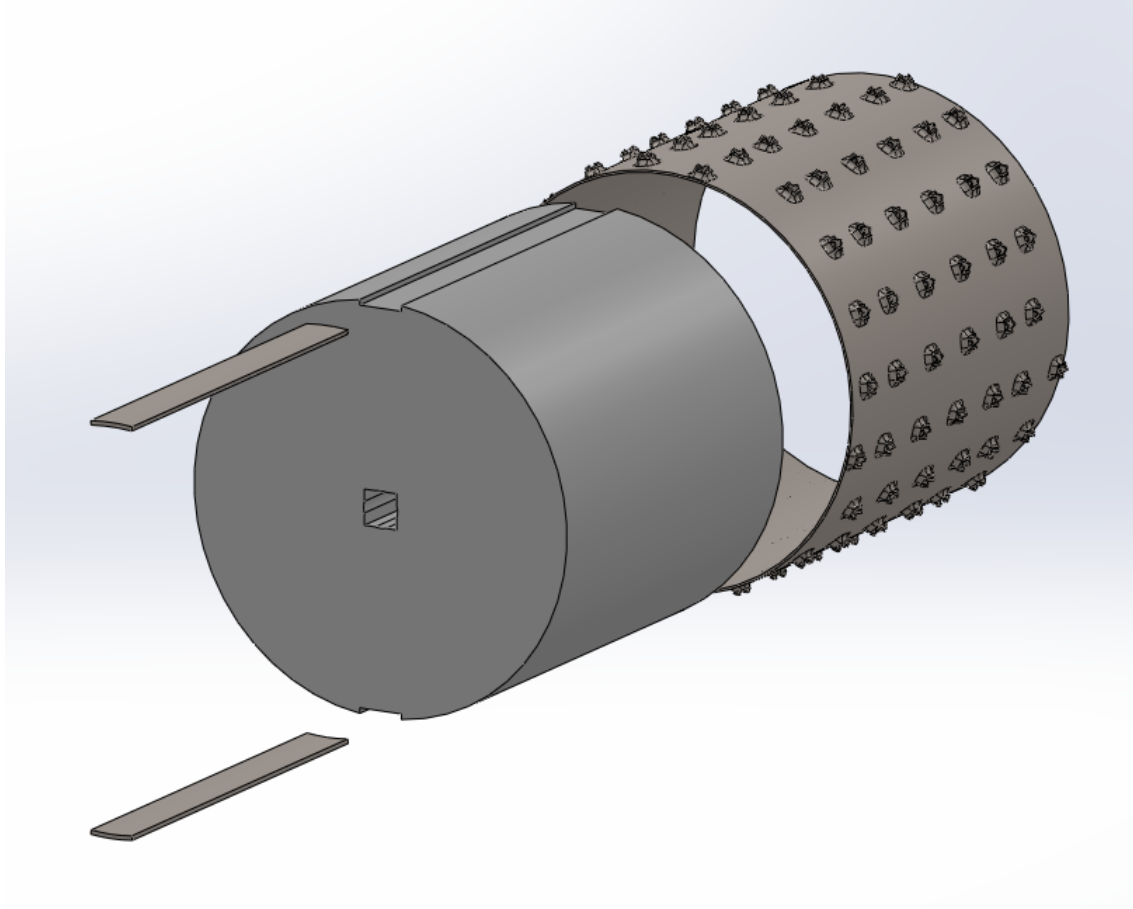


FIGURE: Exploded view of Solid Plastic Head

Shaft

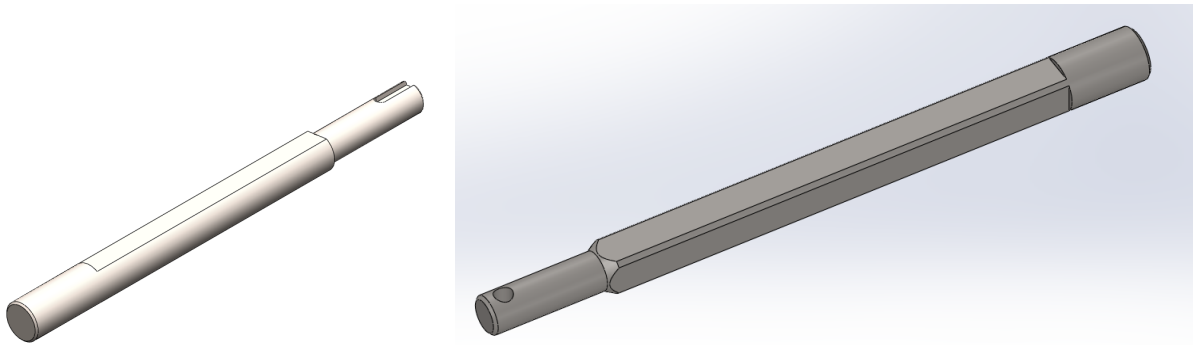


FIGURE: Design Prototype shaft with 2 flats, and Production Prototype shaft with 4 flats

Design Prototype

Requirements

- Food Safe
- Supportable by two bronze bushings, (no keyways where they can scratch up the bushings)

- Easily Removable, pulling out by hand through the bushings
 - Easily Installable, sliding in by hand through bushings
 - Transmit the stall torque of the motor (65 in-lbs) with a FOS of over 2, from the coupling, through the shaft, to the head
 - Minimal manufacturing cost
- Our Design Prototype Shaft shown in Figure **NUMBER** did quite well. It is a $\frac{5}{8}$ shaft with 2 machined flats with a height of $\frac{1}{2}$ " and a $\frac{1}{2}$ " round section turned down on the end with a keyway. It performed well on most of the requirements with the exception of easily installable. The sharp edge at the beginning of the flats had no chamfers because we needed to transmit torque at the very outer edges of the prototype head. The sharp edges made it difficult to locate the flats as the shaft was inserted blindly through the head. A tapered-edged design would have much better interaction, especially if the head could guide the shaft all the way through with some sort of tube.
 - Production Prototype

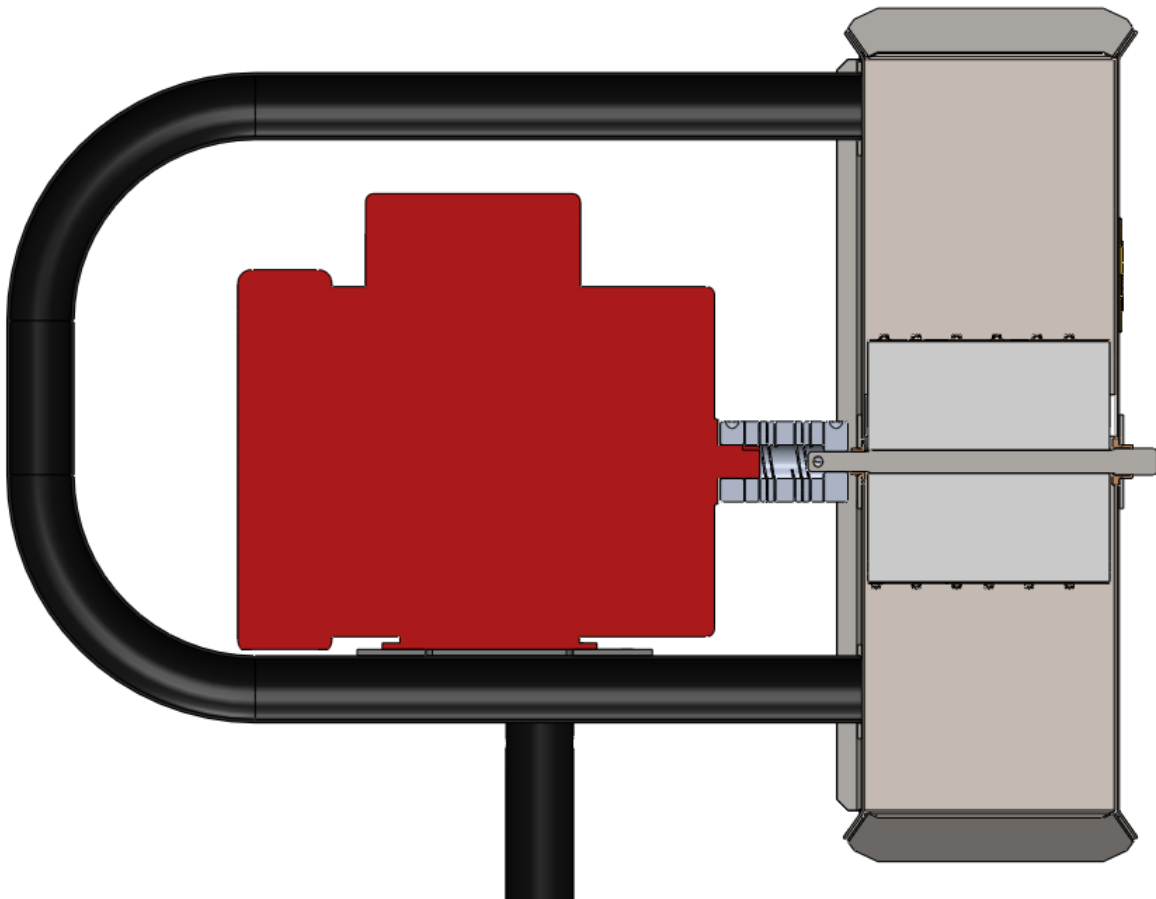


FIGURE: Section View of Production Prototype detailing coupling, shaft, head, and bushings

The production shaft, shown in figure **NUMBER** is smaller diameter and has 4 flats rather than 2. This makes it easier to install and increases its torque transmission capability. A 4-flat shaft can be used with a broached hole from an off-the-shelf square broach. It is self-locating, with a large chamfer on the front face and a tapered edge on the the front edge of the flats. The new design speeds up the head installation process from roughly 45 seconds on the Design Prototype to roughly 9 seconds on the Production Prototype. This is due to the generous chamfer and taper on the previously sharp edges, as well as the lack of a keyway, and the fact that the head's square hole guides the shaft all the way through. The through-hole in the head also improves the torque transmission between the head and shaft because the interaction takes place along the entire length of the flats, rather than just at the end with previous heads.

Coupler



FIGURE: Three types of couplings: Lovejoy Style, Helical Style, and a Cast Rubber concept.

Design Prototype

- For the design prototype we used an off-the-shelf Lovejoy-style coupling. It works well for a prototype, but its cost (\$9), dependance on set-screws and hex-keys, as well as lack of axial constraint prompted us to look for other options.

Requirements:

- Torque transmission
- Axial constraint (could be separate from torque constraint mechanism)
- Allows the shaft to be easily clamped and released (preferably without tools)
- Shaft can easily be removed (preferably without tools)
- Easy to manufacture in Ghana
- Low Cost (\$5 or less)
- Safe to use
- Beautiful

TABLE: Coupler Construction Options

Coupler	Description
Tape	Taping the two shafts together
Rubber Coupler	Custom cast-rubber coupler pressed onto the motor shaft and interlocked with independent shaft
Pin	Pin pressed into through holes on both shafts
Rubber Coupler with Pin	Cast-rubber absorbs vibration and misalignment, pin transmits torque and constrains axially.

Production Prototype

We were not able to design and rigorously test any custom couplers in time for the trip. To make-do we used off-the-shelf helical couplings. They require an allen wrench to clamp and release the grater shaft. The cost is \$67 each, so this is purely a temporary solution. We recommend that the next team should spend part of their focus on creating and qualifying a coupler that meet our requirements. The most promising option to from our initial investigation is a cast rubber coupler with a removable pin.



Motor

Design Prototype

The Design Prototype used the same Chinese Zhaoqing YC-DW motor as the spring 2014 grater. Some cons of the motor are that it's extremely heavy cast iron (40-ish pounds) and that there is some slight imbalance in the rotor so it vibrates slightly, but makes quite a bit of noise when it is coupled to the chute through the shaft. The motor is of moderate quality, with inconsistent, rough castings, and poor waterproofing. It did not come with a switch, cord, or thermal overload reset switch. It is also 50% more expensive than many equivalent Chinese motors. (\$63 vs \$46).

This semester we corresponded with several companies on Alibaba offering totally enclosed-Fan-cooled motors to find one with lower cost and lower weight. We had more options because the new independent-shaft grater design could work with any shape of motor as long as we could mount it and attach a coupling to it.

We found that many companies sell a motor called MC802-4 or YC802-4 with the specs we want, all with standardized body geometry, interchangeable across manufacturers. In the end we found that Yachan motor company was the most cooperative and responsive with our requests for metal terminal boxes, Ghana-type cords, switches, etc., while offering good prices in low and high volume and offering the spec of motor we want. We ordered three of their YC8024 motors complete with all the necessary switches and Ghana-compatible cord for \$46.72 each. Air-shipping to the United States was over \$150 per motor.

Production Prototype

The production grater has the capability to use the Yachan YC8024 motor or the Leeson 10086 motor almost interchangeably. The only difference is that the Yachan motor needs a 0.35" shim under it to bring it up to the correct height. The Yachan motor appears to be a much higher quality product than the Zhaoqing motor from the previous semester. The castings are precise (possibly die cast, not sand-cast), the terminal box is a convenient size and is well sealed, and we received the motors pre-wired with plugs, on-off switches, and thermal reset switches. We are able to specify the shaft length. In the future, we may be able to ask for a more waterproof thermal reset switch, but other than that it looks like an excellent motor to continue using. We corresponded with a woman named Lily (sales@yachanmotor.com) who was very helpful and responsive with reasonably good english.

Frame

Design Prototype

To expedite the prototyping process we modified an existing frame from an existing (Spring 2014) grater. Since the independent-shaft design puts the chute further away from the motor than the previous (motor-mounted head) design, we needed to extend the telescoping chute-mount tubes that protrude out from the handle.

Even without extending the length of the feet, the grater was still extremely stable and not close to tipping over, even with considerable force applied to the plunger. The prototype was quite loud while operating and it may be related to having a longer cantilever and less stiffness.

Production Prototype

For the production machine we are extending the feet so that the center of the chute is within the footprint of the machine. For stiffness and ease of manufacture, we are eliminating the bolted joint at the lower end of the vertical frame member. It will be welded directly to the angle-iron legs.



The frame is designed to accept both the Yachan YC8024 motor and Leeson 10086. The Yachan needs a 0.35" spacer under it to put the shaft at the same height as the Leeson's shaft.

The method for attaching the chute to the handle is also changing from the previous version. The production design has stainless sheet metal flanges welded directly to the handle. These will be spot-welded to the chute.

Learnings/Conclusion

Overall, we have been very pleased with the switch from a cantilevered, motor-supported head to the head with an independent shaft, supported on both ends. Initial testing of the Yachan motor is optimistic and suggests that we can source an appropriate motor from China for under \$50. Work on head-design showed that imbalance over 5 grams is unsatisfactory and we should strive to use heads statically balanced to within 2 grams. Welding jigs were able to speed up the manufacturing process by a factor of 5 or more. Additional jigs could be used to make the process even faster and harder to mess up.

The chute and frame design has become relatively mature. Only incremental change will be necessary, perhaps changing some geometry to be simpler for stamping or bending in production in Ghana. Significant prototyping and testing effort is still needed for the coupling and the head. We currently have the performance we need, but at a very high cost. Future work will need to bring down the cost of the head and coupling while retaining or improving performance and usability. Another large unknown is the cost of producing the shaft at scale. The current design relies on tolerances of less than .001" for the flats, that may not be reached affordably. Additional work is needed for simplifying manufacturing at scale, including production tooling for teeth piercing, and stamping of the sheet metal parts.