Colorado School of Mines

Final Project Report:
Fine Shredder

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MEGN301: Mechanical Integration and Design

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3 May 2024

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Introduction

During World War II, plastic manufacturing increased to support the war effort. Once the war ended, however, the plastics industry had to find new products to manufacture or face going out of business, and so it turned to common consumer goods. Plastics are now everywhere due to it being inexpensive and easy to manufacture goods with. The problem is that most plastics aren't being recycled and don't break down in the environment. In fact, only 9% of plastic is recycled globally while another 22% is mismanaged, meaning it's not recycled, placed in a landfill, or incinerated [1]. There is an estimated 30 million tons of plastic in seas and oceans and another estimated 109 million tons of plastic in rivers [1]. Recycling plastics is in humanity's best interest in order to reverse the damage done to the environment with plastics and will be a prevalent issue for many years to come if no solution is found.

Plastic recycling is a costly operation to run between the collecting and sorting requirements as well as the infrastructure required to actually recycle the plastic. Advancements in technology are necessary if a larger percentage of total plastic is to be recycled. The more the problem is analyzed to get ideas on how to improve the current system, the better. This is where this project comes into play. In a typical recycling operation, there are bulk shredders to take large sized pieces of plastic down to smaller pieces which are then fed into a 'fine' shredder to further break down the plastic into fine pieces of plastic. These pieces are then input into an injection molder for the plastic to be repurposed using a mold of any type of object. Another option is to take the fine shredded pieces and place them in a filament machine for the plastic to be recycled as filament.

The chosen project for this team is the fine shredder. The objective of the fine shredder is to shred the plastic pieces given from the bulk shredder, approximately 0.25 inches in any direction, down into pieces no more than 0.1 inches in any direction. They must also be pourable according to ASTM D1895-17 in order for the injection molder and extrusion teams to be able to use the pieces for their designs. The budget for the design is $230 which does not count a provided 1/3 hp motor. It cannot require more than 120VAC and 15 amps and must be storable and portable. The machine must also be safe to operate which includes precautions such as covering belts and hot surfaces, safely wiring connections, and adding guards for pinch points. Another objective is to be able to shred a sizeable volume of plastic given by the bulk shredder to prove the design's viability in an industry setting and so that the teams needing the plastic for their designs have ample material to produce their outputs.

Design Selection

Initially 4 different design alternatives were brought forward. All 4 designs were very similar when considering the overall objective and the general method by which this objective was achieved. Each design was based on some existing method of fine shredding and adjusted for the use of shredding plastic. When comparing the 4 different methods it was decided that each method must contain the following 4 components: each must be able to take plastic as an intake, shred to approximately 0.1 inches, be compatible with the 1/3 HP motor, and it must stay withing the given budget of $230. These categories were the basis for the ASA table which of the presented ideas would be the most successful as shown in Figure 1.

Statement of Purpose: Create a machine that safely takes in 0.25" pieces of plastic and shreds it down to 0.1" pieces in a fast and effiecient manner								
Evaluation Criteria	**Required Criteria**		**Alternative 1: Chipper Based Shredder**		**Yes / No**	**Alternative 2: Attrition Mill**		**Yes / No**
R1	Takes plastic as an intake		Yes		Yes	Yes		Yes
R2	Shreds plastic to approx 0.1"		Can shred to 0.1"		Yes	Filltered output of 0.01"		Yes
R3	Run off provided motor (1/3 hp)		Can be designed to		Yes	Can be designed to motor		Yes
R4	Costs less than $230		Can be designed to		Yes	Can be designed to budger		Yes
	Desired Criteria	**Value**	**Information**	**Score**	**Weight Score**	**Information**	**Score**	**Weight Score**
D1	No Powder	8	Can only shred to set size	4	32	May powderize pl	1	8
D2	>90% of plastic is <0.1"	5	Will be difficult to make blades to	2	10	Only material <0.1" will pass	4	20
D3	Completely Automated	3	Theoretically yes, no emptying required	4	12	Will be difficult to automate w/ sieve	2	6
D4	2 lbs of intake for plastic	7	Potential for clogging, but can take	3	21	Meets requirement with minimal clogging	2	14
D5	Minimized	4	2nd lightest option	3	12	Heaviest option	1	4
D6	Aesthetic	2	Will look cool to watch blades in	4	8	Large drum will be clunky	2	4
	WEIGHTED TOTAL SCORES				95			56

	Alternative 3: Hammer Mill		**Yes / No**	**Alternative 4: Blender (Spinning Blade)**		**Yes / No**
R1	Yes		Yes	Yes		Yes
R2	Can mill to 10 mesh (0.1")		Yes	Most likely not		No
R3	Yes, with gearing/belts		Yes	Can be design to motor		Yes
R4	Theoretically made much cheaper		Yes	Very cheap to make		Yes
	Information	**Score**	**Weight Score**	**Information**	**Score**	**Weight Score**
D1	May powderize plas	2	16	Likely no	3	24
D2	Only material <0.1" will pass sieve	4	20	Uneven distribution of plastic bits	1	5
D3	Theoretically yes, no emptying required	4	12	No, must be hand emptied	1	3
D4	Should be able to fit more	4	28	No, blade distribution will be poor	1	7
D5	2nd heaviest option	2	8	Lightest of options	4	16
D6	Motor connection and drum fit well	3	6	Clunky build, motor rotates at 90deg	1	2
			90	Fails Pass/Fail test		

Figure 1: Design ASA Table

When creating the criteria that each shredder should meet, it was decided that the most important factors of the shredder would be the amount of plastic that could be taken as an input and the shredders ability to shred fine pieces of plastic without turning the plastic into dust. A shredder that can take large inputs would be convenient and would allow for the user to simply continuously feed plastic without having concerns of clogging or having to constantly switch on and off the machine. Designing a shredder that would not produce dust was also important to the overall recycling process. If the shredder shredded the plastic too small, then it would be too fine to be used in any injection molding or extruding projects and would defeat the purpose of the fine shredder.

As shown in Figure 1, a hammer mill design and a chipper-based shredder were found to be the two most effective designs that would allow for a simple yet effective fine shredder. However, the chipper-based shredder was ultimately selected as the final design since it was more effective at shredding plastic to the desired output without producing a significant amount of dust. Although the hammer mill design would be more effective at taking large inputs of plastic, its bulky and heavy nature combined with chipper mill's ability to minimize powder production was ultimately the reason the hammer mill wasn't selected for the final design.

Looking at other proposed designs different approaches to this shredder resulted in very different scores when considering the objectives set by our group. The blender and attrition mill were deemed to be ineffective designs after further research. Since the blender was unable to offer a clear way to filter and easily recirculate any plastic that had not been shredded to the desired dimensions, it did not meet the required criteria as therefore was not considered as a final design option. Although the attrition mill does meet all required criteria, there was a prominent concern that this shredder design would produce a significant amount of dust and would be relatively heavy compared to the other design options. These factors were the main reasons why our team went with a chipper-based shredder design.

Figure 2 shows the hand calculations that were done in order to estimate the necessary force torque and forces of plastic shearing. The calculations were useful in determining blade diameter, gear ratio, shaft size, and sprocket attachment method. Calculations were done in order to find the minimum torque required to shear PLA which was found to be approximately 16.87 in-lb. With this number in mind, our chosen sprocket teeth were 14 and 45 to achieve a gear ratio that would decrease the RPMs but increase the torque output. With our chosen gear ratio of 3.21:1, our axle produces 39.15 in-lbs of torque. The MATLAB calculation to find that value is shown in Figure 2.

```
% Assumptions
% A36 steel blades

n = 6; %number of blades
tPLA = .2 * 25.4; % mm
wPLA = .2 * 25.4; % mm
A = tPLA * wPLA; % mm^2
rBlade = .8 * 25.4; %mm

sigPLA = 40; % mpa
tauPLA = .5775 * sigPLA; % mpa

F_blade = tauPLA * A; % N
F_blade_mm = F_blade * 1000; % kg*mm/s^2
F_total = n * F_blade; % N
F_total_mm = F_total * 1000; % kg*mm/s^2
I_m_blade = 92.79; % kg*mm^2

w1 = sqrt(F_total_mm * tPLA / (n*I_m_blade)); % rad/s
w2 = sqrt(F_blade_mm * tPLA / (I_m_blade)); % rad/s
RPM = w1 * 30 / pi; % Rotations per minute

work = .5 * w1^2 * I_m_blade; % kg*mm^2/s^2

thetaPLA = asin(tPLA / rBlade); % rad
thetaBetweenCuts = (2*pi / 6) - thetaPLA;
accel = work / (I_m_blade * (thetaBetweenCuts)); % rad/s^2
Torq = I_m_blade * accel; % kg*mm^2/s^2
Torq_Nmm = Torq / 1000; % N*mm
Torq_Nm = Torq_Nmm / 1000; % N*m
Torq_inlb = Torq_Nm * 39.3701 * 0.224809; % in-lb
Torq_inlb
```

```
Torq_inlb =

   16.8675
```

Figure 2: MATLAB calculations to find minimum torque to shear PLA

```
% Gear Ratio
GR = 45/14;

%Torque of the Motor
MotorTorque = (63025*(1/3))/1725

% Torque of the Axle
AxleTorque = MotorTorque*GR
```

```
MotorTorque = 12.1787

AxleTorque = 39.1460
```

Figure 3: MATLAB calculations to find torque produced by axle using the chosen gear ratio

Initial Prototype Development

The initial prototype our group created was a 3D printed version of our design as shown in Figure 4. The first prototype was a smaller version with only 2 spinning blades rather than proposed 5 that would be used in the final design. The design was printed to scale allowing for partial assembly to be complete using some of the key components we had on hand. The main purpose of this prototype was to ensure that there were no major issues with our design concept, and it also allowed us to make any necessary changes to improve the implementation of our design.

In addition to the 3D printed prototype, several test plasma cuts were performed to produce a test component for each part of our shredder. This included a blade, a spacer, a side wall, and a blank (used as a cutting surface for the spinning blades). These test cuts allowed us to address any issues that arose while moving from a CAD model to a plasma cut part and better understand the assembly process and requirements for plasma cut steel pieces. A more detailed description of the tests that were performed on this prototype can be found in the following section.

Figure 4: Shredder 3D Prototype V1

Prototype Testing

Due to our prototype's reduced size but correct scale we were able to test the fit of key components like the shaft, walls, blades, etc. while not being too time intensive to produce. This narrower version was used to test the ease of assembly, search for interferences, and get a basic idea of functional capability. Functional subsystems primarily involve the shredding interface itself, where plastic will be sheared into smaller pieces. The plastic model was used to shred paper as shown in Figure 5. This proved to us that our blade design was capable of catching and shearing material that was approximately the same size as the input plastic we were expecting.

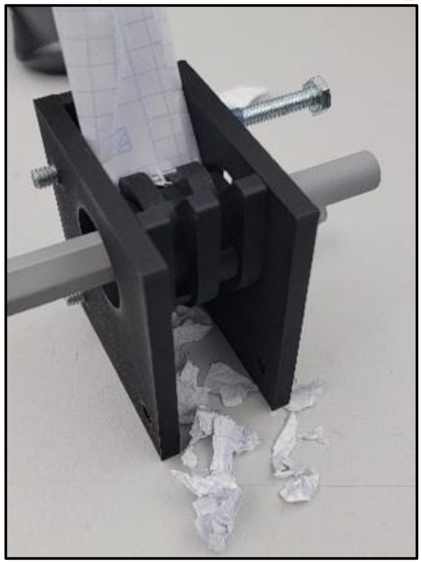


Figure 5: Prototype Paper Shredding Demo

In addition to this, our team was also successful in plasma cutting a blade that fit perfectly onto our 3D printed shaft. This allowed the team to finalize our blade design and be confident in the plasma cutting operation to produce the internal hexagonal geometry that we required for each blade to function. The process of achieving this was iterative, with us plasma cutting a few blades prior to this with different corner radii to try and narrow down to a final cut path. To quantitatively test the near finalized shredder design, our team measured the volume of plastic shredded after a minute of running the shredder. The results of the five tests ran are summarized in Table 1 below. The sizeable volume of plastic being shredded indicated to our team that the shredder design was successful due to the mesh insuring the size of the output plastic. This meant the plastic had to fit the size requirements and a sizeable amount of plastic was still getting produced. Multiple tests were run to account for input plastic discrepancies.

Table 1: Volume of plastic produced from tests

	Test 1	Test 2	Test 3	Test 4	Test 5
Volume of Plastic (in^3)	3.3	2.9	3.6	2.7	3.1

Prototype Refinement

Furthering progress on this project primarily focused on manufacturing and assembling the final shredding system, consisting of the blades, blanks, walls, and shaft. We were successful in producing and assembling a functional prototype of this subsystem, which can be seen below in Figure 6A. We were able to hand-crank the shaft to shred a variety of test plastic pieces and were able to prove that the cutting subsystem was capable in this regard. The outputs of this test can be seen in Figure 6B. Of course, there were a few pieces that were too hard to shred by hand, but the team was confident that the motor would provide enough torque to shred the quantity of plastic we intended to load into the system.

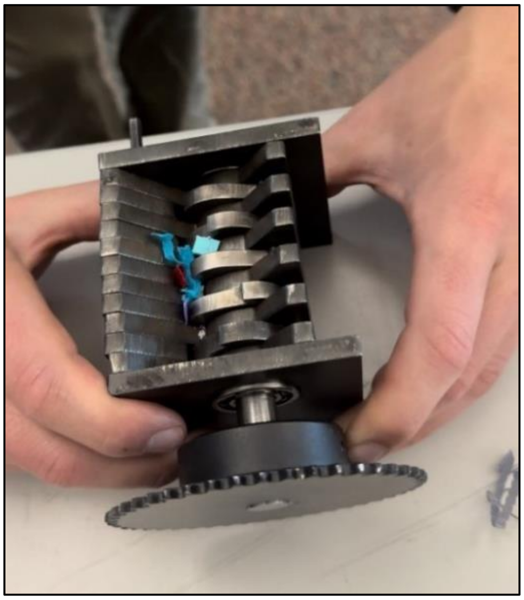


Figure 6: A) (Left) Photo showing plastic being shredded by hand cranked shredder B) (Right) Photo showing plastic that was shredded.

Initial planning of the power switching electronics of the system was also underway at this point of development. A preliminary circuit diagram for this system can be seen below in Figure 7. This consisted of a simple circuit of an Arduino button acting as a switch for a JQC3FF mechanical relay, which fed into an emergency stop and finally completed the circuit through the motor. Wires were to be joined using solder sleeves. Preliminary testing of this circuit proved successful, with the emergency stop button being successfully wired to the motor and proved functional when the system was powered.

As we neared a point where we thought we would be ready to assemble the full prototype, we discovered that the shaft we had machined had severe interference with the spacers that surrounded it. This was because of some inconsistencies in the manufacturing of these spacers which caused the center alignment of them to be off by a few millimeters (shown to the right in Figure 8, the hexagonal shaft is represented in blue). This caused the shaft to slightly 'catch' on some of these areas of misalignment, and we decided that this was a critical issue that had to be fixed before the system could handle being spun at the intended RPM without damage. To solve this, we widened the shaft hole in each of the spacers to ensure that there was no chance of shaft interference. This was done by progressively removing material with a Dremel until we were able to assemble the shredder and spin the shaft by hand without any resistance. Once assembled, further interference was found between the blade's largest diameters and the blanks. Again, we progressively removed material from the blanks, while retaining the cutting edge as much as possible, until the desired free-spinning tolerance was met. We further

tested this solution by attaching a drill to the end of the shaft and rotating it at a high RPM as shown in the video using the link below. In testing this, we found that the issue had been fully resolved and confirmed there were no other major interferences in the system when spun at a high RPM.
YouTube Link: https://www.youtube.com/watch?v=MhfbK -EsPSY

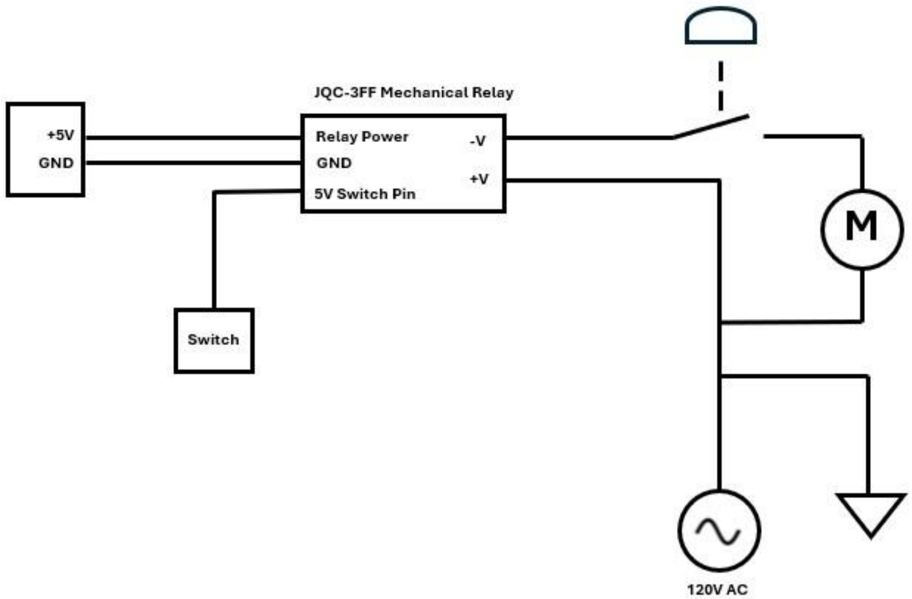


Figure 7: Initial circuit diagram of the motor and e-stop

Figure 8: Axle-Spacer Interference

Final Prototype

The final prototype consists of numerous changes from earlier models and ideas. The general layout of the shredder was kept the same, with the locations of the mountings for the motor and shredder box not changing. A couple of post-processing steps were required, however, to transform the prototype into its final form. The blades for faced off to make them slightly narrower than the blanks, which provided enough of a tolerance for them to spin up to the required RPM without catching or slowing. A few miscellaneous pieces were recreated from excess steel in order to deal with incorrect cutting on an earlier prototype. The hex-shaft was also re-toleranced, using a lathe, to better be able to account for any slight, lateral force during shredding operations.

Additionally, a few additions were made to the model that were not included before. A funnel was installed to hold plastic above the shredding area and a plunger was fitted to allow the plastic pieces to be forcefully pressed onto the blades' cutting surfaces. The emergency stop was also completed and wired to the motor, allowing the shredder to be hooked up to the motor, whereas previous prototypes had relied on hands or power drills to spin the shaft. Finally, a prototype shield was placed over the transmission area to safeguard any hands from becoming caught in the spinning mechanism. Figure 9, 10, and 11 show the completed, final prototype.

Figure 9: Final Prototype Overview

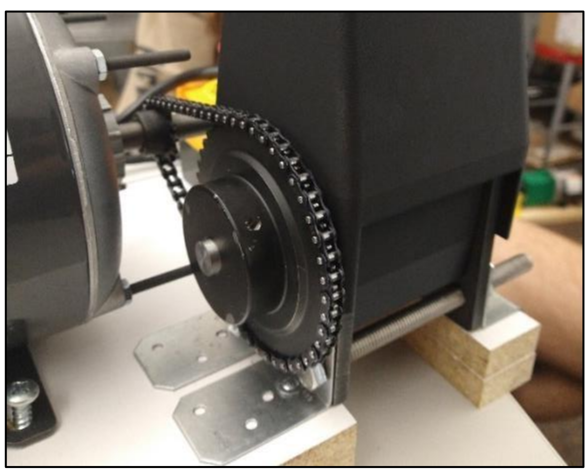


Figure 10: Final Transmission View

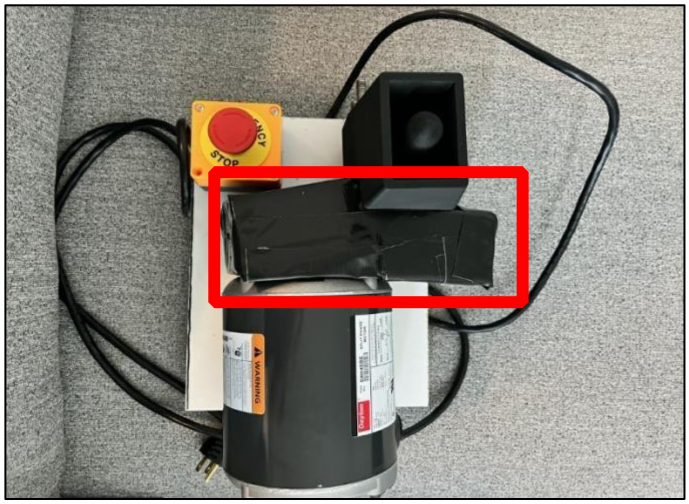


Figure 11: Prototype Transmission Cover

On demonstration day, the final prototype was able to run non-stop for periods of over 20 minutes without clogging, overheating, or breaking. The output of the shredder was able to match the production of the bulk-sized shredders and the demand of the filament extruders and injection molders. The prototype met all design requirements mentioned earlier. Specifically, it produced small enough plastic bits to be used effectively down the production line while not powdering the material.

Ultimately, the prototype met all design factors that the team had considered. While it needed to be retrofitted with a prototype transmission cover at the last minute due to safety concerns, the final design for the transmission cover can be easily manufactured and installed using FFF style printing operations. All this said, the prototype easily fit the budget constraints set by the team and successfully shredded the sizes of plastic required while producing the sizes required. Our shredder was even able to take larger plastic (and even metal) pieces while still producing the required size of output. The fine-size shredder prototype our team created is not only efficient but is cost effective and reliable too.

Additional Work

Glass Box Analysis

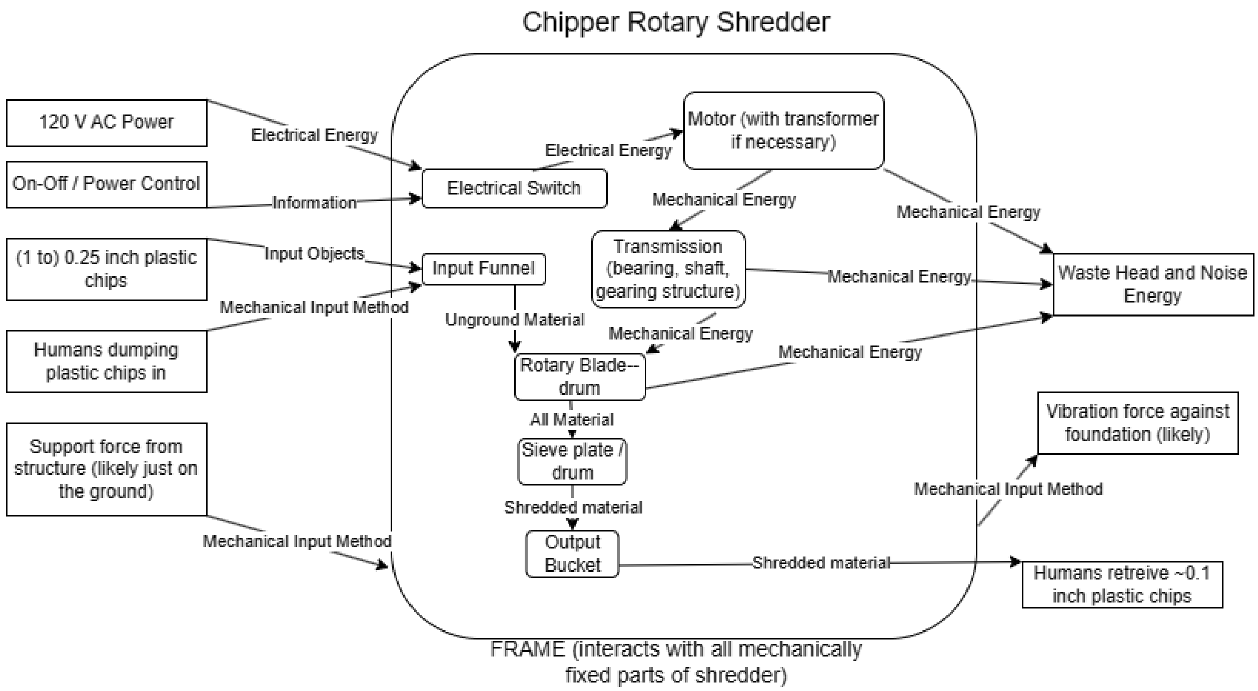


Figure 12: Glass Box Analysis

Iterative CAD Modeling

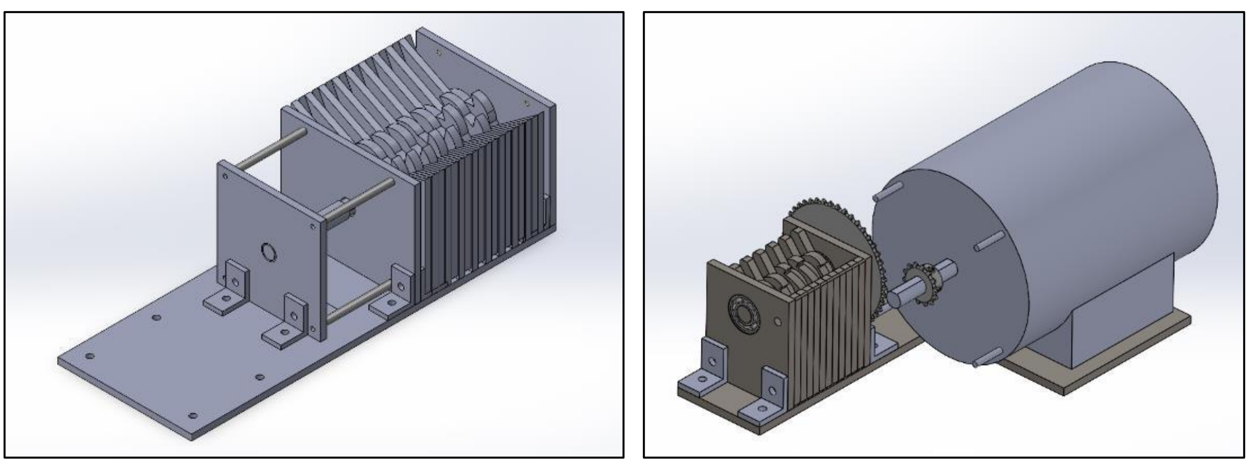
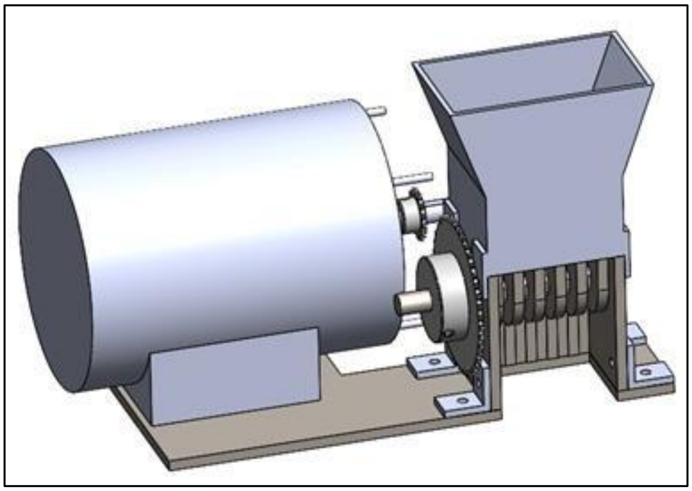


Figure 13: Initial Design Idea (left) with Sprint 2 Updates (right)



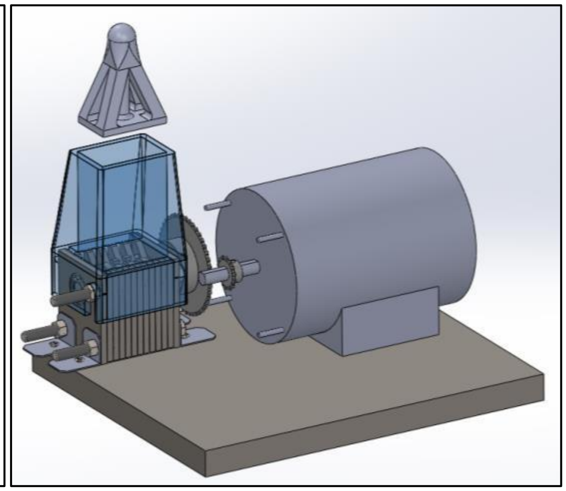


Figure 14: Sprint 3 CAD Updates (left), Final CAD Rendering (right)

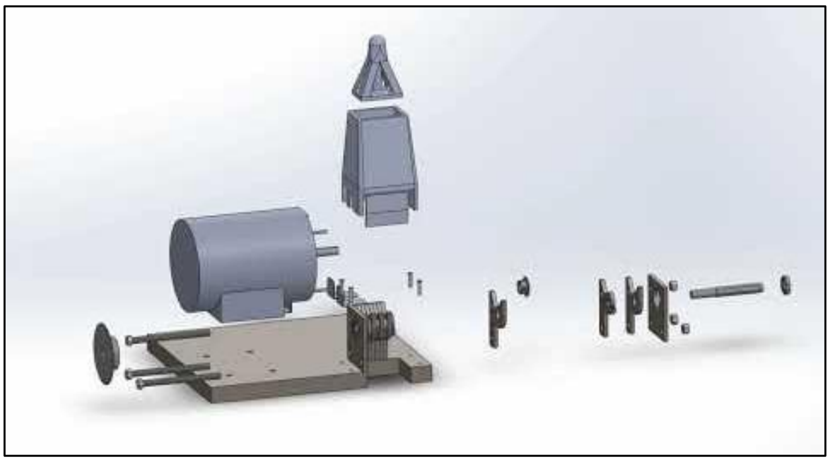


Figure 15: CAD Assembly Animation (https://www.youtube.com/embed/N8GbXt_aRRw?feature=oembed)

Prototype Final Bill of Materials

Part Name	Description	Unit Cost	Quantity	Total Cost
Hex Shaft Axle	1/2” diameter, 12L14 Carbon Steel, 12”	$15.30	1	$15.30
Ball Bearing	Steel ball bearings for 1/2” shaft diameter	$7.11	3	$21.33
Connecting Link	1/4” Pitch, 25 Roller Chain Trade No.	$2.32	1	$2.32
ANSI Roller Chain	1 foot, 1/4” Pitch, 25 Roller Chain Trade No.	$6.84	1	$6.84

Sprocket	45 Tooth Set Screw Sprocket for 1/2" Diameter Shaft	$36.67	1	$36.67
Sprocket	14 Tooth Set Screw Sprocket for 1/2" Diameter Shaft	$14.90	1	$14.90
Sheet Metal	1/4" thickness, A36 Steel, 12" x 12"	$30	2	$60.00
Fasteners	3/8" Fasteners with 5" Length	$6	1	$5.99
Filter	Galvanized Steel wire Cloth	$2.76	1	$2.76
	Total Prototype Cost:			$150.81

Figure 16: Costing Analysis for Final Prototype

Future Work

While we are thoroughly impressed with how our final prototype turned out, there are of course many areas where further refinement and, in some cases, complete redesign would be necessary to bring our design to a state where it could be sold commercially. The main areas that we would improve upon with more time and money are the following:

- Permanent cover to enclose the chain
- More precise machining
- Sharper blade design (more direct shearing surfaces)
- Better base plate material than wood
- Removing excess thread length on shredder bolts
- Removal of bottom 1/3 of each piece, raising the bottom bolt higher
- More effective method of output capture
- Better plunger design and shorter input funnel

While most of these are either simple aesthetic changes or only require a simple change to our CAD model and a reprint of the part, the major areas that we foresee taking more work to adjust are the blade design as well as the machining precision. Elaborating on these two areas further, we found during the demo day that some of the plastic we were being provided by the bulk shredder teams was not what we were expecting, being far larger than the 0.25'' x 0.25'' chunks we anticipated. To account for this, and to generally improve the cutting ability of the system overall, we would redesign the blades to have taller, sharper teeth. This would resolve the issue we faced where certain pieces could not be gripped and shredded very easily as our current blade teeth were too short and dull to grab and pull the plastic further through the shredder. We would maintain the same distance between the new teeth and the blanks, though, as our current design produced nearly perfectly sized output, which is something that we would need to maintain. The issue of the precision in the machining is a more complicated issue that lies more in our groups familiarity with plasma cutting as an operation rather than our design itself. The alignment of some of our pieces was definitely an issue and would not be acceptable to the market in this state, though we do believe that the plasma cutter is capable of producing our parts with minimal post processing required.

Lessons Learned

As a team, we believe that this project has been our most valuable and intensive design challenge to date. We have all learned more than we thought was possible in the timeframe of one semester. For starters, this group of 6 people has been the largest that any of us have ever worked in. This alone has been one of the main areas where we think we all improved greatly. The effort it took to coordinate tasks among this many people was much more than any of us had experienced before and ensuring that the progress being made on the project was clear to everybody was also a challenge. We developed effective modes of communication and methods of organization to solve these issues. These skills will be invaluable in the future to all of us, whether it be in senior design or industry, it is likely that we will be forced to work in large groups, though we are all now far more confident in our abilities to make it effective after this experience. In addition to this, we all learned or further developed a plethora of technical skills. Each member of the team had a different role in the production of the final prototype, so an individual assessment of skills that were learned or developed will be included below:

Stosh Lalik: The project taught me a good amount about the prototyping design process. I was involved in a lot of the design decision making, and over the first few weeks, we spent a lot of time theorizing different problems without creating anything physical. Later as we created progressively more accurate prototype pieces and systems, we were able to identify, address, and solve or remove problems more efficiently. The most productive days were those when we produced something, even if the creation was only partial or imperfect. For example, a plasma cut component could be mounted on the 3D printed prototype, and a fitting test would reveal that the differences between the plasma cut blade and an ideal (3D printed) blade would cause interference. The test would make it clear what post processing needed to be done to plasma cut parts. Essentially, we can’t expect to anticipate every problem ahead of time, so iterative prototypes identify them more quickly, and thus the process is ideal for the future. Another thing I noticed was how much harder mass production would be than creating a one-off prototype. When we had a tolerance issue we could change a hole size or grind a surface down, but such labor time would not be acceptable in mass manufacturing—so designing some thing for mass production takes a lengthier and involved process with many more manufacturing and assembly tests.

Brandon Bayer: Throughout the duration of the project, I focused a lot on the production of the parts for the prototype. I started out working with SolidWorks to create a CAD model of the design; one that would eventually match the designs made by Cade and focus on machineability. I was the main member to use the plasma cutter and I learned a lot about adjusting the Sheet CAM settings to make the plasma cutter work to our wanting. I also learned a lot about postprocessing, since the overall quality of the plasma cutter was not up to par with our prototype's tight tolerance needs. Through the use of mills, drill presses, lathes, and miscellaneous woodworking machines, I honed my skills in the shops on campus. The main challenge for me, as I completed a lot of work in the machine and wood shops, was to make sure the parts produced fit the specs needs for our design. Ultimately, the prototype was assembled and functioned as intended, but it came at no small expense, through many hours of post-processing and fidgeting with the parts in the shops. Through this design project, I was able to improve my ability in the machine and wood shops, as well as keep myself fresh when it comes to using CAD software such as SolidWorks.

Ceja Florendo: I feel like working on this project pushed some of skills I have learned up to this point to their limits and forced me to explore areas that I had never had the opportunity to before. Other than helping with the machining I primarily worked on the electronic components of the design. The extent of my electronic knowledge ended at Arduino's, and I had never worked with any voltages greater than 20V. For this project, I had to figure out how our motor worked and understand how to supply it with the power it needed to work at full capacity. This required me to solder, crimp, and strip wires which I had never really done much before as well as learn how to safely handle high voltages like those supplied from a wall outlet. After a few cases of shorting our power cable and discovering that an E-stop with two normally open terminals wasn't very helpful, I was able to get our motor running with confidence that all of the connections were strong, and the system was safe. I also definitely saw the importance of initial design in this project and am glad that our team took the time at the start to settle on a design we were very confident in and only at that point begin production. Of course, we had a few hiccups along the way, though I think that we could have found ourselves in much worse shape if we didn't have a solid plan to return to in these cases.

Bridget Dick: By the end of the semester, I learned a lot about the different pieces that go into manufacturing. We ran into several issues within our manufacturing process. One issue we had was with the parts that we plasma cut. Since we use a plasma cutter to cut out the hexagonal inserts in the blades for the axle to go through, the corners of the plasma cutter were not sharp and had to be filed down. We also had to take the blanks to a grindstone in order to keep some of the blades from hitting them upon rotation. Also with the plasma cutting, we had to dremel the inside holes of the spacers in order to get the axle to fit correctly across the entire shredder. In the future I would either choose a different manufacturing process or try more test pieces. Outside of the plasma cutting, I learned how to apply classes such as machine design to find bearing calculations and solid mechanics for the torque calculations to a real-life application. This allowed me to learn what the applications of our classes have to a potential industry problem.

Cade Mankle: Over the course of the semester, I had a big focus on the 3D CAD of the prototype and the manufacturing of the design. A major skill I took from this process was the ability to work cooperatively on a CAD design. Before this class, the use of SolidWorks was mainly singular and individual. However, with this project, there were many ideas bouncing around and being able to work cohesively on a single prototype proved challenging in the first couple of weeks. From then on though, it was an enjoyable process and proved to be fruitful with how our prototype turned out. Also, another skill I refined was my manufacturing skills. I had experience with manufacturing given we made derby cars last year. This time around though, the parts were much more complex, and we had to use a variety of machines such as the mill, lathe, band saw, miter saw, and even the plasma cutter.

Nico Carrasco: One of the biggest takeaways from this project for me has been the importance of testing and prototyping. Throughout the course of this project there were times where I felt we as a group made more work for ourselves because we overlooked very simple problem or design aspect that if we had slowed to test our current design or prototype this issue would have come to our attention sooner most likely saving the group more work towards the end of the project since we would likely not have to spend as much time addressing design issues or problems. Another big takeaway from this project has been the importance of designing for ease of manufacturing. This has been one of the first projects where as a group we completed the entire design process from the initial brainstorming of the design, to designing in CAD, to prototyping and ordering parts and then finally building a complete product. One of the biggest challenges we faced was modifying our design in order to make manufacturing and assembling our product as easy and intuitive as possible. Throughout the project I have learned how to consider different aspects of implementation that are easy to overlook when designing in CAD software.

Risk and Reliability Analysis

Our FMEA analysis from Sprint 4 predicted the top five most likely and severe failures as shown in Figure 17. Our team assumed that the most likely areas to fail would be the axle that spins the blades, a bearing coming loose from vibrations, or a sprocket tooth bending due to forces from the chain rotations. There was also some concern that the blanks would fail due to surface fatigue and the base board would fold up onto itself due to the transmitted torque. The values found for the failure effect probability, failure mode ratio, and failure rate were found using the Handbook of Reliability Prediction Procedures for Mechanical Equipment [2].

The key takeaways of this risk and reliability analyses were that the areas of concern for failure were relatively save and unlikely to occur. Even with the base board and sprockets having higher criticality numbers, these failure modes were unlikely and did not occur. However, if done again, efforts would be made in order to make the design more reliable. The efforts would likely be ensuring that the press fit bearings were fit more snugly or deciding to utilize mounted bearings instead. Another way to make the design more reliable is to use a thicker axle shaft to ensure that shearing of the blade from the torque on the blades is not possible. A final way to ensure the reliability of the design is the make the base board out of a stronger material that can still handle vibrations.

Identification Number	Component	Function	Failure Mode	Operational Mode	Severity Class	Failure Effect Probability (β)	Failure Mode Ratio (α)	Failure Rate (λp)	Operating Time (t)	Failure Mode Criticality Number	Item Criticality Number Cr=ΣCm
S01	Shaft	Spins blades	Shearing	Rotation	4	0.5	0.3	0.72	3	0.33	0.33
S02	Bearing	Aligns shaft	Surface Fatigue	Rotation	2	0.5	0.5	1.14	3	0.86	0.86
S03	Blanks	Separate blades	Surface Fatigue	Separation	4	0.5	0.3	1.65	3	0.74	0.74
S04	Base Board	Shredder Foundation	Cracking	Structural	2	0.5	0.5	1.59	3	1.19	1.19
S05	Sprocket	Transmits torque	Tooth bending	Rotational	2	0.5	0.5	1.24	3	0.93	0.93

Figure 17: FMEA of top 5 most likely and severe failures

Works Cited

[1] OECD. (2022, February 22). *Plastic pollution is growing relentlessly as waste management and recycling fall short, says OECD*. OECD. https://www.oecd.org/environment/plasticpollution-is-growing-relentlessly-as-waste-management-and-recycling-fall-short.htm

[2] Naval Surface Warfare Center Cardrock Division. (January 2010). Handbook of Reliability Preidction Procedures for Mechanical Equipment. https://mines0my.sharepoint.com/personal/jewheele_mines_edu/_layouts/15/onedrive.aspx?i

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