

Hops Baler 2.0 Project
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Clients: UVM Extension

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United States
Department of
Agriculture

National Institute
of Food and
Agriculture



Disclaimer



With respect to the University of Vermont College of Engineering and Mathematical Sciences:

The intent of this report is to present the design, analysis, prototype realization and test of a hops baler for the Hops Baler 2.0 project. The work presented here was performed as a two-semester long project as a part of the UVM School of Engineering's Capstone Design courses (ME 185/186, EE 187/188) instructed by Professors Frolik and Novotny. Although we have exercised utmost care while working on all components of this project, the reader should be aware that the work was performed within a short time period and by students. This work was directed and reviewed by the course instructors and Dr. Mike Rosen.

The reader is advised that before using any part of this report or the device itself, the work should be independently evaluated.

In receiving the prototype device, the Client understands that UVM is not warranting or representing that the device is functional for any particular purpose in its existing form. The Client agrees to indemnify, defend and save harmless UVM, its agents, students and employees from any and all liability, claims, causes of action or demands of any kind and nature which may arise in connection with this device.

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Rosalie Madden
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With respect to the University of Vermont Extension:

This report and associated design documents are provided "as-is" without guarantee or warranty of any kind to communicate the findings of a research project with the aim of developing a small-scale hops baler for use in the Northeastern United States. The design is based on standard practices in agricultural equipment operation. This description of the machine is based on the first year of operation (one harvest season), during which several modifications were made. The design team expects future modifications will also be made as improvements are sought to the machine's functionality and as maintenance is required. Additionally, the design should be reviewed for relevance to the user/reader's specific location and operation. The design of this machine assumes experienced and attentive operation teams who demonstrate safe practices when using equipment. The machine is not intended to be operated unattended or by unskilled operators. Risks of bodily injury, include, but are not limited to those that may occur as the result of various pinch points. Any deviation from the design may create safety risks that are unknown to the designers. UVM, NeHA, their employees and their contractors do not assume liability for any actions or machine assemblies that result in personal injury or loss of property or damage to property on the part of the user of these documents or any operators of the equipment.

To: Dr. Heather Darby
Rosalie Madden

In our report, there are detailed description and analyses of all parts of the Hops Baler 2.0 Project. We clarify the objectives and constraints to show we have met all the requirements you were looking for. We have designed and built our machine to the best of our abilities and are glad you approve of our work. We cannot thank you enough, Heather and Rosalie, for the opportunity and support throughout the year. We also appreciate the insight and wisdom of Dr. Mike Rosen who constantly pushed us to better our project. We have learned so much throughout the whole project and would not have been able to if it were not for our sponsors UVM Extension, SEED, and the College of Engineering and Mathematical Sciences. We were also funded in part by the Vermont Agricultural Innovation Center through the United States Department of Agriculture, Rural Development. These funds were secured through the efforts of Senator Patrick Leahy. We could not have done it without all these great people and programs.

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Problem Statement

Vermont and other Northeastern states have seen resurgence in hops production. The demand for locally produced foods has spurred an interest by microbreweries to search out local hops. The small acreage of Northeastern hop farms requires scalable production and processing infrastructure. The available hops balers are aimed at major producers that construct a 200 lb bale. Our team will develop an alternative design, aimed at producing 5-10 lb bales using human power, with a particular emphasis on preserving quality, safety, low cost and time efficiency.

Design Overview

The design uses human power with a mechanical advantage to supply an uncompressed volume of hops with a load large enough to compress them down to a small, compact bale. The initial volume of hops is determined by a value for the initial density, which was found through test trials in the materials testing laboratory. The density of hops varies depending on how long they have been drying, hop variety, and level of compaction prior to entering the baler. With this in mind, an initial density value was chosen that took all of those aspects into consideration.

A final Solidworks model of our design can be seen in Figure 1. The design and subsystems will be explained in detail in the Design Details section of this report.

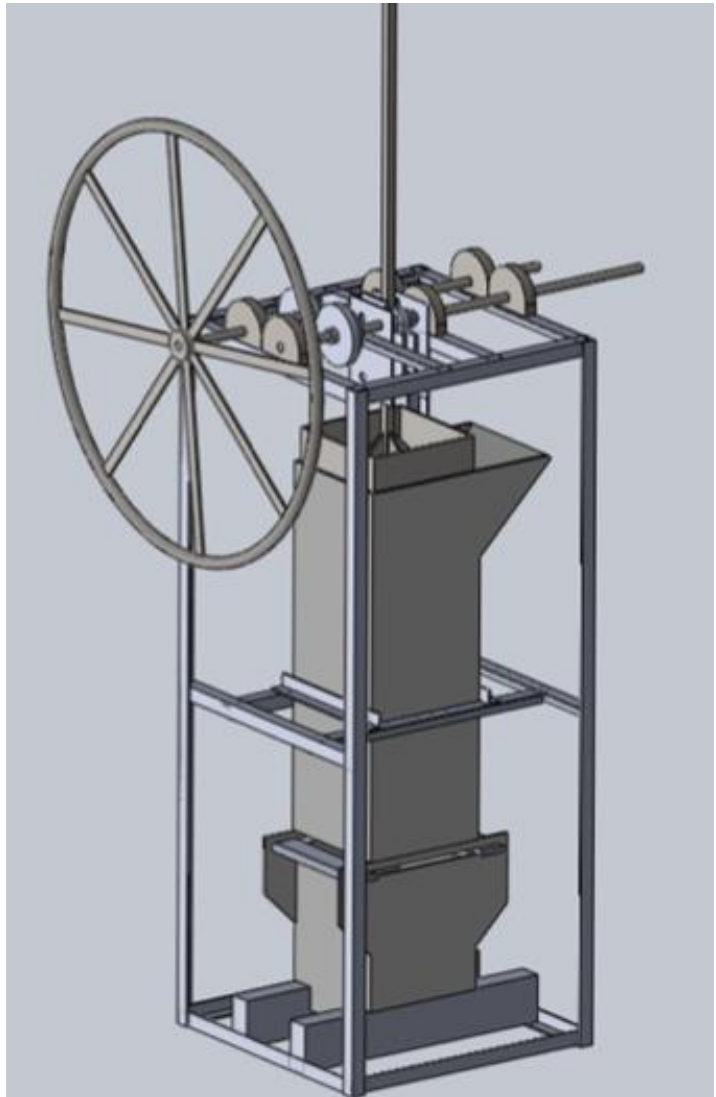


Figure 1. Final Solidworks model for Baler 2.0.

Objective Analysis

Through an aggregate rank ordering, four basic objectives were determined for the hops baler, as seen below in the objective tree. We determined that the baler needed to be scalable to produce bales from 5 to 10 pounds, that it needed to be automated in the sense that a continuous flow could be established, it needed to be safe i.e. no exposed sharp edges and no risk of getting caught in moving parts, and most importantly it needed to be marketable. In order to determine how well our final design will fulfill each of these objectives, we constructed a metrics chart and used projected values for each objective to determine a final performance score of our design.

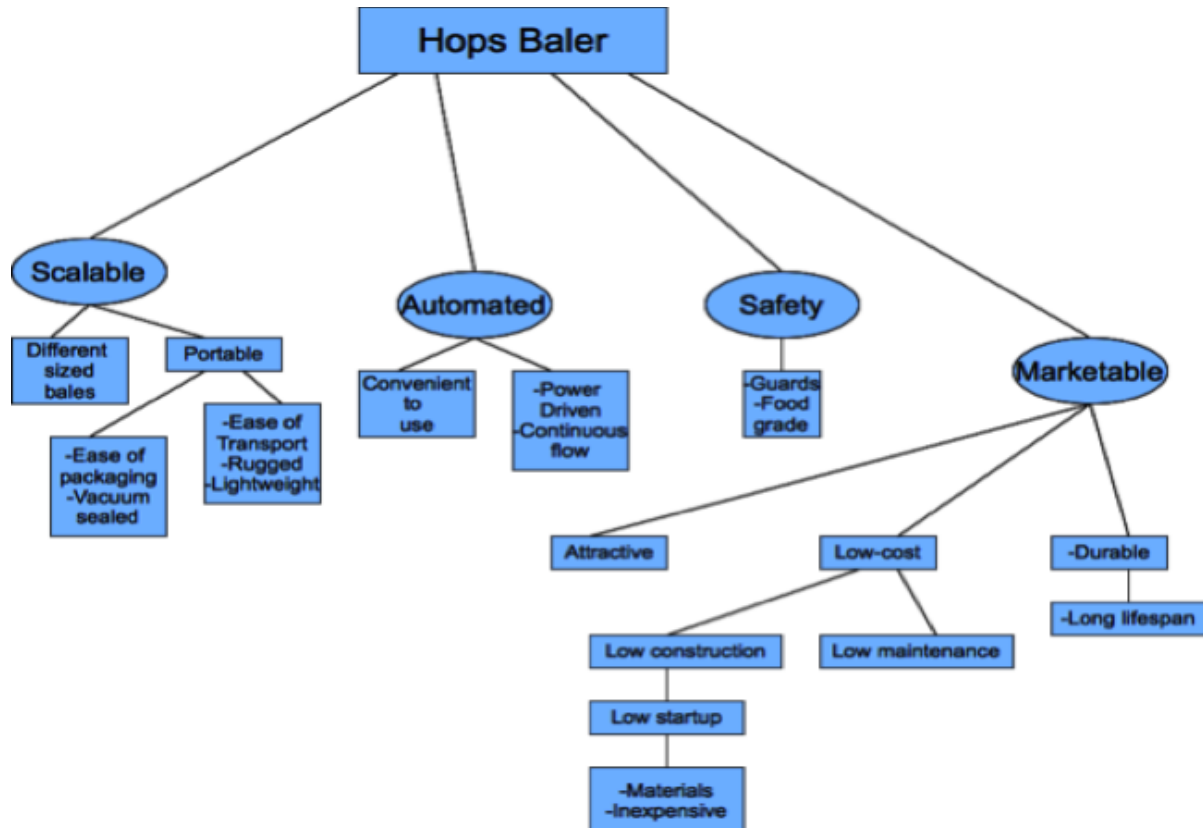


Figure 2. Metrics chart used to determine final performance score for Baler 2.0.

Our device has met all the objectives besides automation, safety guards and lightweight. When we were initially listing objectives we thought our baler would be powered pneumatically or by electricity, but after testing we determined that all power requirements could be satiated with human power. By making the machine human powered we actually increased its marketability (one of our objectives) because the baler produces zero carbon emissions. The safety guard objective was simply not met because we did not completely enclose the gearbox. We did not enclose the gearbox because we wanted easy access to it in case anything went wrong. Although the baler is not lightweight, it also is not very heavy. It is easily transported by removing the crank wheel and moving it with a hand dolly.

Function Analysis

To perform a function analysis we mapped out the flow of inputs, sub-functions, and means in a function-means tree. This provided us with an excellent organized graphic of the required steps involved in manufacturing a hops bale, and the required inputs and means that would be needed to accomplish these steps and at what point these inputs needed to be introduced. This helped us look at individual steps and discuss all possible methods of accomplishing each, and ultimately which method we felt was the best.

Requirements:

In order to complete the task of forming a hops bale of a given size, we determined four requirements that the hops baler design needed to have. The design needed some method of packaging and maintaining hop quality, an adequate mechanical power source input, a method of adding hops efficiently, and a well designed compression system to actually press the hops into a bale. Through a brainstorming session we found several means of accomplishing each requirement in order to allow for a broad range of design ideas which we could later narrow down based on a ranking system as well as experimentation.

Function	Requirement
Unite Hops to Bag	No Loss of Hops
Compress Hops	Achieve Desired Density
Allow Bale to Form	Create Stackable Shape
Vacuum Sealed	Eliminate All Air
Seal the Bag	Food Grade

Our device met all of the requirements that we had set in December. The baler had some method of packaging and maintaining hop quality, an adequate mechanical power source input, a method of adding hops efficiently, and a well designed compression system to actually press the hops into a bale. According to the metrics we constructed in December (seen below) we predicted that the baler would have a total quality of 0.56 with 1.0 being the best.

Preliminary Metric:

	Best Case (BC)	Worst Acceptable (WA)	Estimated Actual (A*)	W*
Bale Size (lb)	10	1	5	0.444444444
Machine Weight (lb)	100	300	150	0.75
Longest Dimension (ft)	4	7	5	0.666666667
Life Span (years)	15	1	6	0.357142857
Price (\$)	300	2000	1000	0.588235294

$$W^* = (A^* - WA) / (BC - WA)$$

$$Q = \text{Quality} = \sum(W^*) / n$$

$$Q = 0.56$$

Actual Metric:

	Best Case (BC)	Worst Acceptable (WA)	Estimated Actual (A*)	W*
Bale Size (lb)	10	1	5	0.4444444444
Machine Weight (lb)	100	300	225	0.375
Longest Dimension (ft)	4	7	5	0.6666666667
Life Span(years)	15	1	15	1
Price (\$)	300	2000	1578.4	0.248

$$W^* = (A^* - WA) / (BC - WA)$$

$$Q = \text{Quality} = \sum(W^*) / n$$

$$Q = 0.55$$

By inputting all of the actual numbers post-testing, our total actual quality achieved is 0.55. The quality found for our final product is much lower than it should be. Initially we decided upon the best case and worst acceptable numbers during our design process. At that time we did not fully understand the magnitudes of our features, especially for our best case price and worst acceptable weight. If they had been made more reasonable, the quality would be higher.

Design Details

Frame:

Figure 3 shows the frame portion of the design. It is made entirely of 5/4" wide by 3/16" thick square angle iron stock. The frame dimensions are 2' by 2' by 5', and all the pieces are welded together.

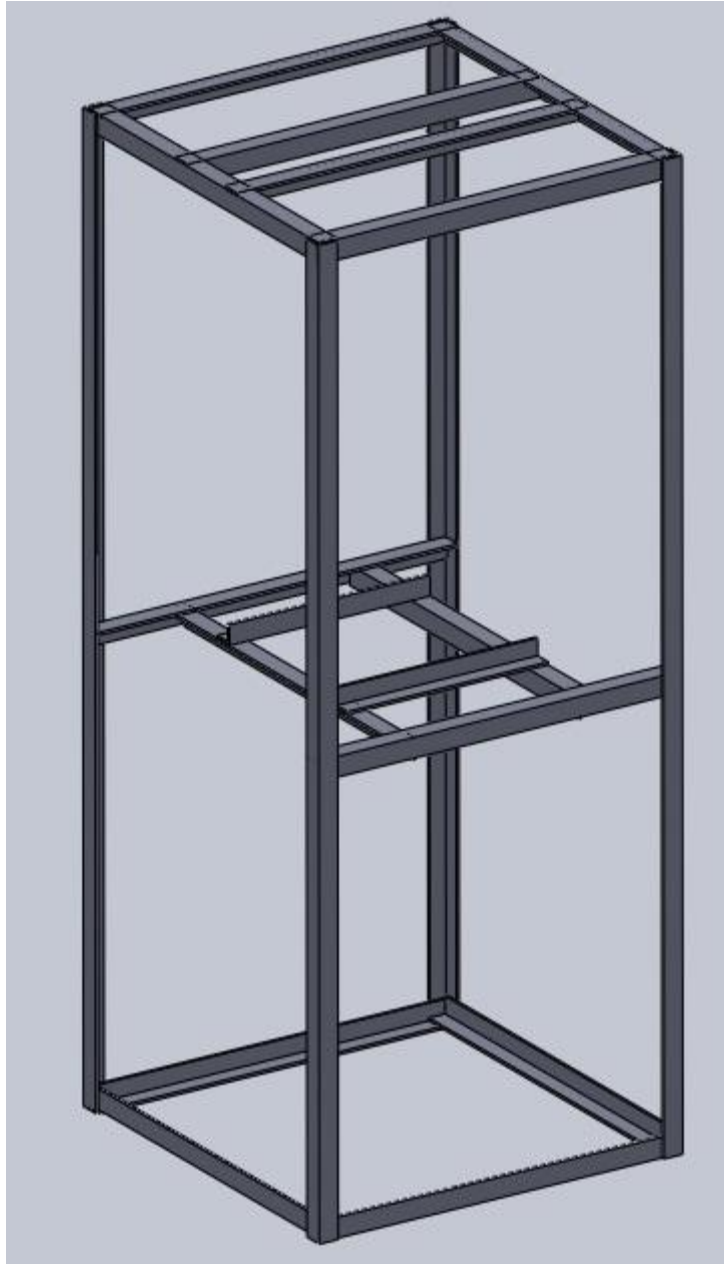


Figure 3. Baler 2.0 frame.

Funnel:

Figure 4 shows the funnel component of the design. The funnel walls are made of high density polyethylene, chosen for its low friction value, which is held together by aluminum angle stock fastened with self-tapping screws. The polyethylene sheet material is $\frac{3}{8}$ " thick. The screws are fastened from the inside of the funnel walls, and the heads are countersunk to prevent obstruction of the plunger. The funnel dimensions are 30" high by a 10 in² inside dimension. The fill line which ensures a 5 lb bale is located at 24" from the base of the funnel and exactly at the start of the angled piece where the hops are poured in.

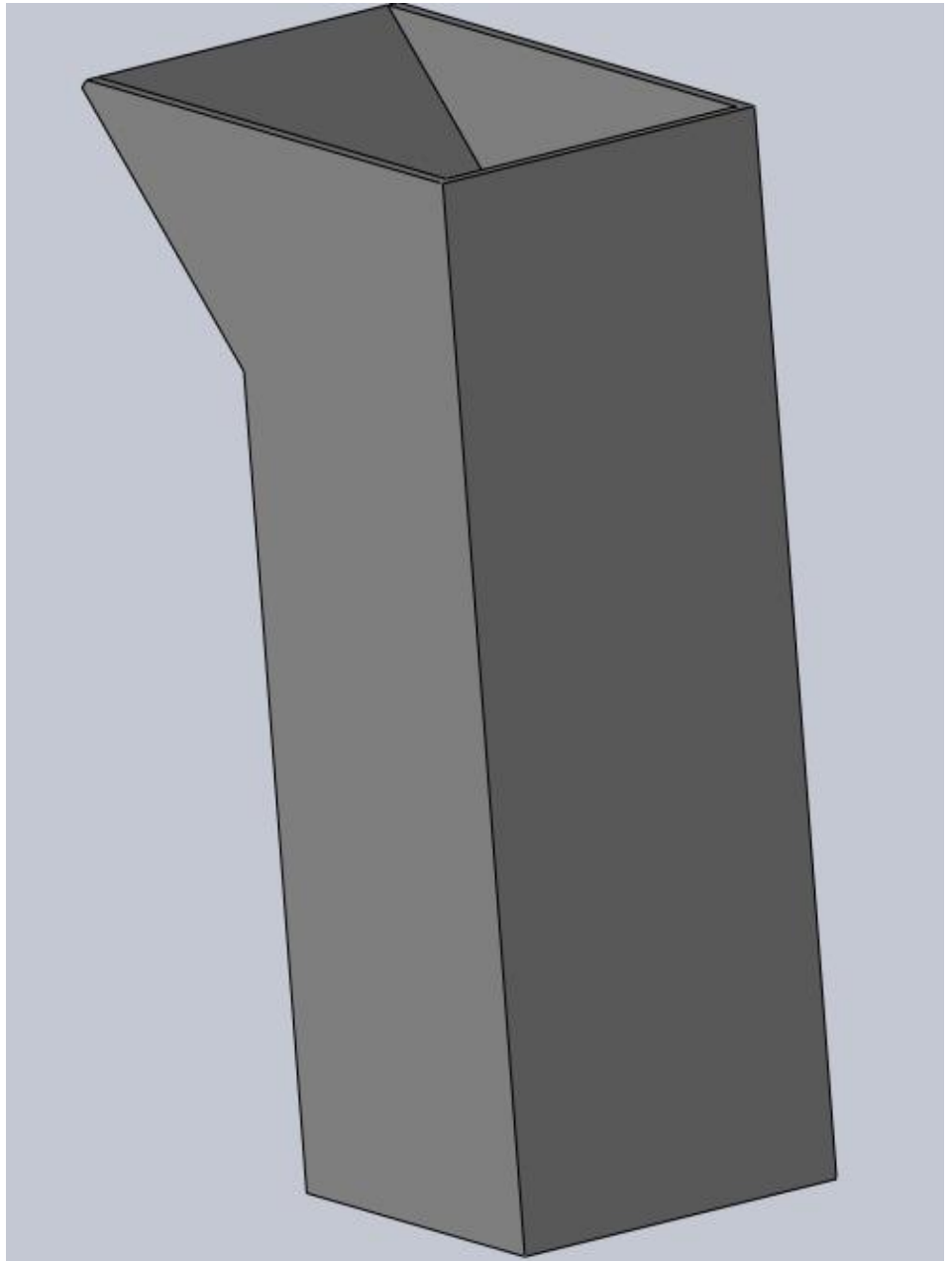


Figure 4. Funnel.

Gear Assembly:

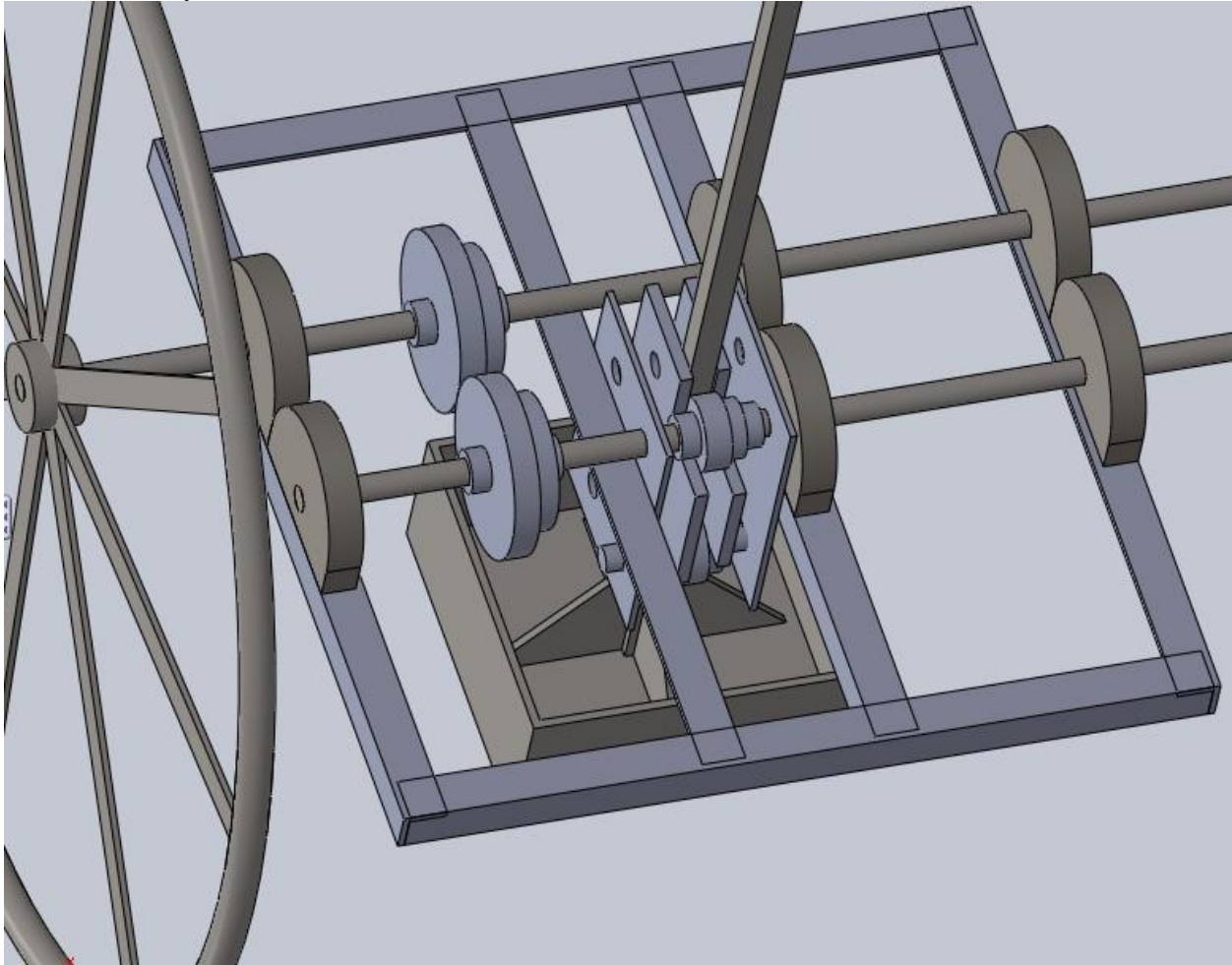


Figure 5. Gear assembly for Baler 2.0.

The gear assembly (Figure 5) transmits the force applied on the crank wheel to the rack and thereby to the plunger. The crank wheel is fixed to a keyed input shaft, which is fixed by three cast iron mounted bearings and also holds the first input gear. The shaft is 30" long and has a diameter of $\frac{3}{4}$ ". It is fully keyed with a $\frac{3}{16}$ " by $\frac{3}{32}$ " keyway. The input gear has a diameter of 5.125", a 20° pressure angle, a pitch of 16, and a face width of $\frac{3}{4}$ ". The force from the input gear is transferred to a second 5.125" gear with the same specifications held by the transmission shaft. This shaft transmits the force to a 2.125" gear, also with a pitch of 16, a 20° pressure angle, and a $\frac{3}{4}$ " face width, which in turn transmits the force to the rack. A second 2.125" gear is located directly below the first on a rolling shaft in order to provide bracing for the rack. The shaft is held in the gear box by press-fit high density polyethylene spacers that fit snugly on the roller shafts. These spacers and the gears and rollers are sandwiched by two high density polyethylene boards made from the same material as the funnel. These boards are then held in place by two steel plates that are welded to the cross braces. The cross braces are angle iron of the same dimensions as the frame and are welded to the frame. All gears are held in place on the shafts by keyways with key stock, and two collars with set screws for each gear. The mounted bearings also have set screws to hold the shafts in place.

Plunger:

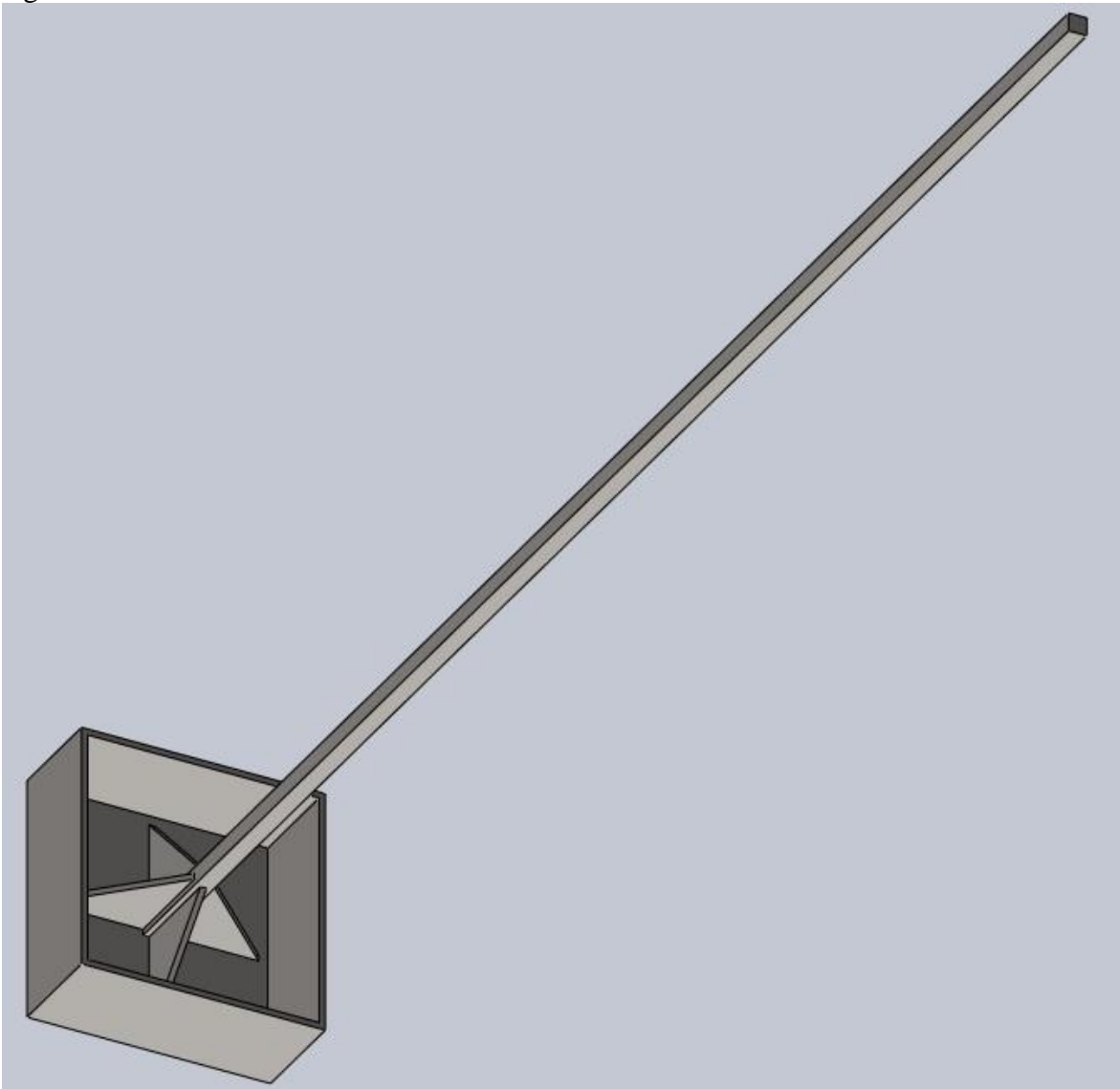


Figure 6. Plunger component for Baler 2.0.

The plunger component (Figure 6) consists of a flat plate base made of $\frac{1}{4}$ " thick steel with guide plates welded onto the top of the plate to prevent it from becoming misaligned with the funnel and form box. Welded onto the plate is our rack, which receives the power input and delivers it to the hops. The rack is 5' tall and has pitch of 16 with a 20° pressure angle and is a $\frac{3}{4}$ in². The rack is braced by four angled pieces of plate steel, which are welded to both the rack and the plunger plate. Several small holes have been drilled into the plate and small pieces of thin rubber have been epoxied over them to act as one-way air valves. As the plunger compresses the hops, air is released from the holes, and upon starting the upstroke the valves close over the holes so air is not allowed to flow back into the hops.

Crank Wheel:

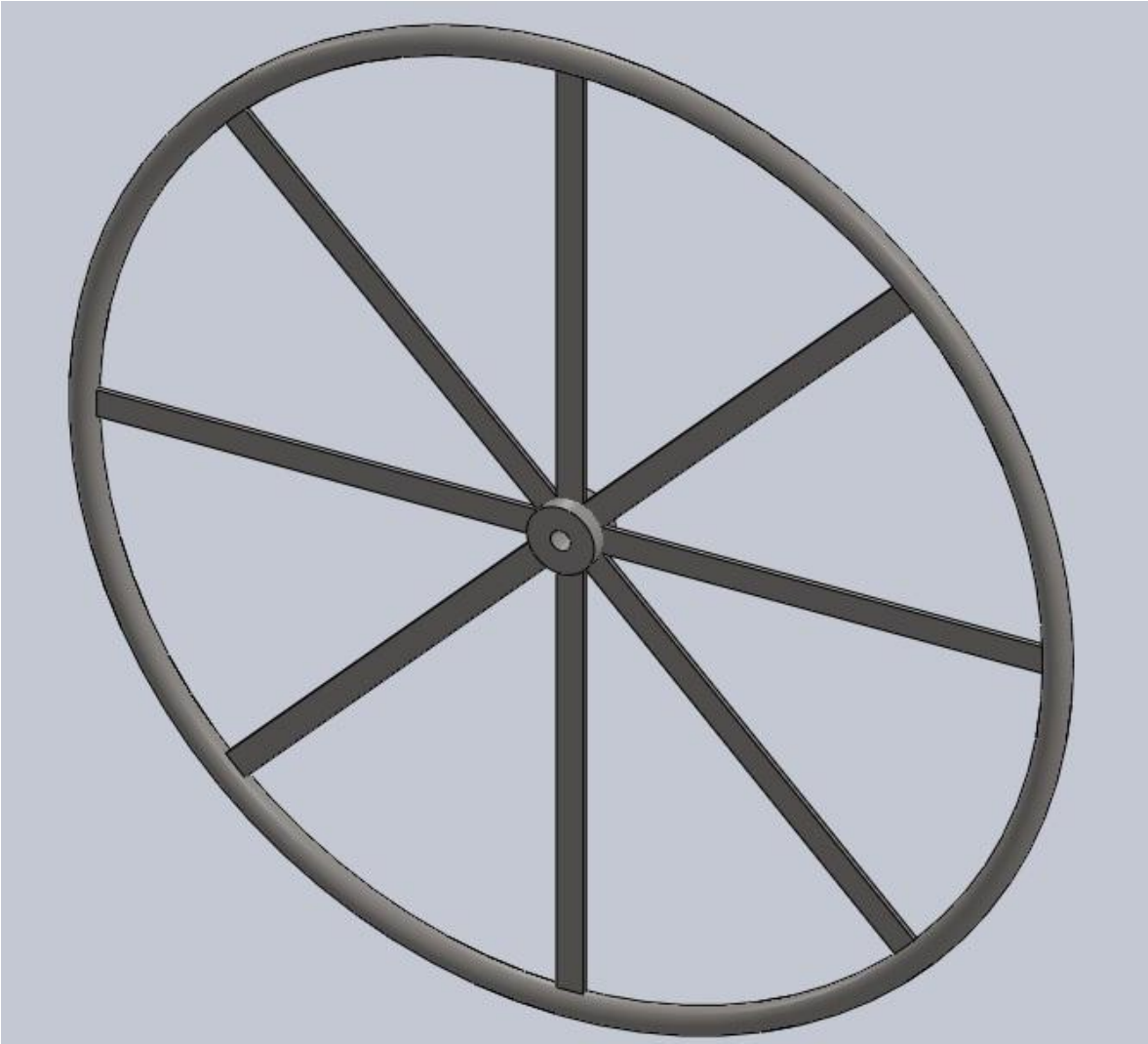


Figure 7. Crank wheel for Baler 2.0.

Our crank wheel (Figure 7) was manufactured by Clews Machining, LLC. It is made of steel bar stock with a diameter of $\frac{3}{4}$ ". The outer portion of the wheel was rolled, and 8 spokes were welded on. The hub has an outer diameter of 2.5" and a thickness of 2". The hub has a bore diameter of $\frac{3}{4}$ " to fit around the drive shaft and has also been keyed to $\frac{3}{16}$ " by $\frac{3}{32}$ ". The wheel has a total diameter of 36", which is necessary to provide the 17:1 gear ratio desired. The wheel also has a significant mass, which helps to act as a flywheel to store momentum when completing the compression stroke.

Shaper Box:

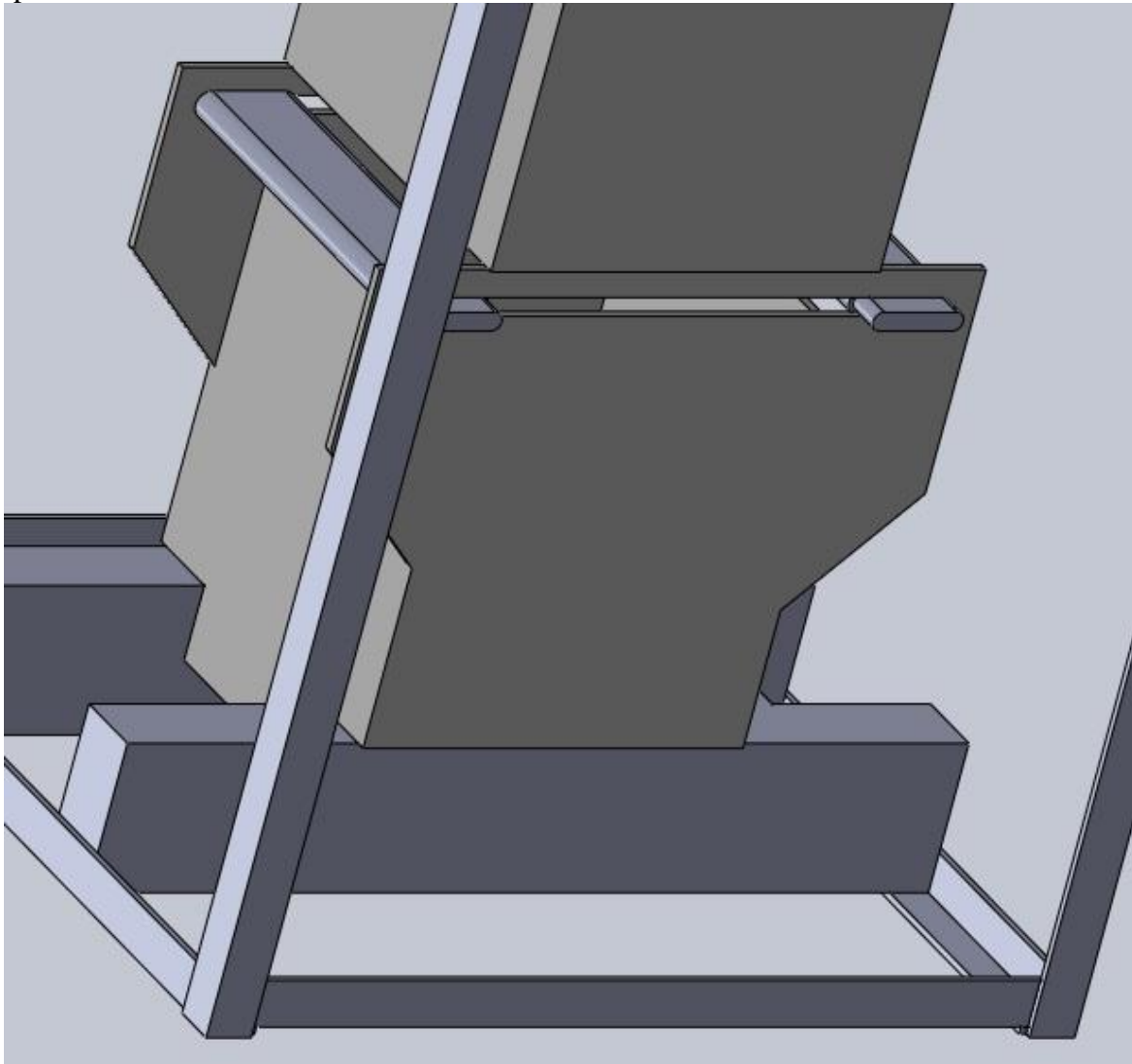


Figure 8. Baler 2.0 shaper box.

Our bale shaper box (Figure 8) is constructed of the same material as the funnel, but instead of being braced by aluminum angle stock it is braced by steel to provide a stronger skeleton. The box is 12.75" tall, with a 10" inner footprint. The base of the box is a 10.75 in² piece of plate steel with a ¼" thickness. Two of the sides opposite each other are not fixed into the box but instead are held in place by small pieces of angle iron welded to the base plate on the inside of the box. This design feature allows the pieces to be removed easily which makes removing the bale very smooth.

Test Results

We built and refined a hops testing device to be used in conjunction with the University of Vermont's force transducer in the materials testing lab in Perkins 003. Testing began Friday 2/10/12 morning and yielded graphs of load and displacement. Our testing apparatus comprised of a 1' PVC pipe with an inside diameter of 4.1", a plywood disc to be placed on top of the hops, a wooden base to interface with the force transducer's bottom plate, and another 9" PVC pipe with a slightly smaller diameter to interface with the force transducer's top plate and the plywood disc. Our test method comprised of three basic steps: first, we filled the large PVC test tube with hops which gave us a known volume. We then weighed this volume of hops which gave us initial density. Secondly, we placed the testing apparatus on the force transducer and set the test parameters (test rate, maximum force, and maximum displacement) and ran the test until break. We measured the total time of the test and stopped the timer once the stress relaxation point had been reached (i.e. when the load applied readout stopped decreasing rapidly.) The force transducer also gave us a readout of final displacement, which we used to determine the final density. Lastly, we removed the apparatus from the force transducer and removed the hops from the cylinder and placed them in a separate ziplock bag marked with the trial number for later use in detecting the presence of crushed lupulin sacs by alpha-acid testing. We conducted six total tests and the returned data was relatively constant throughout except for the initial test which involved some error due simply to operating blunders. The information we collected ultimately helped us determine the total force needed as well as an approximate spring constant for hops under compression. We also considered these calculations to determine gear type, gear ratio, lever arm, and funnel material (i.e. strength characteristics) required for compression.

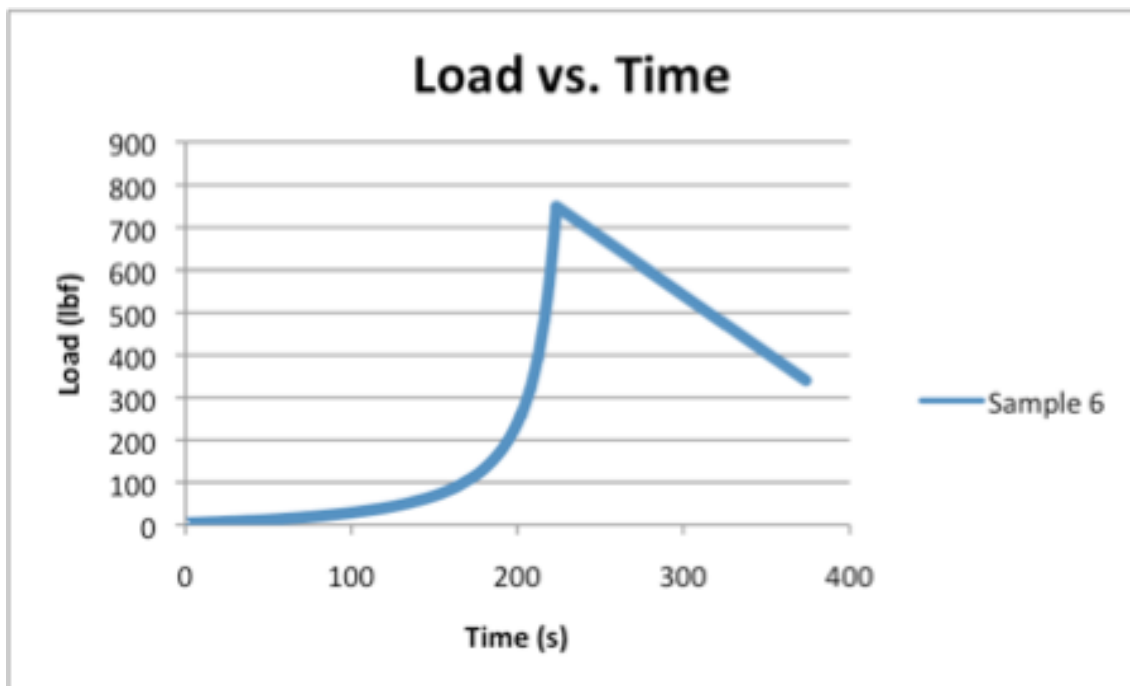


Figure 9. Load vs. time.

Note that in Figure 9 the stress relaxation period is linear because of the fact that the force transducer stops recording force versus time once the maximum force is reached. The data

seen was recorded entirely manually by using a stopwatch to determine the time of relaxation and watching the force readout for the point at which the relaxation slowed considerably.

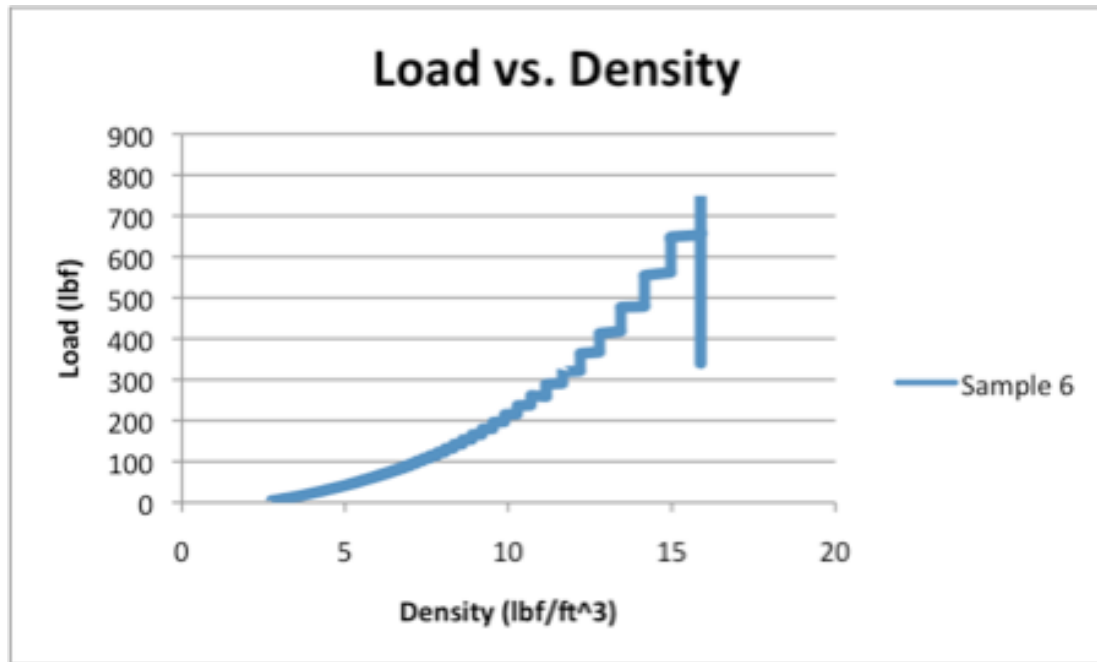


Figure 10. Load vs. density.

Calculations:

Load at desired density of 9 lbf/ft³ for the model: 100 lb

Cross sectional area of model: 13.2 in²

Cross sectional area of funnel/shaper box: 100 in²

$$\text{Stress} = 100 \text{ lb} / 13.2 \text{ in}^2 = 7.574 \text{ psi}$$

To find the needed force to compress the 5 lb of hops, we use the stress calculated for the model:
 $7.574 \text{ psi} = P / 100 \text{ in}^2 \Rightarrow 757 \text{ lb}$

We estimated the load at the desired density to be 50 pounds lower due to relaxation. Our model was a disk of wood that fit snugly into a pipe. When we compressed it with the force transducer it did not exhaust air well. Once the stroke was completed, we would let the model sit for a minute and read the force of the rebound. After the relaxation, which exhausted the air and allowed the hop cones to settle, the rebound force was reduced to about half of the break force. Thus, at the desired density, it had a force reading of 150 pounds and we estimated it would only needed 100 pounds of compression had it been better conditions.

We then related the model to our designed hops baler dimensions to find the needed force at the end of the stroke. It came to be 757 pounds, which through proper gearing could be achieved.

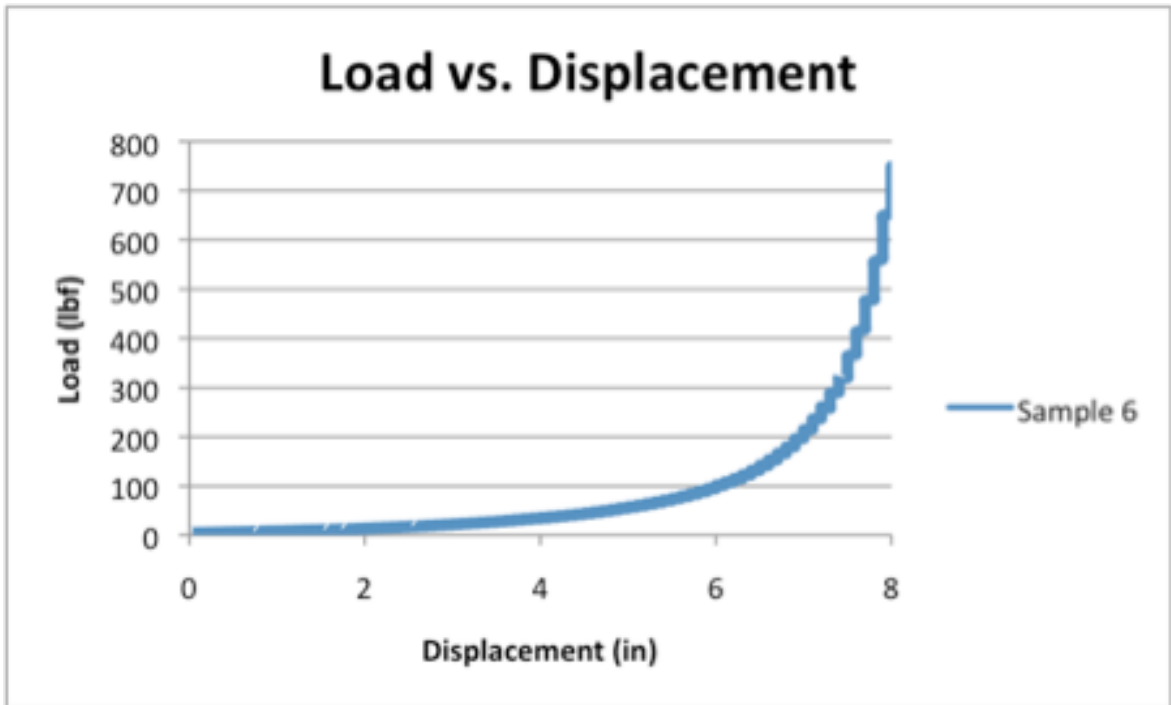


Figure 11. Load vs. displacement.

Using Excel's exponential line of best fit function on the load versus displacement plot (Figure 11) we obtained a spring force equation of $F(x)=4.1437e0.5565x$ with an R^2 value of 0.983. The major area of variance between the equation and the data was seen in higher displacements where the density was above our desired 9.2lb/ft^3 , which tells us that the variance shouldn't affect us much.

Stress testing of the frame:

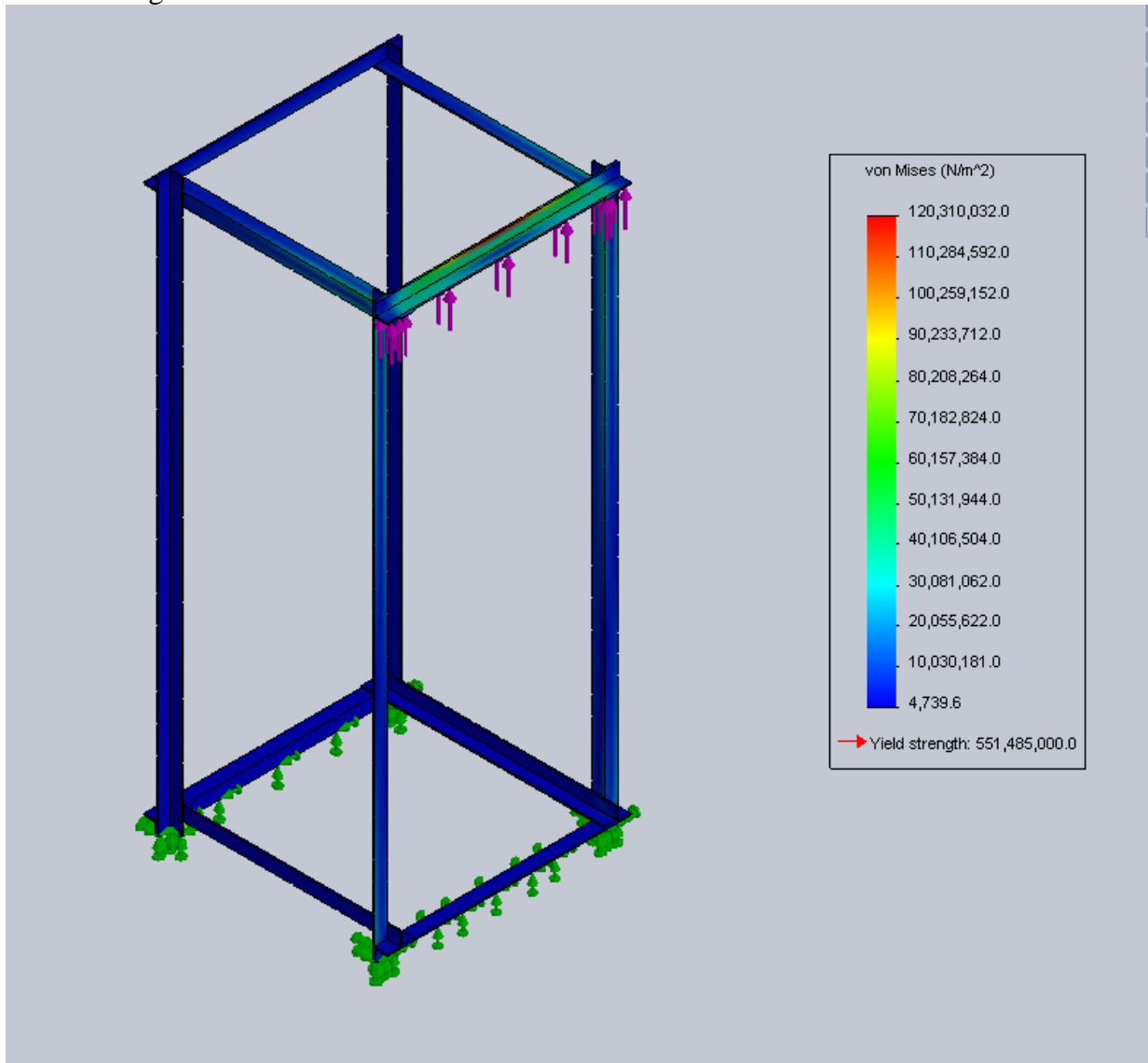


Figure 12. Simulated stress test results on frame.

From the testing done in the lab, and from our calculations which can be seen above, we conducted simulation testing on the necessary components of our design. In Figure 12, a simulation on the frame was conducted where a 757lb load was applied to one side (which is an extreme case since the load will be distributed between the two sides.) The stress plot shown to the right demonstrates that the maximum stress felt by the frame is well below the yield strength of our frame material.

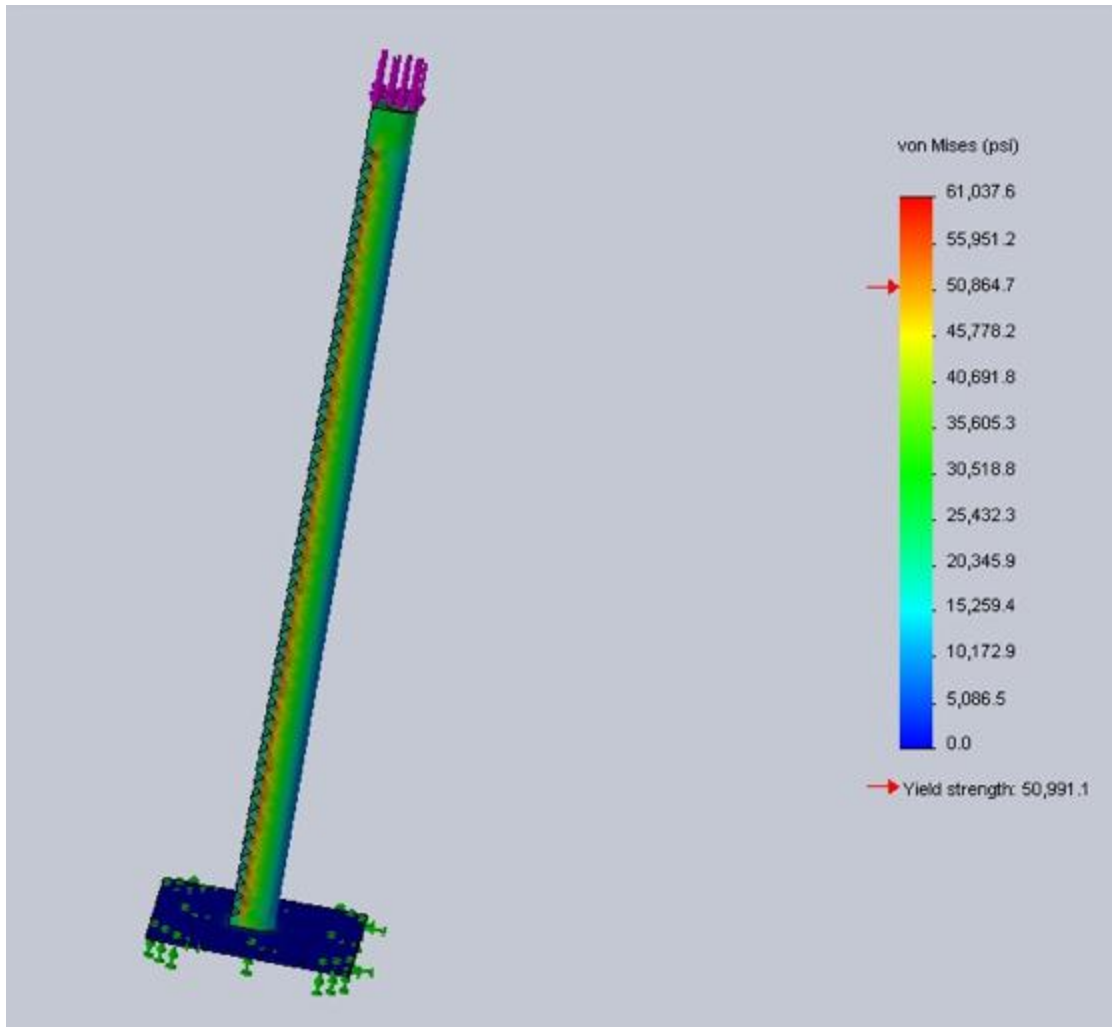


Figure 13. Simulated stress test results on plunger.

Figure 13 shows the plunger apparatus fixed at the bottom face with a load on the top of 70000lbf, which created failure. This analysis tells us that the plunger can withstand a load slightly less than 70000lbf, which again is well above what we expect the plunger will have to endure.

Analysis

Weight of hops: 5 lb

Density of loose hops: 2.5 lb/ft³

Density of compressed hops: 9 lb/ft³

Cross sectional area of funnel/shaper box: 0.694 ft²

Maximum output force: 757 lb

Maximum input force: 50 lb

Diameter of crank wheel: 36 in

Larger gear: 5.125 in

Smaller gear: 2.125 in

To find height to the fill line, we use the density equation:

$$2.5 \text{ lb/ft}^3 = 5 \text{ lb} / (0.694 \text{ ft}^2 * h) \Rightarrow h = 2.882 \text{ ft}$$

Then we find the height at which the piston head needs to stop to acquire the desired density:

$$9 \text{ lb/ft}^3 = 5 \text{ lb} / (0.694 \text{ ft}^2 * h) \Rightarrow h = 0.8 \text{ ft} = 9.6 \text{ in}$$

The linear travel of the piston in contact with hops:

$$2.882 \text{ ft} - 0.8 \text{ ft} = 2.082 \text{ ft}$$

Number of crank wheel rotations for piston travel:

$$2.082 \text{ ft} / (\pi * (2.125 \text{ in} / 12 \text{ in/ft})) = 3.75 \text{ rev}$$

Force multiplier:

$$757 \text{ lb} / 50 \text{ lb} = 15.14$$

Acquired gear ratio:

$$(36 \text{ in} / 5.125 \text{ in}) * (5.125 \text{ in} / 2.125 \text{ in}) = 16.94$$

Actual needed input force:

$$757 \text{ lb} / 16.94 = 44.68 \text{ lb}$$

The baler amplifies power by about 17 times the power inputted when the bale only requires a multiplier of about 15. The extra power means the user only needs to put in about 45 pounds of force right at the end of the stroke. The good news is that the force needed to compress the hops is exponential and only gets tougher near the desired density. The stroke is also found to travel a linear distance of about 2.1 feet in contact with the hops. The stroke is actually a little longer because the piston head rises above the funnel to allow the operator to pour the hop cones in easily. But, to visualize the time it takes to form the bale, the crank wheel only spins about 4 revolutions from top to bottom.

Conclusions

By using only human power and a mechanical advantage of a 17:1 gear transmission, a 5lb bale can be compressed to the threshold density of 9lbs/ft³. The transverse stress that develops as a result of the vertical compression on the hops is almost negligible, and design considerations for this stress are minimal. After conducting multiple trials, it is clear that the rebound of the hops after compression is small and does not interfere with bagging.

After testing, only a couple of open issues stand out. When testing, we were only able to procure 2 year old dried up hops, which behave differently than freshly cut hops off the vine. Fresh hops secrete a resin when crushed that could potentially clog the one way air valves. Another issue is the possibility for the lupulin sacs to burst. It is important for the lupulin sacs to maintain their structural integrity because they contain alpha acids which are essential in the brewing process. The lupulin sacs bursting would be due to a final density greater than 10lb/ft³.

Future developments could include but are not limited to adjustments to increase the air seal and subsequently the vacuum effect, designing for faster and easier bale removal, adding incremental marks on the rack/plunger for different bale sizes and densities. The reason the airtight seal was not achieved in time is because the epoxy that we purchased did not bond well to the metal plunger head even after polishing. Ordering a highly adhesive epoxy would have taken weeks to be delivered.

User Manual

Step by step instructions are as follows:

- 1) Spin the crank wheel to raise the piston to its stop point, if not already raised, and lock it in place by moving the steel rod in the way of the crank wheel's spoke.
- 2) Place vacuum sealable bag in the shaper box then slide it towards its stop and wrap the bag around the outside of the funnel and secure in place with rubber bands.
- 3) Make sure the funnel and shaper box are firmly pressed against their stops so they are in line for the piston to smoothly move inside of them.
- 4) Pour loose hop cones into the top of the funnel up to the fill line, which is the base of the angled polyethylene plastic.
- 5) Once filled, remove the stop from the crank wheel's spoke and begin spinning it and thus compressing the hops until the piston reaches its final position which is held by a stop on the rack.
- 6) To allow some relaxation to occur, place the crank wheel stop in again and let the system sit for about a minute.
- 7) Remove the crank wheel stop, and quickly spin the wheel until the piston reaches the top again and once again put the crank wheel stop back in the way of the spoke.
- 8) Push the funnel towards the edge of the frame and pull the shaper box towards the opposite edge of the frame.
- 9) Pinch the top of the bag shut and hold tightly as you remove one or both sides of the shaper box to make for easier removal of the bale.
- 10) Take the bale to a vacuum sealer to lock the bag in shape and remove the excess air.

For a YouTube video of the baler in action, please visit:

<http://www.youtube.com/watch?v=8jQdQWiZ4KU>

Budget

Preliminary Estimated Budget:

Heat Sealer/Slicer: Impulse by U-line	\$215
Frame: Twelve 6' 90° angle steel	\$180
Plunger Rod: 5' hollow 1' outside diameter tube	\$150
Funnel Head/Pipe: Two 4'x4' sheet polyetheline	\$80
Piston Head: 1'x1' stainless steel plate	\$75
Bagging: 16"x400' heavy duty plastic tubing	\$60
Gears: Three steel plain-bore pressure angle spur gear	\$45
Bearings: Three 1/8" lubricated steel	\$30
Drive shaft: 4' solid steel bar	\$20
Wood: Lazy susan and shaper blocks	\$10
Piston Head Gasket: Polyethylene rubber	\$7

Total \$872

Actual Budget:

Quantity	Item and Supplier	Unit Price (\$)	Total Price (\$)
2	McMaster HDPE Polyethylene, 3/8" Thick, 48" X 48"	87.47	174.94
1	McMaster Fully Keyed 1045 Steel Drive Shaft, 3/4" OD, 3/16" Keyway Width, 36" Length	42.88	42.88
2	McMaster Fully Keyed 1045 Steel Drive Shaft, 3/4" OD, 3/16" Keyway Width, 24" Length	33.23	66.46
1	McMaster Steel Standard Key Stock, 3/16" X 3/16", 12" Length	2.74	2.74
8	McMaster Black-Oxide Steel Set Screw Shaft Collar, 3/4" Bore, 1-1/4" Outside Diameter, 9/16" Width	1.26	10.08
1	Clews Machining (Crank Wheel)	350	350
1	McMaster FDA Compliant Neoprene Rubber, 1/8" Thick, 12" x 24", 55A Durometer	32.32	32.32
2	McMaster Steel 20 Degree Pressure Angle Spur Gear, 16 Pitch, 32 Teeth, 2" Pitch Diameter, 3/4" Bore	33.54	67.08
1	McMaster Impact-Resistant UHMW Polyethylene Tube, 1-3/8" OD X 3/4" ID, 1' Length	7.87	7.87
6	McMaster Cast Iron Base-Mounted Steel Ball Bearing, Set-Screw Lock, for 3/4" Shaft Diameter	39.08	234.48
2	McMaster Steel 20 Degree Pressure Angle Spur Gear, 16 Pitch, 80 Teeth, 5" Pitch Diameter, 3/4" Bore	77.37	154.74
1	McMaster Steel 20 Degree Pressure Angle Spur Gear Rack, 16 Pitch, 1/2" Face Width, 1/2" Height, 6' Length	64.46	63.46
1	Sears Clear Food Grade Silicone Sealant	8.35	8.35
1	ULine 24X24 6MIL POLYBAG 200	140	140
	Queen City Steel		153.00
	Aubuchon Hardware		25.00
	West Marine		45.00
		Total Price	\$1578.4

Our clients assigned us a budget of \$2000 and we were able to complete the project with a reasonable final price. Most of our parts were bought from the McMaster-Carr online store and Queen City Steel. Our most expensive item, the crank wheel, was outsourced to Clews Manufacturing and cost \$350. Initially we just wanted them to roll the outside handle of the

wheel but they suggested we have them build the whole thing. Allowing them to make the crank wheel did save time and is probably stronger and more precise than we could have managed. The second most expensive item was the vacuum sealable bags from ULine. The ULine poly bags only come in 200 count, so ordering the 10 bags we needed to do the testing could only be done in bulk. Also, to insure durability, we made the baler extra robust and designed all the weight bearing items out of steel. In hindsight, we could have used strong wood for many of the features, which could reduce the price. The cost of labor is also not included because all of our work was done for our own learning and experience. The hops baler is designed for local farmers who will probably build their own baler based on our design and the size of their crop yield.

Bill of Materials

Part Name	Size	Material	Supplier and Catalog Number	Amount	Unit Cost (\$)	Total Cost (\$)
Funnel/ Shaper Box	3/8" Thick, 48" x 48"	HDPE Polyethylene	McMaster 8619K437	2	87.47	174.94
Fully Keyed Drive Shaft	3/4" OD, 3/16" Keyway Width, 36" Length	1045 Steel	McMaster 1497K62	1	42.88	42.88
Fully Keyed Drive Shaft	3/4" OD, 3/16" Keyway Width, 24" Length	1045 Steel	McMaster 1497K61	2	33.23	66.46
Standard Key Stock	3/16" X 3/16", 12" Length	Steel	McMaster 98535A140	1	2.74	2.74
Set Screw Shaft Collar	3/4" Bore, 1-1/4" OD, 9/16" Width	Black-Oxide Steel	McMaster 9414T15	8	1.26	10.08
Crank Wheel	36" Outside Diameter	Steel	Outsourced to Clews Machining	1	350	350
FDA Compliant Air Valves	1/8" Thick, 12" x 24", 55A Durometer	Neoprene Rubber	McMaster 8616K44	1	32.32	32.32
20 Degree Pressure Angle Spur Gear	16 Pitch, 32 Teeth, 2" Pitch Diameter, 3/4" Bore	Steel	McMaster 5172T23	2	33.54	67.08
Impact-Resistant Rollers	1-3/8" OD X 3/4" ID, 1' Length	UHMW Polyethylene	McMaster 8705K37	1	7.87	7.87
Base-Mounted Steel Ball Bearing Set-Screw Lock	3/4" Shaft Diameter	Cast Iron	McMaster 6244K53	6	39.08	234.48
20 Degree Pressure Angle Spur Gear	16 Pitch, 80 Teeth, 5" Pitch Diameter, 3/4" Bore	Steel	McMaster 5172T25	2	77.37	154.74
20 Degree Pressure Angle Spur Gear Rack	16 Pitch, 3/4" Face Width, 3/4" Height, 6' Length	Steel	McMaster 6295K124	1	64.46	64.46
ULine Poly Bag (200 count)	24" x 24", 6 mil Thick	Polyethylene	Uline S-3628	1	140	140
Nuts and Bolts	2", 3/8" Diameter	Steel	Aubuchon Hardware	12	1.75	21
Self Tapping Screws (80 count)	1/8"	Steel	Aubuchon Hardware	1	3	3
JB Weld Cold Welding Compound	1 Package	Epoxy	JB Weld 8265S	1	5	5
Frame Angle Iron	5/4" x 3/16", 20' Length	Steel	Queen City Steel	3	24	72
Angle Aluminum	5/4" x 3/16", 20' Length	Aluminum	Queen City Steel	1	27	27
Sheet Metal	1/4" Thick, 2'x 3'	Steel	Queen City Steel	1	29	29
				Final Cost		1505.05

Schedule

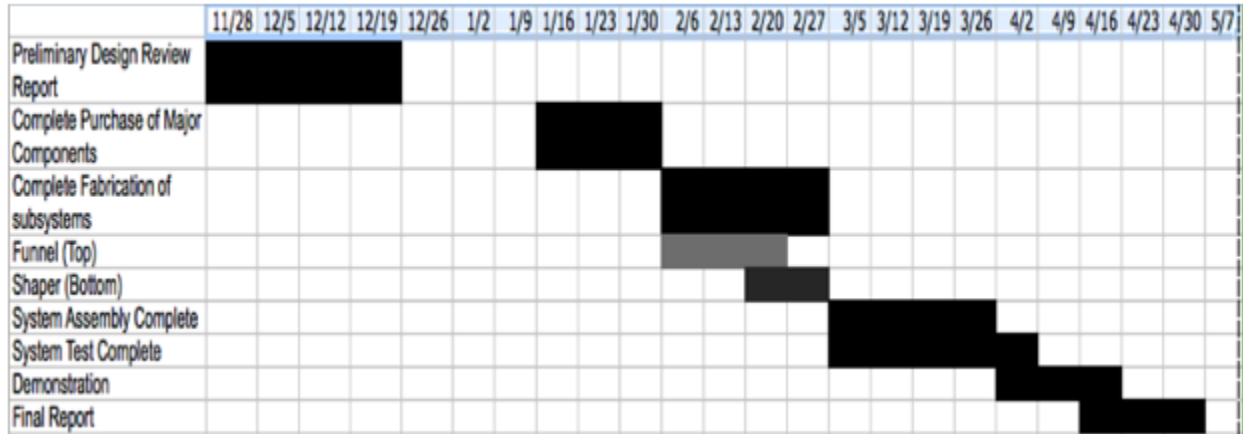


Figure 14. Preliminary Gantt chart.

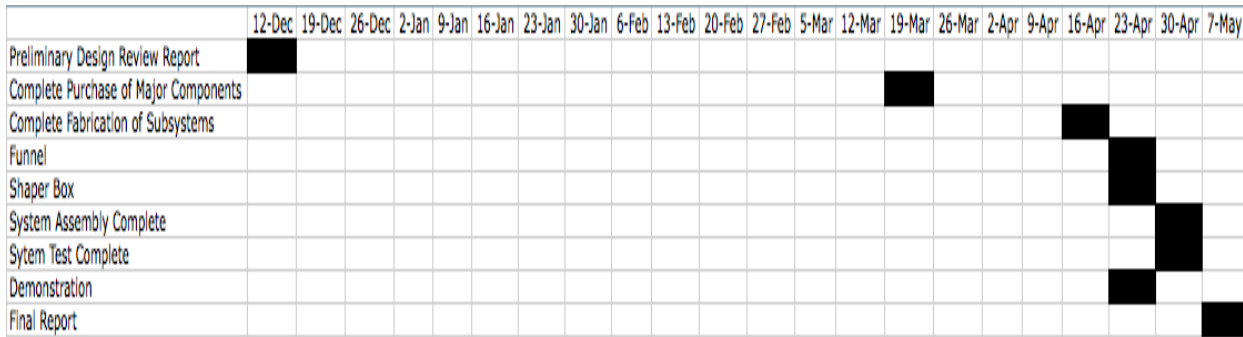


Figure 15. Final Gantt chart.

Our preliminary Gantt chart had us completing many parts of our project before the actual completion of them. We finished many of our features later than expected due to complications during the building process and the high demand for machine shop time. We also had our crank wheel come in a week later than expected when it was already arriving late in the building process. All in all, the entire build took more time and effort than expected.

Test Plans

Once we completed the hops baler, we tested it in outside conditions. We went through the whole process from attaching the bag and pouring hops in to compressing the bale and removing from the shaper box. The process from start to finished bale takes about 2 minutes. We were unable to use the vacuum sealer for our final step because our clients possess it. Instead we folded the excess bag neatly and duct taped it, which proved to help the bale withhold its shape for a few hours. If the bale is properly heat sealed then it will hold its shape as long as the bag is not punctured.

We also allowed some select guests at the University of Vermont's design night to spin the crank wheel and feel the max force at the end of the stroke. Observing their cranking styles and the machine stability has proven that the baler is quite balanced and has no reason to tip or slide.

For a YouTube video of the baler in action, please visit:

<http://www.youtube.com/watch?v=8jQdQWiZ4KU>