DESIGN, CONSTRUCTION, AND TESTING OF

A WALNUT CRACKER

by

Michael Dasso

BioResource and Agricultural Engineering

BioResource and Agricultural Engineering Department

California Polytechnic State University

San Luis Obispo

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TITLE	:	Design, Construction, and Testing of a Walnut Cracker
AUTHOR	:	Michael Dasso
DATE SUBMITTED	:	June 6, 2012

Andrew Holtz
Senior Project Advisor

Signature

Date

Richard A. Cavaletto
Department Head

Signature

Date

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ABSTRACT

This senior project involves the design, construction and testing of a walnut cracker for Beecher Lane Walnut of Stockton California. This prototype cracker is one piece of a walnut processing system to package walnuts. Beecher Lane Walnut currently utilizes a conical cracker design whereas this new design entails a twin barrel configuration.

The goal of this project was to design, construct and test a prototype walnut cracker that would help determine the variables necessary to yield the highest percentage of walnut halves.

The testing of this walnut cracker involved two varieties: Eureka and Chandler. Testing indicated the optimal output of walnut halves for the Eureka variety was with the parameters of 15^{o} and a speed of 200 rpm. The higher of the two produced 30.4% halves out of a 100 walnut sample run. The data from the Chandler testing proved to be somewhat inconclusive: however, further testing may be done to fine tune the specified variable surrounding the highest yielding combination.

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INTRODUCTION

The California walnut industry produces approximately 450 to 550 thousand tons of walnuts every year (Miller 2012). Some of the walnuts are sold in-shell in fifty pound sacks, and others are cracked and sold in various size packages based on walnut variety, size and color. Beecher Lane Walnut is a walnut processing company located in Stockton California.

In terms of cracked walnuts the desired piece is the half. These pieces are the largest and sell for the highest price. It is obvious that companies want the highest percentage of cracked walnuts to come out as halves.

The objectives of this project were to design, construct and test a prototype cracker that would determine the cracker characteristics that would produce the optimal percentage of walnut halves. This project was promising because of the realistic design and construction and the possibility that it may be used in the future in industry.

LITERATURE REVIEW

The most common current method of walnut cracking involves two metal drums which are tapered at different angles. The outer drum is hollow which contains the solid inner drum that also rotates. Because the drums taper towards one another the space in between the two surfaces decreases at the bottom. The walnuts are fed into the cracker from the top side and travel down towards the bottom of the machine. The spinning of the inner drum and gravity cause the walnuts to move down into the smaller and smaller space and eventually crack and leave the machine out the bottom. The figure below is a picture of a James Jesse conical cracker located at Beecher Lane Walnut.

Figure 1. Conical Walnut Cracker

There are many different varieties of walnuts, resulting in a wide range of average sizes. For one particular variety the cracker may crack the walnuts so much that they crumble into many small pieces leaving few or no halves. Whereas with a different variety the cracker may barely crack the shell and the walnut leaves the machine unscathed. To account for this there is a manual accessory drive on the cracker that moves the center drum up or down depending on the average size of walnut for a particular "cracking session". One important statistic to be aware of is the percentage of cracked halves by meat weight. For more difficult varieties to crack such as the Eureka, halve percentages will be in the twenties, while the easier varieties such as the Chandler will be as high as the eighties. In order for a piece of walnut meat to be considered a half, approximately 7/8 or more of the half must be present (Dasso 2012).

Figure 2. Inside the conical cracker

One process of the walnut cracking line that is important to understand is what happens right after the walnuts pass through the cracker. This next step is a vibrating table that separates the partially cracked walnuts from the shell. This allows for walnuts that may not have been cracked all the way to avoid having to go back through this process again as a re-crack (Dasso 2012).

The design for this prototype cracker is modeled after the concept of how many agricultural products are sized. The method referred to is a pair of rollers, or barrels, rotating side by side. The barrels are rotating upwards away from each other so as not to smash the produce. The barrels are also tapered away from each other. In the process the produce travels down the rotating barrels until they slide to the location where the barrels are as far apart as the size of the produce itself. At this spot the produce will fall between the barrels and are transported to the next step of the packing line. Again like the conical cracking machine, the barrels on the sizing machine are adjustable to accommodate all average sizes of produce. The speed of the barrels for most sizing applications is around 200 rpm (Dasso 2012). The following figure is a picture of a barrel sizing machine in a cherry packing line.

Figure 3. Cherry Sizing Machine

In order to determine the stresses that will be acting on the rotating barrels of this design, the force required to crack a walnut must be known. This was found in a study conducted and published by Biosystems Engineering. This study found that the average walnut would rupture at a force of 0.6 kN, which is approximately 135 lb. In determining if the barrels will exceed the allowable yield strength during use, the yield strength of mild steel must be known. According to Shigley's Mechanical Engineering Design, this is approximately 60 ksi.

In a personal interview with California Walnut Board commission member David Miller, it was found that California yields approximately 450 to 550 thousand tons every year. It was also discussed how for a cracked walnut to produce a half, the cracker needs to be adjusted to crack the walnut just enough to get it to break but not so much that it will burst the nut open and into many pieces.

PROCEDURES AND METHODS

Design Procedure

General Overview. The model of this design is similar to that of a produce sizing machine, except the barrels rotate in a downward direction towards each other. The walnuts feed into the machine at the top end of the barrels and travel towards the bottom end. The inward rotation of the barrels grabs the walnuts when they reach their sized spacing and pass through. This action cracks the walnuts as they pass through and drop below. The cracker was designed to be adjustable in terms of barrel angle relative to horizontal and rotation speed. The designed angles possible were: 15^o, 17.5^o and 20^o. The designed barrel rotation speeds were: 150 rpm, 200 rpm and 250 rpm. These chosen speeds are in the proximity of 200 rpm because that is the common speed found in produce sizing using counter-rotating barrels.

Main Frame. The main frame is the support of the cracker. It must be strong enough to support both self-weight and the weight due to the load of walnuts. The frame was designed out of 2" square tubing with 0.120" wall thickness. This size frame is sufficient to withstand the loads applied while under operation but was not "overbuilt". The frame hinges together by ¼" thick plates with 7/16" bolts. The cracker was also designed with four 3" legs in the bottom corners for ease of movement with a forklift. The plates used for the bearing mounts were designed to be 3/8" thick and allow for the bearing to adjust in and out. The plate has two gussets for added strength. The movement of the bearings allows for the adjustability of the barrel spacing.

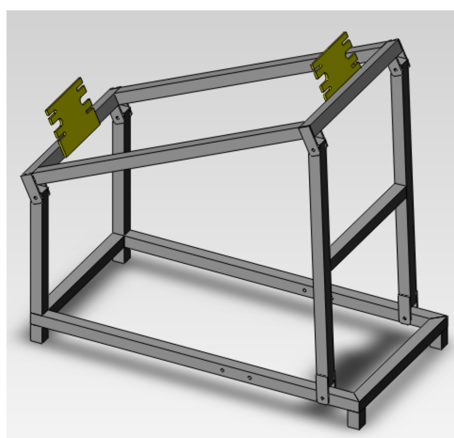

Figure 4. Model assembly of main frame

Barrels and Hubs. The barrels chosen were an outside diameter of 6 5/8". This larger diameter created a "valley" seat for the walnuts to ride in until they are cracked. This deeper valley also allowed for more surface area of the walnut for the barrel to "grab" and allow it to crack than would smaller diameter barrels. The barrels were also chosen to be four feet long. This length was chosen so that a gradual taper could occur from ¾" to 1

3/8”. The more gradual the spacing increase meant the more accurate the walnut was in finding where to lodge and crack and then fall through. The barrels are attached to the frame with hubs made out of ½” plate. The hubs were designed with 1” shafts from cold rolled steel.

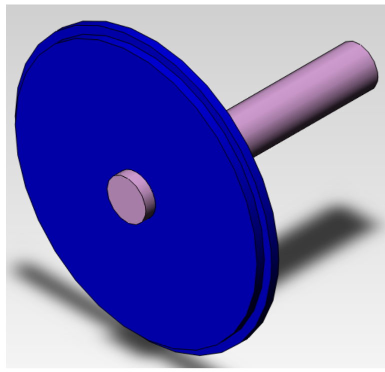

Figure 5. Model assembly of stepped hub and shaft

Bearings. Standard duty flange bearings were chosen to support the shafts of the barrels. These bearings are two flange bearing placed vertically on the mount plate and are able to slide left and right to adjust the barrels spacing.

Trough. The trough hanging under the barrels was designed out of 16 gauge galvanized sheet metal to catch the cracked walnuts after they crack.

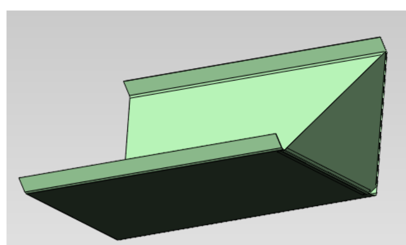

Figure 6. Model assembly of trough

Hydraulics. The cracker was chosen to be powered by the XX Hp gasoline-powered power supply located in Lab 7. This supply puts out a maximum flow rate of approximately 5 gallons per minute at a pressure of XX psi. To achieve the desired rotation speed, motors with a displacement of 4.6 in^3/rev were chosen. Because the torque requirement for the barrels is low, these smaller motors are sufficient.

Torque Arms. The torque arms for this project were designed out of ¼” plate and attach to the motors with two 7/16” bolts. They curve to the sides of the motors and travel in and fork around the square tubing, hereby preventing motor rotation.

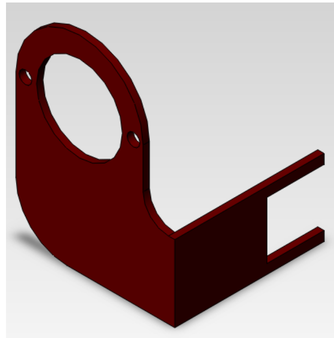

Figure 7. Model assembly of torque arm

The figure below is a solid works model assembly of the entire cracker.

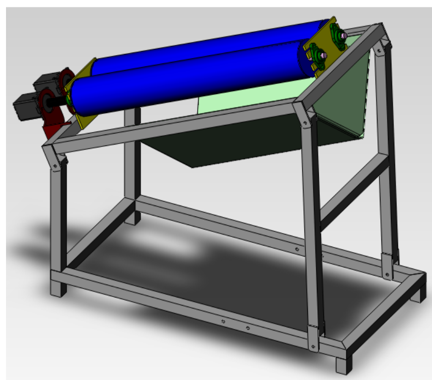

Figure 8. Model assembly of Cracker

<u>Construction Procedure</u>

<u>Main Frame</u>. The square tubing for the main frame was cut to size using the Marvel 8 band saw. Some of the square tubes were cut at a 45^{o} angle in order to form a closed corner when placed together. The frame was assembled using a MIG welder. Before welding, bevels were ground into the edges of the tubing that were going to be welded together in order to ensure adequate penetration. For end pieces such as the four legs, caps were placed inside and welded over and then buffed out to make them enclosed. Holes were marked and drilled with the drill press for the hinges and for the adjustment slots. For all welding situations, the material was situated at the proper angle with a square and clamped down to prevent distortion. The bearing mount plates were drawn in AutoCAD and cut out using the CNC plasma. They were then clamped and welded to the main frame.

Figure 9. Cutting of main frame member using marvel 8 band saw

Barrels and Hubs. The barrels were cut to size from 6" SCH 40 pipe on the Marvel 8 band saw. The barrels were placed in the four jaw chuck on the lathe in order to turn the ends, bevel the outside corner and bore out approximately 0.020". The barrels were such a large diameter and length so a saddle was needed to support the end. The hubs for the barrels were cut out on the CNC plasma with an oversized O.D. by ¼" and an undersized inner diameter by ¼". The hub was then bored out in the lathe to 1". The cold rolled 1" shaft was then welded to the hub. The hub was then re-chucked into the lathe and machined down to the correct O.D. Next a step was machined into the hub half way so it could fit into the barrel. A chamfer was also machined into the hub to ensure adequate penetration to with the barrel during welding. The hubs were then welded onto the barrels and buffed out. Keyways were milled into the drive-end shafts and the barrels were mounted to the frame.

Figure 10. Adjustment of bearing

Trough. The galvanized sheet metal used to make the trough was cut to length using the shear located in Lab 6. The bends were put into the sheets using the metal bender located along the back wall of Lab 6. The 2" flanges were bent at an angle of 135^o, and the center bend was bent at an angle of 90^o. The back cover of the trough has two lips of 1" bent at 90^o inward. The main trough was screwed into the main frame using ½" sheet metal screws which were screwed into pre-drilled holes. The back cover to the trough was bolted to the main trough using ¼" bolts.

Figure 11. Trough in sheet metal bender

<u>Hydraulics</u>. The hydraulic motors were rigidly mounted to the barrel shaft with a 1" diameter, 4" long direct shaft coupler. The fittings and hoses were found in the shed located on the BRAE ramp. These were used to connect the motors and to the power supply.

<u>Torque Arms</u>. The torque arms for the motors were cut out using the CNC plasma from ¼" hot-rolled plate. They were clamped into the band saw and were cut approximately three quarters of the way through the thickness. They were then bent along this cut to a 90^{o} angle and the backside was filled in with a fillet weld. The torque arms were then attached to the motor with two 7/16" bolts and turned in to fork around the square tubing of the main frame to prevent motor rotation.

Figure12. Walnut cracker completed and connected to power supply

<u>Testing Procedure</u>

For the testing of the walnut cracker, two varieties were used: Eureka and Chandler. Each variety had a total of 18 testing combinations. The cracker was tested at three different angles and three different barrel rotation speeds for nine different variations. The barrels rotational speeds were then offset by 10 rpm, creating another nine combinations of testing. The testing took place in Lab 7. Each of the main groups of nine test sample used

100 hundred walnuts except for the offset barrel speed for the Eureka variety which had only 70 walnuts. For each test an empty bucket was placed at the end of the trough and walnuts were fed into the machine handfuls at a time. Once all the walnuts in the sample were cracked the machine was turned off and then the walnuts were collected and placed in a labeled bag.

The pressure of the hydraulic system was read off the pressure gauge on the power supply at 850 psi. Because the motors are in series and the return pressure is 0 psi, the pressure distribution is equal to both motors. Therefore the pressure drop at each motor is equal to 425 psi.

RESULTS

The cracked walnuts were collected from the cracker after being processed and were brought into Lab 4 for analyzing. The walnuts were separated into three groups. The first group was for walnuts that had not been cracked and will go through the process again as re-cracks. The next group was for the desired meats: the halves. The third and final group was for all other meats that had been cracked and were not halves. Another important process in the sorting of the cracked walnuts involved analyzing the walnuts that were partially cracked and would most likely separate from the shell on the vibrating table following the cracker. These meats were separated from the shell and placed in their corresponding meat group.

Figure 13. Sorting cracked walnuts in Lab 4

Eureka Results

Table 1: Eureka Test 1. Motors in Series

Test 1: Motors in Direct Series							
Weight of Walnut Halves (oz)				Weight of Walnut Pieces (oz)			
Angle	Speed (rpm)			Angle	Speed (rpm)		
	150	200	250		150	200	250
15	3.5	3.5	3.5	15	10	8	14
17.5	2	2.5	2	17.5	12.5	11.5	9.5
20	2.5	1.5	3.5	20	11.5	10	10.5
Total Walnut Meat Weight (oz)				Weight of Walnut Re-Cracks (oz)			
Angle	Speed (rpm)			Angle	Speed (rpm)		
	150	200	250		150	200	250
15	13.5	11.5	17.5	15	17.5	20.5	17
17.5	14.5	14	11.5	17.5	15	15.5	18.5
20	14	11.5	14	20	16	17	14.5
Percent Walnut Halves by Weight				Percent Re-Crack			
Angle	Speed (rpm)			Angle	Speed (rpm)		
	150	200	250		150	200	250
15	25.9%	30.4%	20.0%	15	36.5%	42.7%	35.4%
17.5	13.8%	17.9%	17.4%	17.5	31.3%	32.3%	38.5%
20	17.9%	13.0%	25.0%	20	33.3%	35.4%	30.2%

In this table it can be seen which combination of speed and angle produced the highest and lowest combinations of both halves and then re-cracks. The combination that produced the highest percent of halves with 30.4% was at 15^{o} and 195 rpm. The combination that produced the lowest percent halves with 13.0% was at 20^{o} and 195 rpm. The combination that produced the highest percent of re-cracks with 42.7% was at 15^{o} and 195 rpm. The combination that produced the lowest percent re-cracks with 30.2% was at 20^{o} and 250 rpm.

Table 2: Eureka Test 2. Motors in Series with Flow Control Valve

Test 2: Motors in Series with Flow Control Valve							
Weight of Walnut Halves (oz)				Weight of Walnut Pieces (oz)			
Angle	Speed (rpm)			Angle	Speed (rpm)		
	150/140	200/190	250/240		150/140	200/190	250/240
15	1	2	2.5	15	7	6	8.5
17.5	1	1	1	17.5	7	8	7.5
20	1.5	1	1	20	7	6	7
Total Walnut Meat Weight (oz)				Weight of Walnut Re-Cracks (oz)			
Angle	Speed (rpm)			Angle	Speed (rpm)		
	150/140	200/190	250/240		150/140	200/190	250/240
15	8	8	11	15	13	12	5
17.5	8	9	8.5	17.5	11	12	8.5
20	8.5	7	8	20	9.5	13	12
Percent Walnut Halves by Weight				Percent Re-Crack			
Angle	Speed (rpm)			Angle	Speed (rpm)		
	150/140	200/190	250/240		150/140	200/190	250/240
15	12.5%	25.0%	22.7%	15	38.2%	35.3%	14.7%
17.5	12.5%	11.1%	11.8%	17.5	32.4%	35.3%	25.0%
20	17.6%	14.3%	12.5%	20	27.9%	38.2%	35.3%

In this table it can be seen which combination of speed and angle produced the highest and lowest combinations of both halves and then re-cracks. The combination that produced the highest percent of halves with 25.0% was at 15^{o} and 195 rpm. The combination that produced the lowest percent halves with 11.1% was at 17.5^{o} and 200/190 rpm. The combinations that produced the highest percent of re-cracks with 38.2% were at 15^{o} and 150/140 rpm and at 20^{o} and 200/190 rpm. The combination that produced the lowest percent re-cracks with 14.7% was at 15^{o} and 250/240 rpm.

Chandler Results

Table 1: Chandler Test 1. Motors in Series

Test 1: Motors in Direct Series							
Weight of Walnut Halves (oz)				Weight of Walnut Pieces (oz)			
Angle	Speed (rpm)			Angle	Speed (rpm)		
	150	200	250		150	200	250
15	4	8.5	7.5	15	7	7.5	7.5
17.5	5.5	6.5	7.5	17.5	6.5	6	5.5
20	5	8	7	20	6	5.5	6
Total Walnut Meat Weight (oz)				Weight of Walnut Re-Cracks (oz)			
Angle	Speed (rpm)			Angle	Speed (rpm)		
	150	200	250		150	200	250
15	11	16	15	15	6.5	3	3
17.5	12	12.5	13	17.5	5.5	6.5	5
20	11	13.5	13	20	6.5	4.5	5
Percent Walnut Halves by Weight				Percent Re-Crack			
Angle	Speed (rpm)			Angle	Speed (rpm)		
	150	200	250		150	200	250
15	36.4%	53.1%	50.0%	15	13.5%	6.3%	6.3%
17.5	45.8%	52.0%	57.7%	17.5	11.5%	13.5%	10.4%
20	45.5%	59.3%	53.8%	20	13.5%	9.4%	10.4%

In this table it can be seen which combination of speed and angle produced the highest and lowest combinations of both halves and then re-cracks. The combination that produced the highest percent of halves with 59.3% was at 20^{o} and 200 rpm. The combination that produced the lowest percent halves with 36.4% was at 15^{o} and 150 rpm. The combinations that produced the highest percent of re-cracks with 13.5% were at 15^{o} and 150 rpm, 17.5^{o} and 200 rpm, and 20^{o} and 150 rpm. The combinations that produced the lowest percent re-cracks with 6.3% were at 15^{o} and both 200 and 250 rpm.

Table 2: Chandler Test 2. Motors in Series with Flow Control Valve

Test 2: Motors in Series with Flow Control Valve							
Weight of Walnut Halves (oz)				Weight of Walnut Pieces (oz)			
Angle	Speed (rpm)			Angle	Speed (rpm)		
	150/140	200/190	250/240		150/140	200/190	250/240
15	5.5	7.5	5	15	6.5	4.5	4.5
17.5	5	11	8	17.5	5.5	7	5.5
20	7	7	5.5	20	7	6.5	6
Total Walnut Meat Weight (oz)				Weight of Walnut Re-Cracks (oz)			
Angle	Speed (rpm)			Angle	Speed (rpm)		
	150/140	200/190	250/240		150/140	200/190	250/240
15	12	12	9.5	15	7.5	8	11
17.5	10.5	18	13.5	17.5	8.5	2	4.5
20	14	13.5	11.5	20	3.5	5	10.5
Percent Walnut Halves by Weight				Percent Re-Crack			
Angle	Speed (rpm)			Angle	Speed (rpm)		
	150/140	200/190	250/240		150/140	200/190	250/240
15	45.8%	62.5%	52.6%	15	15.6%	16.7%	22.9%
17.5	47.6%	61.1%	59.3%	17.5	17.7%	4.2%	9.4%
20	50.0%	51.9%	47.8%	20	7.3%	10.4%	21.9%

In this table it can be seen which combination of speed and angle produced the highest and lowest combinations of both halves and then re-cracks. The combination that produced the highest percent of halves with 62.5% was at 15^{o} and 195 rpm. The combination that produced the lowest percent halves with 45.8% was at 15^{o} and 150/140 rpm. The combination that produced the highest percent of re-cracks with 22.9% was at 15^{o} and 250/240 rpm. The combination that produced the lowest percent re-cracks with 4.2% was at 17.5^{o} and 200/190 rpm.

Figure 14. Group of walnut pieces

DISCUSSION

It can be seen in the data collected that the optimal percentage of halves was produced in the Eureka variety with the combination of variables of a 15^o barrel angle and a speed of 200 rpm. Because walnut halves are calculated on a per weight basis it makes sense that the variables producing the highest percentage of halves would create the most re-cracks as well. This is because for a walnut to crack into halves the shell needs to crack just to the point of breaking. If too much force is exerted on the walnut it will burst open and the meat will turn into many smaller pieces. If the machine is fine-tuned just right the walnuts will crack just enough to release the meat in larger pieces. Because this prototype is not fine-tuned the variables that produced the most halves were just on the low side of force applied in order to crack the walnuts enough, therefore producing more re-cracks.

For the construction of this project some difficulties occurred during the machining of the barrels. It was difficult to chuck the barrels in the four jaw chuck because of their overall size. The barrels themselves were not very accurate in terms of their concentricity along the length of the barrels. This proved to be difficult in centering the barrels as much as possible before machining the ends. Another problem that occurred was the order of operations used to machine the drum shafts. The hubs were welded to the barrels before the keyways were machined into the shafts. The process of mounting the barrels onto the mill was possible and did work, but it was more difficult than it should have been.

The machining and fabrication of this project was done using very capable technology in the labs of the BRAE department. However, human error must always be taken into account for a construction project of this magnitude. The cracker most definitely works, but there are visible signs of imperfections. The axis of the barrels is not perfectly true and could affect the results of cracked walnut halves. All this must be taken into account when determining the reliability of the results of this project.

For the safety of operating this machine, sheet metal covers were bent and mounted over the top of the machine. These covers act as protection from the power drive of the hydraulic motors to the barrels and as protection from the large rotating barrels themselves. The underside of the barrels is shielded by the trough itself that catches the walnuts. There is an opening on the backside at the top for walnuts to be fed into the machine. Even though the machine is shielded by sheet metal, proper safety precautions are always advised, especially seeing as how testing involves the cracking of walnuts which can cause flying debris.

RECOMMENDATIONS

Because this project was a prototype testing machine, a cheaper “quick and dirty” materials list was used. However, if the machine was to be made for an actual processing line component, it would be advisable to use a higher quality material for the barrels. One such option would be to use a solid round stock of aluminum and machine it to the exact specification desired. This would provide for a more accurate outcome of barrel spacing and shaft machining. These circumstances would be desired if the project were to be done in a commercial production line situation.

In terms of continuing the problem it would be relevant to design and construct a hopper that would feed the cracker. Testing could be done to determine if a certain rate of application affects the yield of cracked walnut halves. The most efficient way to do this would be to create a type of belt that would force the walnuts to form a single line before entering the barrels. This would cause the walnuts to already be traveling on the same axis before entering the cracker which would prevent the bouncing up and down that happened with the hand feeding of the walnuts. Another continuation step would be to create another hopper or conveyor belt line underneath the machine that would take the cracked walnuts away to the next processing step.

For a commercial application the company using this machine may choose to use a different power source than hydraulic motors. This new source may be electric motors in which case a similar in line coupler system may be used, or a chain driven accessory drive may need to be designed and constructed.

REFERENCES

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APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

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Major Design Experience

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes fundamental elements as outlined below. This project addresses these issues as follows.

Establishment of Objectives and Criteria. Project objectives are established to meet the needs and expectations of the California Walnut Board.

Synthesis and Analysis. This project incorporates stress, hydraulic and natural frequency calculations.

Construction, Testing and Evaluation. The walnut cracker was designed, constructed and tested.

Incorporation of Applicable Engineering Standards. The project utilizes AISC standards for allowable stresses and ISO standards for hydraulic circuit schematics.

Capstone Design Experience

The BRAE senior project is an engineering design project based on the knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses).

- BRAE 129 lab Skills/Safety
- BRAE 151 AutoCAD
- BRAE 152 Solid Works
- BRAE 234 Mechanical Systems
- BRAE 421/422 Equipment Engineering
- ME 211/212 Engineering Statics/Dynamics
- CE 204/207 Strength of Materials
- ENGL 149 Technical Writing

Design Parameters and Constraints

This project addresses a significant number of the categories of constraints listed below.

Physical. The cracker size is 51” x 29” x 49” and must be able to transport from the school location to the final destination of testing.

Economic. N/A

Environmental. N/A

Sustainability. N/A

Manufacturability. N/A (This project is a one of a kind machine)

Health and Safety. The machine utilizes sheet metal covers to protect from moving parts and bits of shell and walnut from flying out.

Ethical. N/A

Social. N/A

Political. N/A

Aesthetic. The machine was ground down to eliminate sharp edges and could be painted to provide visual contrast.

Other-. N/A

APPENDIX B

DESIGN CALCULATIONS

Required Motor Displacement

The motor displacement was determined with the given maximum rpm speed of 250 and maximum flow rate of 5 gallons per minute.

5 gal/1 min x 1 min/250 rev x 231 in^3/ gal = 4.62 in^3/rev

Natural Frequency

It is important to calculate the natural frequency of the barrels because once the frequency is calculated the cracker can be designed around it so as to avoid resonance.

Displacement = [-5 x (68lb/48in) x $(48in)^4$]/[384 x (29 x 10^6 psi) x (pi/4) x ($6.625^4 - 6.125^4$)] = -8.28 x 10^{-6} in

ω_n = sqrt[(32.2 ft/s^2)/(-8.28 x 10^{-6} in)] = 65,000 rpm

This natural frequency is well above the speeds that the machine is running at and is therefore ok.

Barrel Stress

Power = 5 gpm x 425 psi/1714 = 1.24 Hp

Torque = (1.24 Hp/250 rpm) x (1 rev/2 x pi rad) x (550 ft-lb/s-Hp) x (60s/min) x 12 in/ft = 1250 in-lb

Shear stress = (1250 in-lb x 3.3125 in)/[(pi/2) x ($6.625^4 - 6.125^4$)] = 5.08 psi

Moment = (135 lb x 48 in)/4 = 1620 in-lb

Normal Stress = (1620 in-lb x 3.3125 in)/[(pi/4) x ($6.625^4 - 6.125^4$)] = 13.2 psi

Circle Center = 13.2 psi/2 = 6.58 psi

τ_{max} = sqrt[$(6.58)^2 + (5.08)^2$] = 8.32 psi

Using the shear stress caused by the motor, the normal stress caused by the cracking of the walnuts and Mohr's Circle it can be determined that the maximum stress on the barrels is approximately 8.32 psi which is very low and well below the yield strength.

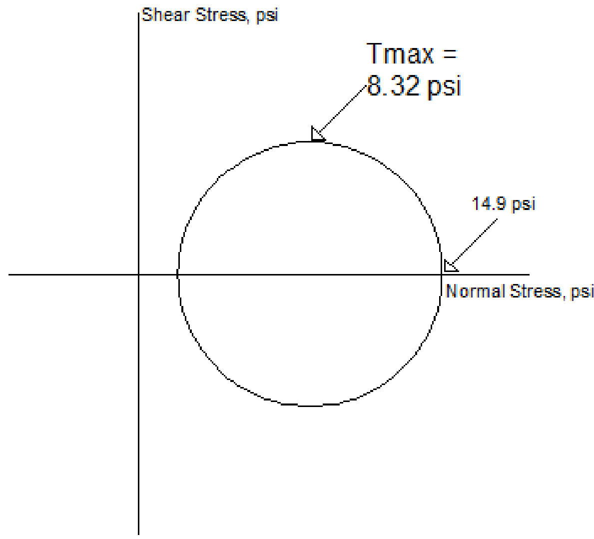

Figure 15. Mohr’s Circle for barrel stress

APPENDIX C

HYDRAULIC SCHEMATIC

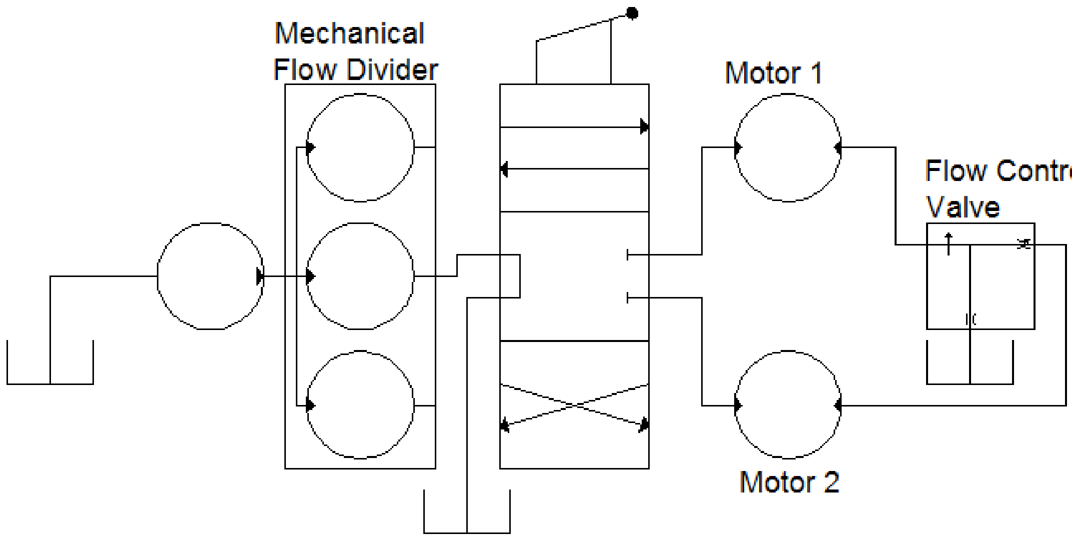

Figure 16. Hydraulic Schematic

APPENDIX D

PART DRAWINGS