Hozhoni Button Maker

Midpoint Report

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DISCLAIMER

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TABLE OF CONTENTS

1 BACKGROUND

1.1 Introduction

The Hozhoni Foundation is an agency that provides services and advocacy for the developmentally disabled population of Northern Arizona. Hozhoni currently employs a day program, including art therapy, as a means of improving the lives of those who may not be able to participate in society in traditional ways; Hozhoni also aims to make employment possible for many of these individuals. Currently, Hozhoni owns a large, cast iron press for making buttons that pin on to clothing: these buttons are ordered by organizations in Northern Arizona and can be made using company logos or images. This machine is difficult to operate because of its size and the dexterity required to complete the process of making a button. Because of this, only one client at Hozhoni is currently able to use the button maker as a means of earning income. This is the problem the design team was asked to solve. By modifying the process and machine, or by creating an entirely new device, more clients at Hozhoni will be able to make buttons as a job and gain a higher level of independence. This will also provide clients with a sense of integration into society.

The project is sponsored by W.L. Gore and Associates, who has provided the design team with a budget of $1500.00. W.L. Gore and Associates is well-known for supporting members of their community in a variety of ways, as well as providing projects and internships to engineering students. The client, the Hozhoni Foundation, will benefit from this sponsorship and project by obtaining an enhanced button making process that will give their clients a job and income. By enabling the clients to do this job, the sponsor and design team have helped in providing Hozhoni's clients with a path to financial, social, and emotional wellness.

1.2 Project Description

Following is the original project description provided by the faculty advisor at the beginning of the term [2].

> *Several of this coming year's capstone design projects will focus on assistive devices for people with disabilities. The Hozhoni Foundation is a local Non-Profit Agency (NPA) in our area that specifically provide work opportunities for people with disabilities. W. L. Gore and Associates (a global engineering company with local offices) will be funding the projects.*
> *Currently only one client at Hozhoni Foundation is able to use the Button maker due to precision and physical requirements (Figure 1). An assistive device is needed to either modify the existing set-up or create a brand new set-up that allows new clients to create buttons that they are contracted to make by numerous local Businesses.*
> *Issues with the current set-up include: need strength in at least one leg to push down the mechanism, need to precisely align the bottom portion (that contains the pin) with the top picture, need upper body strength to cut out the pictures, and finger dexterity to separate the pieces (plastic cover, picture, etc.).*

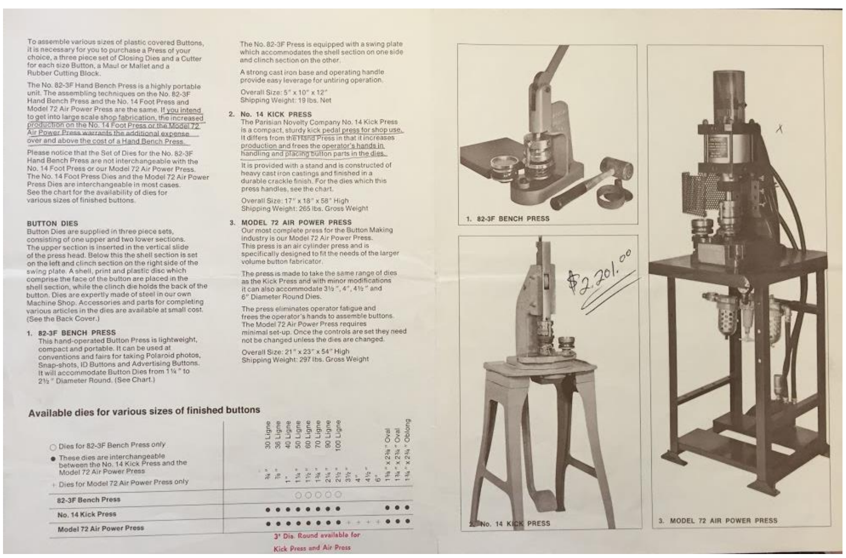
Figure 1: Cutting the Patterns

1.3 Original System

The design team is currently pursuing plans to modify the current button maker setup to increase access to clients of different abilities. The original button maker is detailed in the following sections.

1.3.1 Original System Structure

The Button Maker at the Hozhoni Foundation offices is a cast iron press. It was purchased from the Parisian Novelty Company in the early 1970's. Figure 2 shows the original brochure for the button maker, which was provided by the project customer contact, Justin Cartwright. The brochure details the variety of die sizes available (for making various button sizes).



To assemble various sizes of plastic covered Buttons, it is necessary for you to purchase a Press of your choice, a three piece set of Closing Dies and a Cutter for each size Button, a Maul or Mallet and a Rubber Cutting Block.

The No. 82-3F Hand Bench Press is a highly portable unit. The assembling techniques on the No. 82-3F Hand Bench Press and the No. 14 Foot Press and Model 72 Air Power Press are the same. If you intend to get into large scale shop fabrication, the increased production on the No. 14 Foot Press or the Model 72 Air Power Press warrants the additional expense over and above the cost of a Hand Bench Press.

Please notice that the Set of Dies for the No. 82-3F Hand Bench Press are not interchangeable with the No. 14 Foot Press or our Model 72 Air Power Press. The No. 14 Foot Press Dies and the Model 72 Air Power Press Dies are interchangeable in most cases. See the chart for the availability of dies for various sizes of finished buttons.

BUTTON DIES
Button Dies are supplied in three piece sets, consisting of one upper and two lower sections. The upper section is inserted in the vertical slide of the press head. Below this the shell section is set on the left and clinch section on the right side of the swing plate. A shell, print and plastic disc which comprise the face of the button are placed in the shell section, while the clinch die holds the back of the button. Dies are expertly made of steel in our own Machine Shop. Accessories and parts for completing various articles in the dies are available at small cost. (See the Back Cover.)

1. **82-3F BENCH PRESS**
This hand-operated Button Press is lightweight, compact and portable. It can be used at conventions and fairs for taking Polaroid photos, Snap-shots, ID Buttons and Advertising Buttons. It will accommodate Button Dies from 1¼" to 2½" Diameter Round. (See Chart.)

The No. 82-3F Press is equipped with a swing plate which accommodates the shell section on one side and clinch section on the other.

A strong cast iron base and operating handle provide easy leverage for untiring operation.

Overall Size: 5" x 10" x 12"
Shipping Weight: 19 lbs. Net

2. **No. 14 KICK PRESS**
The Parisian Novelty Company No. 14 Kick Press is a compact, sturdy kick pedal press for shop use. It differs from the Hand Press in that it increases production and frees the operator's hands in handling and placing button parts in the dies.

It is provided with a stand and is constructed of heavy cast iron castings and finished in a durable crackle finish. For the dies which this press handles, see the chart.

Overall Size: 17" x 18" x 58" High
Shipping Weight: 265 lbs. Gross Weight

3. **MODEL 72 AIR POWER PRESS**
Our most complete press for the Button Making industry is our Model 72 Air Power Press. This press is an air cylinder press and is specifically designed to fit the needs of the larger volume button fabricator.

The press is made to take the same range of dies as the Kick Press and with minor modifications it can also accommodate 3½", 4", 4½" and 6" Diameter Round Dies.

The press eliminates operator fatigue and frees the operator's hands to assemble buttons. The Model 72 Air Power Press requires minimal set-up. Once the controls are set they need not be changed unless the dies are changed.

Overall Size: 21" x 23" x 54" High
Shipping Weight: 297 lbs. Gross Weight

Available dies for various sizes of finished buttons

○ Dies for 82-3F Bench Press only
● These dies are interchangeable between the No. 14 Kick Press and the Model 72 Air Power Press
+ Dies for Model 72 Air Power Press only

	¾" 30 Ligne	⅞" 36 Ligne	1" 40 Ligne	1¼" 50 Ligne	1½" 60 Ligne	1¾" 70 Ligne	2¼" 90 Ligne	2½" 100 Ligne	3½"	4"	4½"	6"	1⅛" x 2⅜" Oval	1¾" x 2¾" Oval	1¾" x 2¾" Oblong
82-3F Bench Press				○	○	○	○	○							
No. 14 Kick Press	●	●	●	●	●	●	●	●					●	●	●
Model 72 Air Power Press	●	●	●	●	●	●	●	●	+	+	+	+	●	●	●

3" Dia. Round available for Kick Press and Air Press

1. 82-3F BENCH PRESS
$2,201.00
2. No. 14 KICK PRESS
3. MODEL 72 AIR POWER PRESS

Figure 2: Parisian Novelty Company Brochure [2]

The button maker consists of a press, with two circular dies in which the button components (button back with pin, plastic covering, and picture or pattern) are placed, and where the assembly occurs. The press is activated by depression of a foot lever. Figures 3, 4 and 5 show the location of these features.

Figure 3: Button Maker Press

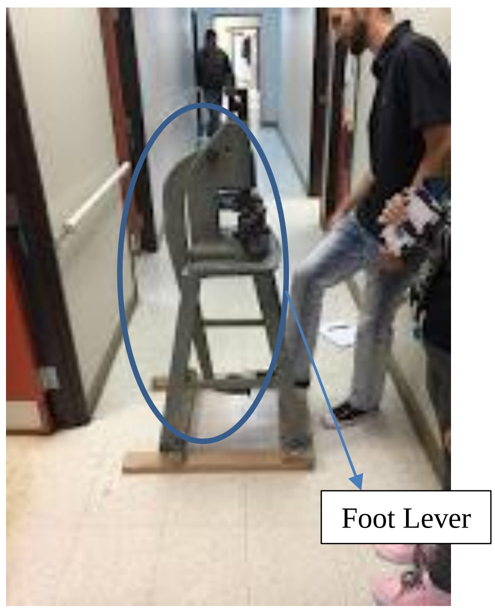


Figure 4: Button Maker Foot Lever

Figure 5: Button Maker Dies

The Hozhoni Foundation possesses dies in various diameters, providing the option for making different sized buttons, but currently Hozhoni only makes 2.25" diameter buttons. This is due to the difficulty of changing the dies in the press and the economic benefit of buying a large amount of button components for one diameter only.

1.3.2 Original System Operation

It should be clarified that the button maker used by Hozhoni Foundation is a device that creates buttons with a pin back that displays an image, logo, or message. These are NOT clothing buttons. In order to make a button, the pictures are first cut from the sheet as in Figure 1. An 8.5"x11" sheet is printed with the image by a local printing company with 6 images per sheet. The customer contact is currently the only one at Hozhoni that is able to complete this step of the process, due to the difficulty in aligning the cutting die and because the die is pounded with a heavy mallet to make the cut, an inherently dangerous task. After the patterns are cut, they can be taken to the button maker. The button components are placed into the dies of the press (Figure 4). Great care must be taken to ensure that the button backing with the pin is properly aligned. The dies swivel, and different button components are placed in one of the two castings on the swivel. The foot lever is pushed one time to capture the button backing containing the pin in the press, and once the picture and plastic covering are added and aligned properly, the lever is pressed again to completely assemble the button and release it from the press. This process may take up to a minute, although the Hozhoni client currently making buttons can assemble about 300 buttons in an hour.

1.3.3 Original System Performance

The performance of the Button Machine is completely dependent upon the dexterity and strength of the operator. As it is a completely manual machine, there are no power requirements. The accuracy of the machine, especially as it pertains to the alignment of the button components, requires manual dexterity, sufficient hand-eye coordination, and practice. The alignment of the button components, and of the dies throughout the process is especially important because the buttons must be made in such a way that the pin back lies completely horizontal while the image is upright on the wearer. Alignment issues are the single largest reason for rejects from the process.

1.3.4 Original System Deficiencies

The deficiencies in this process are numerous, especially when considering that the goal is make the process simple and accessible enough for clients with developmental disabilities or physical limitations to be able to do it.

First, cutting the patterns from the sheet is dangerous, requires significant arm strength, and must be done very accurately. For this reason, the customer contact is the only one able to do this part of the process.

Next, it requires a fair amount of thought to assemble the button components in the proper order in the press, and they must be aligned precisely. This alignment and placement of components is difficult, even for a person who has average ability. The foot lever does not require significant force, but does require a very large leg extension. A person in a wheelchair or with limited use of their legs cannot use the machine for this reason. If a person has difficulty with balance, they may fall when operating the foot lever. These deficiencies are the focus of our solution, and the new design must address them.

2 REQUIREMENTS

The design team met with the customer contact, Justin Cartwright, to discuss what he and the clients would like addressed in an improved button making process. The following sections discuss the requirements generated at this meeting and their relative importance.

2.1 Customer Requirements (CRs)

The following list of customer requirements were generated based on the stated needs and concerns of the customer contact. This list is preliminary and may be subject to revision or addition throughout the project. The listed weightings are out of a total of 250.

1. Create arm actuation for the button maker: **25**
   The addition of this feature will allow clients with limited or no use of their legs to operate the button maker.
2. Add alignment mechanism for button components: **30**
   Alignment issues are the primary cause of "rejected" buttons (the images placed into the buttons are not aligned in a way that allows the end user to attach the button pin horizontally). It is difficult for clients using the button maker to align all components properly, and the new system/process should allow for more accurate placement of components and should enable adjustment of the dies after components have been placed into the machine.
3. Enable clients to cut patterns: **25**
   By creating a cutting device or process that allows clients to reliably and safely cut the images from the sheets, a new job is created for clients and the customer contact will not have to spend his time preparing the patterns.
4. Decrease range of motion for foot lever: **20**
   As the range of motion needed for using the foot lever is large, this excludes clients who have limited use of their legs or poor balance.
5. Increase pattern cutting efficiency: **25**
   The customer would like to be able to cut more patterns from the sheet at one time.
6. Larger size range for cutting dies ********
   Because the button maker already has the ability to create buttons of different sizes, the cutting process should be modified to cut patterns corresponding to the various die sizes.
7. Allow Table Height to be Adjusted ****
   The height of the button maker may need to be adjusted to accommodate those who cannot stand.
8. Safety **35**
   The system should be safe and pose no risk to clients, whether they actually use the machine or may come in contact with it incidentally.
9. Reliability **30**
   The system should operate as intended, with minimal maintenance, every time it is used
10. Overall Efficiency **30**
    The system should be as efficient as possible, minimizing time to assemble buttons, cut patterns, and should be as simple and "straightforward" to use as possible.

11. System Changes are Reversible: **25**
    Any and all changes made to the process of making buttons must be reversible; the client should be able to return to the original state of the process if so desired.

It should be noted that Customer Requirements 6 and 7 (highlighted in yellow) have been eliminated at this point in the project. They were not explicitly stated customer needs but rather features the team was hoping to add if within the scope of the project. They will be removed from this point forward in the project to allow the team to focus on the requirements explicitly stated by the client and within the scope of the designs being pursued. Customer Requirement 11 has been added since the Preliminary Proposal based on the recommendation of the Faculty Advisor.

2.2 Engineering Requirements (ERs)

Engineering Requirements were developed to map the customer requirements outlined above to specific, quantifiable measurements. The Engineering requirements are related to three areas of design focus: actuation of the button maker, the cutting process for the patterns, and the alignment of button components and the button maker dies.

1. Force required to operate hand actuation (in pounds)
2. Force to operate foot lever (in pounds)
3. Distance to depress foot lever (in inches)
4. Patterns cut per cutting operation (#)
5. Size range for patterns (in inches)****
6. Size range for button maker dies (in inches)****
7. Cost (in dollars)
8. Table height (in inches)***
9. Time to Align Button Components and dies (seconds)
10. Pinch Points (#)
11. Time to cut one sheet of patterns (seconds)
12. Time to assemble one button (seconds)
13. Number of sheets cut per lever pull (#)
14. Necessary preparation time before cutting (seconds)

The target values for these requirements, along with tolerances, can be found in the House of Quality in Section 2.5. Engineering Requirements 5, 6 and 8 (highlighted in yellow) have been eliminated to reflect the change in the Customer Requirements.

2.3 Testing Procedures (TPs)

Testing Procedures were outlined as a means of verifying the effectiveness of all devices, modifications, and changes to the button making process. It should be noted that the success of the designs must, by nature, be evaluated subjectively: is the process easier, faster, and more comfortable to complete?

1. A standard U.S. (inch) tape measure will be used to verify the decrease in distance the user must extend their leg to depress the leg lever on the button maker. The foot lever extension should decrease this distance by 4 inches. Team members will also use the foot lever, with and without

the extension to verify that the extension makes the leg lever “easier” to operate, which is a subjective quality.

2. The foot lever extension should take no more than one minute to add or remove to the foot lever. This will be tested by team members and should require only a screwdriver/wrench.
3. All sharp edges and corners must be deburred. A gloved hand will be run over the gearbox housing, handles, and arbor press trays to verify that there are no rough edges.
4. The gearbox and arbor press cutting blades must be housed appropriately to ensure that fingers cannot be injured during operation of the button maker or arbor press. A pencil will be used to attempt to breach the housing on the gear box, and the cutting blades on the arbor press should be no farther than the stack of paper than 0.25”.
5. The arbor press must cut through at least 10 sheets of paper (standard weight, 20 lb.) per operation.
6. The hand cranks should be comfortable operate for a people of a variety of heights. To test this, people ranging from 5’4” tall to 6’2” will be asked to use the hand cranks to ensure that operation is comfortable.
7. It takes an inexperienced user approximately 45 seconds to make one button, not including the cutting process. The team would like to shorten this time by 15 seconds. All team members will practice making a button to ensure that this time improvement has been met.
8. The cutting arbor press will be tested by conducting a full Design of Experiments to determine optimal lever arm length, blade thickness, and number of sheets that may be cut at one time. All team members (and possibly others) will test the machine to ensure that people with a range of arm strength will find the process comfortable.

2.4 Design Links (DLs)

1. Purchase a small arbor press with ability to deliver sufficient force to cut six images from an area of approximately 8.5”x11”, and to cut through 5 to 10 sheets.
2. Purchase five cutting blades (for a total of six – one was purchased for prototyping) to be attached to the top tray of the arbor press to cut six images from each sheet.
3. Purchase/machine housing for cutting tool blade and paper trays.
4. Construct foot extension of wood blocks.
5. Select and purchase appropriate size gear for rack/pinion system.
6. Two circular handle cranks.
7. Housing for rack/pinion
8. Purchase T-Slot nuts to fit in t-slot of button maker, allowing the button maker dies to travel linearly.

2.5 House of Quality (HoQ)

The House of Quality (Table 1) has been revised several times to reflect accurate and reasonable target values with tolerances. The customer needs 6 and 7 have been eliminated and the associated engineering requirements are highlighted in red. Design links and Testing Procedures are listed in the bottom two rows.

Table 1: Complete House of Quality

Customer Requirement	Weight	Engineering Requirement	Distance to operate hand crank (inches)	Force to operate foot lever (pounds)	Distance to depress foot lever (inches)	Patterns Cut per Operation (#)	Size range, patterns (inches)	Size Range, Button Maker (inches)	Cost (dollars)	Table Height (inches)	Time to Align Button Components (seconds)	Pinch Points (#)	Time to cut one sheet of patterns (seconds)	Time to Assemble one button (seconds)	Sheets Cut Per Cutting Operation	Necessary Preparation Before Cutting (seconds)
1. Add hand actuation on button maker	25		9						9			6		3		
2. Increase Ease-of-Use for Foot Lever	20			9	9				3							
3. Add Alignment Mechanism	25							3			9	3		9		
4. Enable clients to cut patterns	25					9	9		9			3	9		9	9
5. Increase Pattern Cutting Efficiency	25					9	9						9		9	9
6. Larger size range	10					9	9	9	9				1		1	
7. Safety	35		3	3	3							9				1
8. Reliability	30		3	3	3	3					3		3	3	9	
9. Overall Efficiency	30		3	3	3	3					9		9	9	9	9
10. Changes are Reversible	25															
Target(s), with Tolerance(s)			5±3	8±3	8±4	4±2	3.5±2	3.5±2	<1500	36±12	10±5	1±1	15±10	30±10	10±5	20±10
Testing Procedure (TP#)			1	1	2	1			1 thru 8		3,7	4	5,8	3,7	5	5
Design Link (DL#)			5,6,7	4	4	1,2					8	2,3,5	1,2,3	2,8	2	2

3 EXISTING DESIGNS

The team conducted a review of existing designs for making pin back buttons. There are industrial processes for creating these types of buttons, but the team identified that the button makers that are most relevant to the type of button making that takes place at Hozhoni, which is essentially a small-scale commercial operation, are button makers meant for personal or home use. Designs at the sub-system level were also researched in this way for the three areas of design focus.

3.1 Design Research

The team conducted a review of existing designs for making pin back buttons. There are industrial processes for creating these types of buttons, but the team identified that the button makers that are most relevant to the type of button making that takes place at Hozhoni, which is essentially a small-scale commercial operation, are button makers meant for personal or home use. Designs at the sub-system level were also researched in this way for the three areas of design focus.

3.2 System Level

The team researched and performed benchmarking for small-scale, personal use button makers. The team discovered that personal use button makers may fall into either automatic (electric) button makers or manually operated button makers. As the team feels strongly that an automated solution to the button maker redesign defeats the principles and goals of the project as discussed with the customer contact and faculty advisor. Manually operated, small scale button makers have been researched and these designs are described below.

3.2.1 Existing Design #1

Figure 6 shows a manually operated button maker meant for personal use or small business applications. It relies on a lever mechanism to transfer the force supplied by the operator. This machine may be mounted to a desk or workbench to avoid movement and to provide stabilization. The short length of the lever arm increases the amount of force needed from the operator. This design, from American Button Machines [3]. This model also features swivel motion of the die cups, as does the button maker at Hozhoni. This model does not accept different sized or shaped dies, so the low price ($229) may not remain low if additional models must be bought to gain to ability to make different size buttons.

Figure 6: American Button Machines, Manual

3.2.2 Existing Design #2

The button machine company, Tecre, manufactures both automatic and manual button makers[4]. Figure 7 shows a button maker that uses a lever and a swivel die design as above, but is mounted on a platform that also features a graphic cutter. This offers the advantage of being able to cut the image, or pattern, with the same piece of equipment that will be used to assemble the buttons.

Figure 7: Tecre Mounted Manual Button Maker

3.2.3 Existing Design #3

Figure 8 shows a manual button maker from USA Buttons, Inc. [5]. This system is a compact machine with one distinct advantage over the above designs is that the lever changes position rather than the dies, eliminating any swivel action that can complicate the alignment of button components.

Figure 8: USA Buttons, Inc., Manual Button Maker

3.3 Subsystem Level

The team has decomposed the button making process into three areas of design focus: the cutting process, die and component alignment, and button maker actuation. These three areas of focus constituted our subsystem level benchmarking.

3.3.1 Subsystem #1: Cutting

The customer contact for this project has identified that it would be helpful to create a safe, usable system for cutting the images from the sheets (delivered from the printing company) that the clients could use. Because the customer contact is currently using a die and mallet to punch the images from the paper, and because the process is noisy and inherently dangerous, he would like to see the clients able to do this part of the button making process as long as it is safe and efficient. The team benchmarked methods and devices currently on the market for cutting small circles.

3.3.1.1 Existing Design #1

Figure 9 shows a graphic cutter made by Tecre [4]. This graphic cutter is similar to the cutter mounted on the combination system in Figure 7, but can be purchased separately. The sheet containing the images must be cut to slide into the cutter. A lever is used to “punch” through the sheet. Although several sheets may be cut through at one time, only one image per sheet may be cut at one time.

Figure 9: Tecre Graphic Cutter

3.3.1.2 Existing Design #2

The circle cutter shown in Figure 10 is made by Fiskars (available through Amazon.com, [6]). This circle cutter is placed directly over the image to be cut, and it is visualized through the clear acrylic dome. The advantage of this cutter is that it can cut different diameter circles, but it can only cut one image per sheet at one time and likely cannot cut through multiple sheets without wearing down the blade.

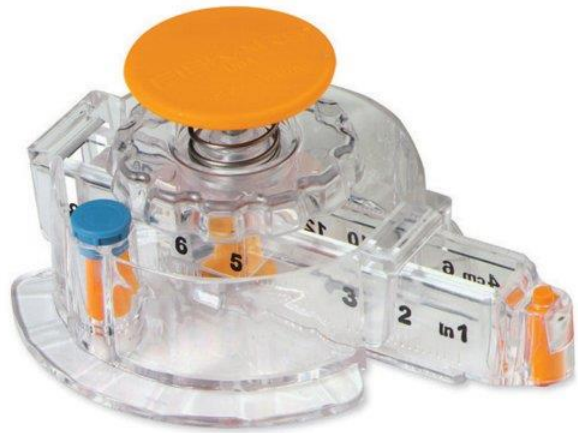


Figure 10: Fiskars Circle Cutter[6]

3.3.1.3 Existing Design #3

The “Foamwerks Foamboard Circle Cutter”, Figure 11 (available through engineersupply.com [7]), relies on a clear dome as with the Fiskars circle cutter, but instead of a punch it uses a rotating blade operated by a crank. This cutter is designed for foamboard, and as such may be able to cut through multiple sheets of paper, but as with the Fiskars circle cutter it can only cut one image on the sheet at a time. This type of device would also require good hand-eye coordination in order to center it, as well.

3.3.2 Subsystem #2: Alignment

The next subsystem the team considered is the type of alignment mechanisms available for the button components and dies.

3.3.2.1 Existing Design #1

The manual button maker in Figure 8 from USA Buttons, Inc.[5], relies on rotating the lever arm actuator from one die to the other, eliminating the need for swiveling die cups. The swiveling of the die cups in the Hozhoni button maker make it difficult to place button components in the dies in such a way that they will be aligned AFTER they are swiveled into place.

3.3.2.2 Existing Design #2

Figure 12 shows a button maker from badgeaminit.com[8]. This button maker has the dies aligned in a linear arrangement, overcoming the problems caused by the swivel motion. As long as the pin back is placed in the crimping die with the pin straight, and the image is placed oriented “straight up and down”, the button will be properly aligned. This type of system does not ultimately assist the user in placing the components in the dies properly aligned.

Figure 11: Foamwerks Foamboard Cutter

Figure 12: Badgeaminit Button Maker

3.3.2.3 Existing Design #3

The “Economy Round Button Maker” (Figure 13) from “makebuttons.com”[9] uses a die arrangement of one stacked on the other vertically. Although this would be an advantage over the current swivel system, there is a distinct lack of space in which to work and adjust the button components.

Figure 13: Button Maker from makebuttons.com

3.3.3 Subsystem #3: Actuation

The final subsystem on which the team will focus is the actuation mechanism of the button maker. The Hozhoni button maker uses a foot lever, whereas most of the button makers on the market for personal or small-scale use are hand-actuation. A combination of both types of actuation will be implemented for the project redesign.

3.3.3.1 Existing Design #1

The button makers in Figures 6,7,8,11 and 12 all feature a lever for actuating the button maker and transferring the force from the user to the die press. Because the Hozhoni button maker is so much larger than these small, table-top devices, a hand lever would have to be quite large to deliver the necessary force.

3.3.3.2 Existing Design #2

The website "peoplepowerpress.com"[10] displays a button maker that is air powered, and a foot pedal is used to deliver the force from an external air compressor (Figure 14). This type of setup is more complicated and requires an air compressor, but the foot pedal requires very little limb extension or force from the user. This type of button maker is typically used for industrial applications where high volumes of buttons must be made.

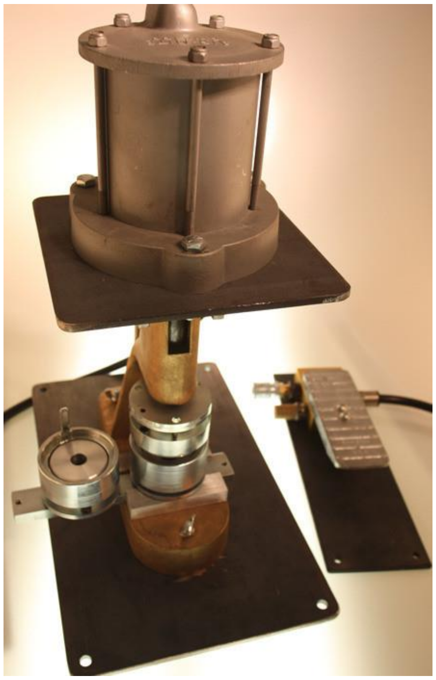


Figure 14: Compressor Powered, Foot Pedal Operated Button Maker

3.3.3.3 Existing Design #3

Tecre [5] also makes electric/automatic button makers. Although the team is not interested in automating the button making process, the team has considered if it might be advantageous to automate the the actuation of the press, meaning that the user would be responsible for aligning and placing components, and for actuating the automated portion of the process, but not for delivering the physical force to assemble the buttons. An automatic button maker from Tecre is shown in Figure 15.

Figure 15: Tecre Automatic Button Maker

4 DESIGNS CONSIDERED

The design team conducted a process of brainstorming using the following methods, both individually and as a group: external search, gallery method, and C-Sketch. Each teammate was responsible for generating 10-15 concepts in the three areas of design focus: actuation, cutting process, and alignment. The top scoring designs from the Pugh Charts (Appendix A.1) will be reported on in the following sections, with the final designs selected via Decision Matrix (Appendix A.2).

4.1 Designs #1-4, Actuation

Concept 1: Add extension to foot lever to decrease the limb extension necessary to actuate the press (Figure 16).

Pros: Relatively simple, inexpensive solution for those clients that are better suited to using their legs than their arms to operate the machine.

Cons: None

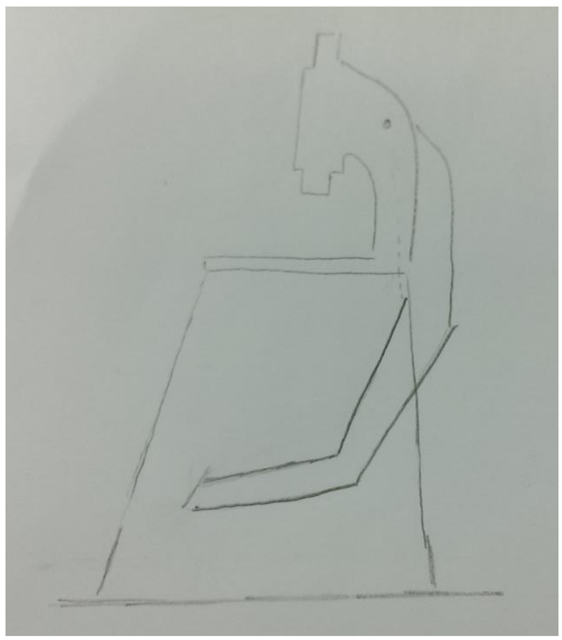


Figure 16: Foot Lever Extension, Concept 1

Concept 2: Attach U-Shaped Bar to the rear of the foot lever for arm actuation (Figure 17)

Pros: Takes advantage of existing system for actuation; simple to construct, low machining costs

Cons: Requires significant overhead reach and arm strength to push the lever down.

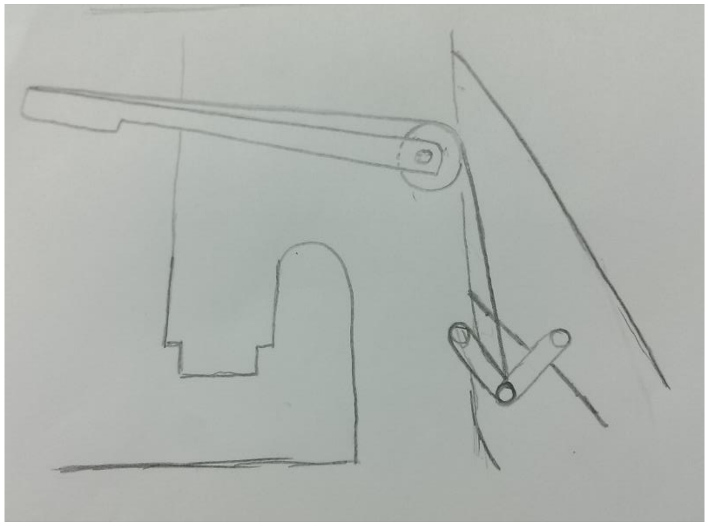


Figure 17: U-Shaped Bar for Arm Actuation (Concept 2)

Concept 3: Hand Crank with Gearbox and screws to actuate existing mechanisms for lowering/raising the press

Pros: Very little limb extension and arm strength needed to operate the press

Cons: Gearboxes can be complicated to design, machine, and assemble.

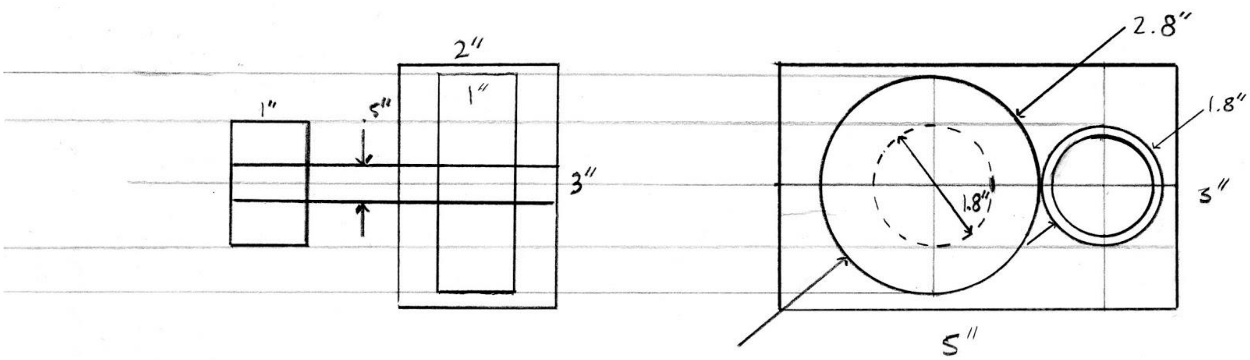


Figure 18: Approximate Layout and Dimensions for Hand Crank with Gears

Concept 4: Bicycle crank with chain to move the press up and down

Pros: Little limb extension needed, needs only small force to operate

Cons: Difficult to integrate with the current system, possibly bulky, many pinch points

4.2 Designs #5-7, Cutting Process

Concept 5: Modify Small Arbor Press (Figures 15 and 16), adding cutting stencils and board to cut multiple images from one sheet at a time

Pros: Inexpensive materials, delivers adequate force to cut multiple images/sheets in one operation

Cons: May be difficult to make modifications, requires careful construction to ensure alignment with images on a sheet. Possible safety issues.

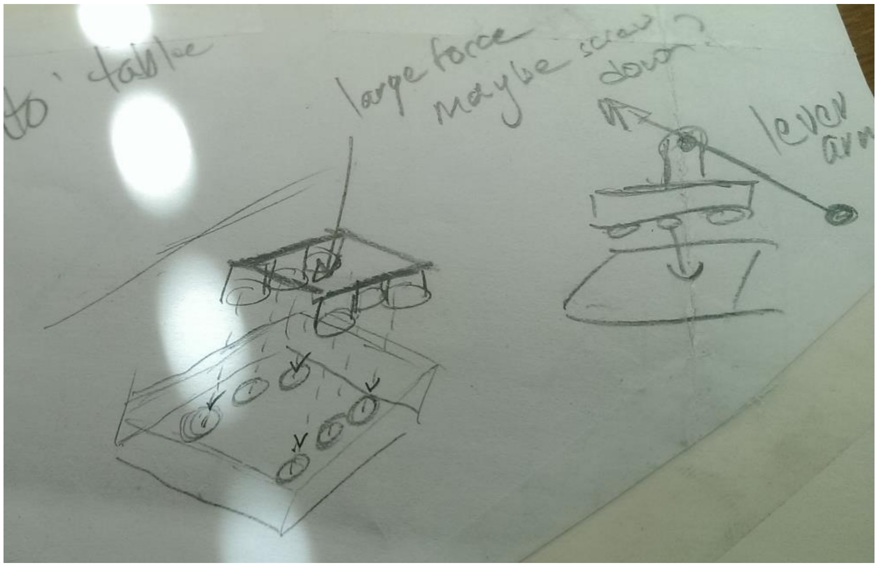


Figure 19: Image Cutter for Arbor Press

Figure 20: Arbor Press to be Modified[11]

Concept 6: Handheld Circle Cutter, Press Type (Figure 21)

Pros: Inexpensive, may cut different diameters. Handheld and will suit any layout of the images on the sheet

Cons: Requires careful placement over the image, cuts only one image on the sheet at a time, may not cut through multiple sheets in one operation

Figure 21: Handheld Circle Cutter, Press-type[6]

Concept 7: Handheld Circle Cutter, Crank Type (Figure 12)

Pros: Blade will cut through multiple sheets at a time, offers flexibility to cut images from a sheet in any layout

Cons: Need separate cutter for different dimensions, difficult to align over the image, cuts only one image at a time

4.3 Design #8-11, Alignment

Concept 8: Arrange fixed dies in a linear layout rather than the angled layout requiring a swivel motion

Pros: Eliminates the need to adjust alignment to compensate for the swivel of the dies. Dies may be combined with color aids on the dies to assist with proper placement of components.

Cons: Does not offer a reliable, mechanical method for ensuring that the components are placed properly in the dies.

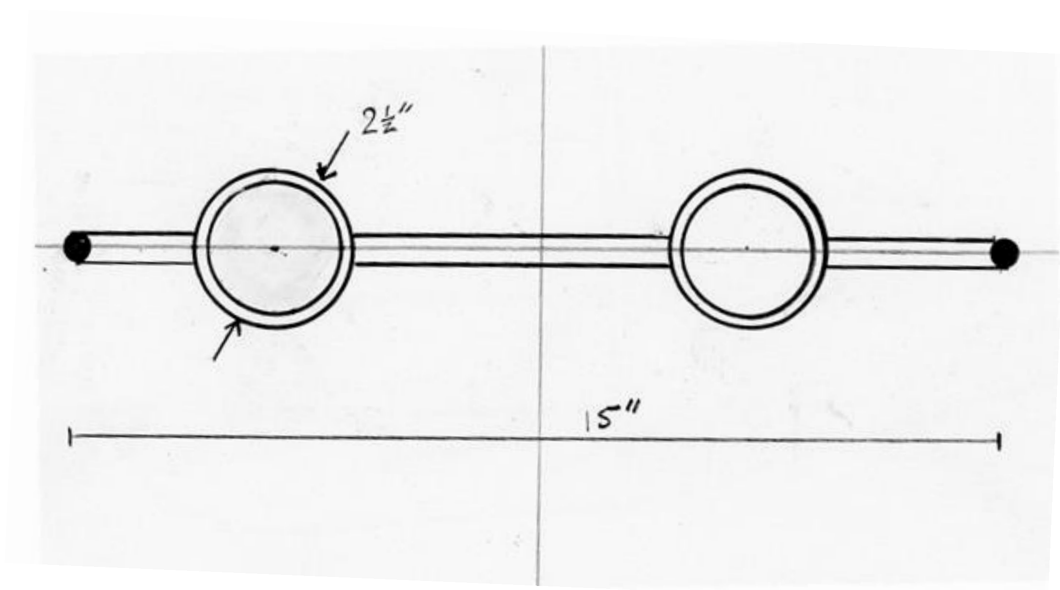


Figure 22: Linear Die Arrangement with Dimensions

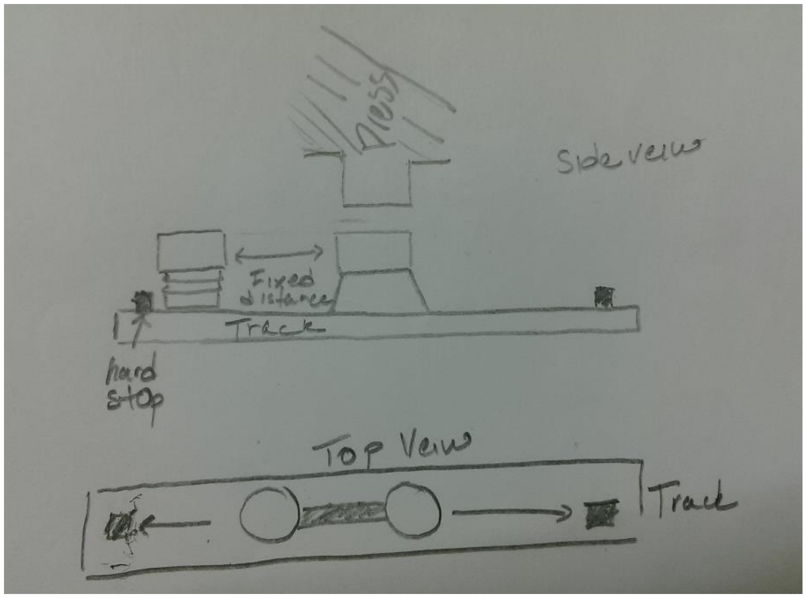


Figure 23: Linear Die Arrangement, Concept 8

Concept 9: Change to swivel pin-back; because the pin swivels 360 degrees, it would be impossible to misalign the image and the pin back

Pros: Eliminates the need to align components at all

Cons: More expensive to purchase, current inventory would need to be scrapped or used before implementing this concept

Concept 10: Change Die Shape to Square, the images would also be cut square

Pros: User would only have to ensure that images are placed with the image oriented vertically

Cons: Unsure if the dies could be modified in such a way that would still allow operation of the button maker

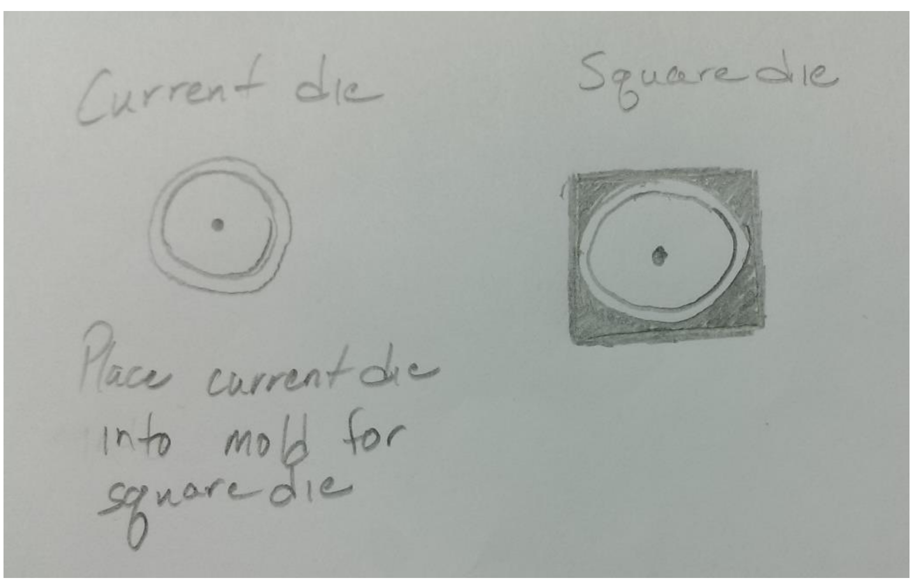


Figure 24: Square Die Shape (Concept 10)

Concept 11: Change the back fixation by placing a hard stop to prevent a very tight "crimp" of the button front to button back. If the fixation were secure, but allowed for the back to rotate, this would overcome alignment issues.

Pros: Eliminates the need to achieve careful alignment, reduces time to make one button, will work with current inventory

Cons: Difficult to achieve a fit that is secure but still allows rotation of the pin components.

Concept 12: A "bear ear" feature (Figure 24) will be added to the images during cutting. By aligning the "bear ears" in the Button Maker die, to which visual guides will be added, the user will achieve a perfectly aligned button and rejects can be minimized. The team has already confirmed that this concept is viable (see Section 6).

Pros: Makes the alignment of the button images and components "easy to do right and hard to do wrong". A "bear face" is an easily recognizable shape.

Cons: Creating the cutting dies and modifying the button maker dies may be challenging and expensive (with respect to manufacturing/machining costs).

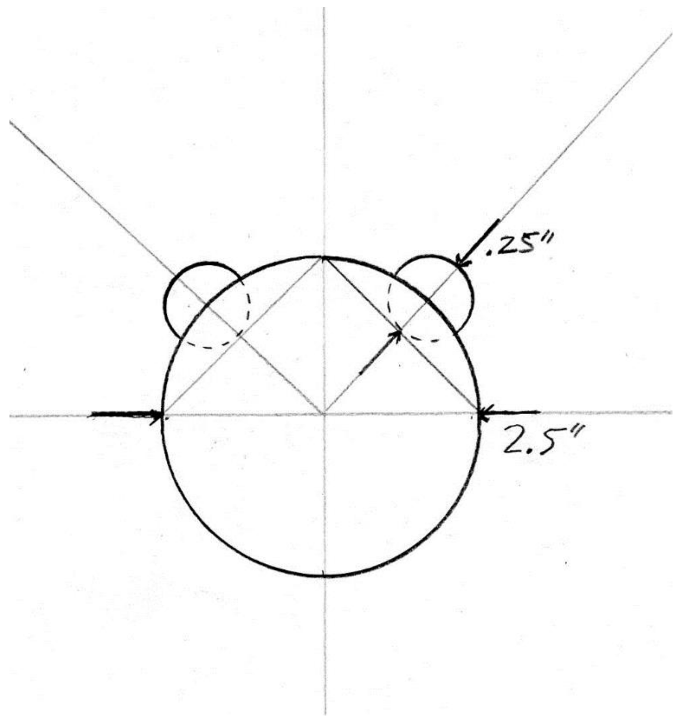


Figure 25: Layout and Dimensions of Concept 12

5 DESIGN SELECTED

5.1 Rationale for Design Selection

According to the criteria in the Pugh Chart/Decision Matrices (Appendix A.1, A.2), the following designs scored the highest and were subsequently chosen by the team as the designs to be pursued in the testing/prototyping phase.

ACTUATION:

The team took the two highest scoring concepts from the decision matrix for actuation, as both concepts will need to be implemented to completely meet the needs of the clients. These concepts are adding the foot lever extension (Figure 26), and creating a hand crank attached to a gearbox for hand actuation(Figure 27) (Concepts 1 and 3). Whether the user is better suited to using their legs or arms, the button maker was modified to make that much easier and safer.

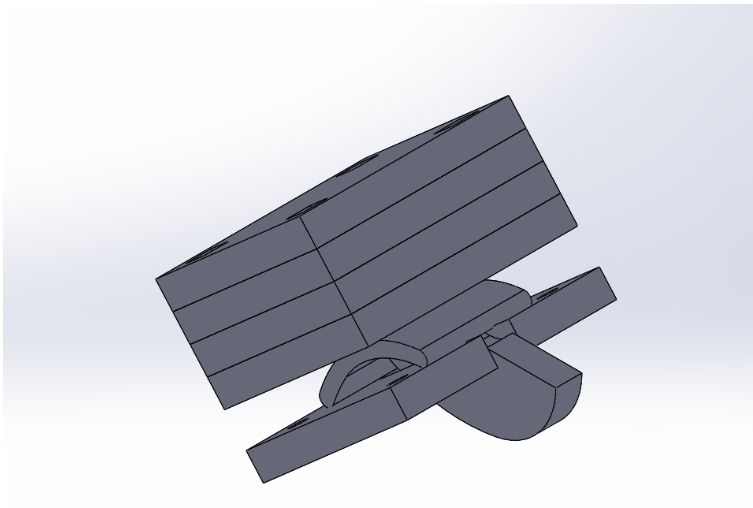


Figure 26: 3-D Model of Foot Extension

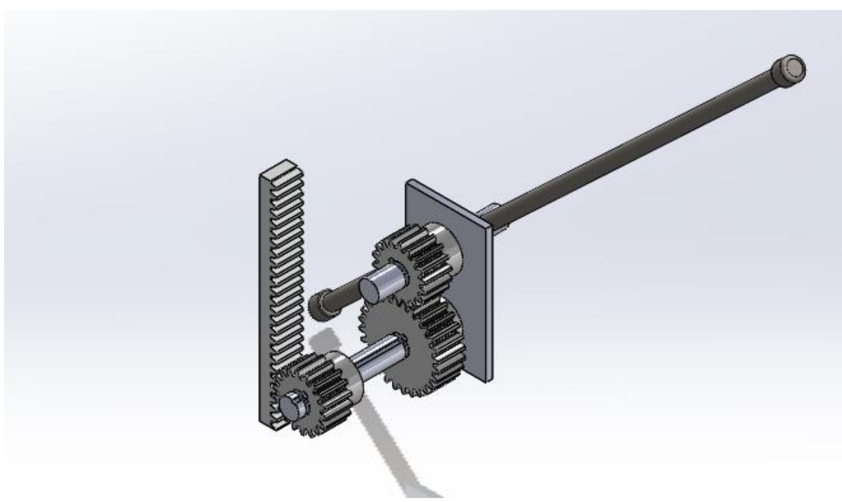


Figure 27: Button Maker Gear Box with Arm Lever

CUTTING PROCESS:

The highest scoring concept, according to the decision matrix for the cutting process, was the Modified Arbor Press (Figures 28 and 29)(Concept 5). This method is relatively inexpensive, can be modified to cut multiple images from a sheet in one operation, can cut through multiple sheets in one operation, and requires small forces to operate. Safety issues were addressed during detail design, testing, and prototyping to ensure that all users will be safe while using this device.

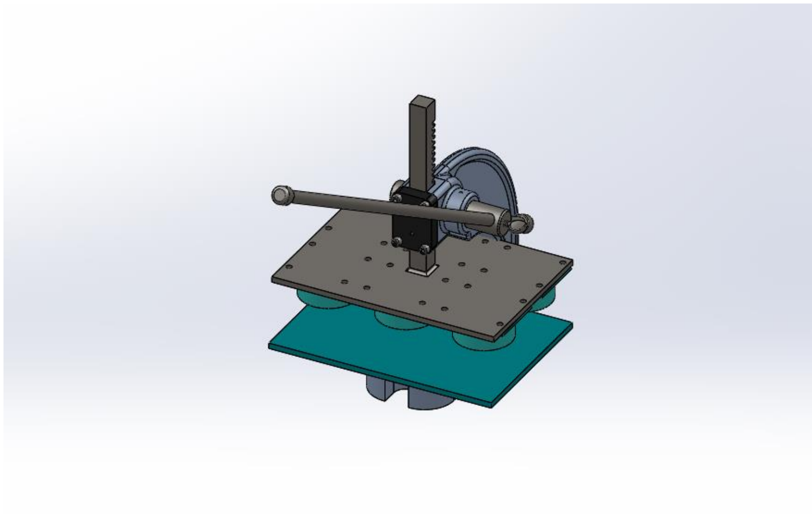


Figure 28: Arbor Press Image Cutter with Blades and Arm Lever

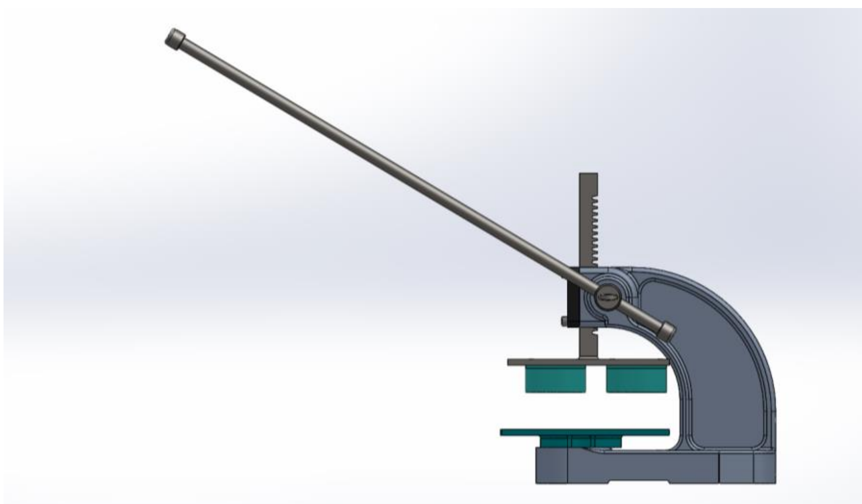


Figure 29: Side View, Arbor Press Image Cutter

ALIGNMENT:

Although the highest scoring concept for alignment was found to be Concept 11, or changing the button back fixation, the team had a moment of insight after concept selection. This insight was the “bear ears” concept (Concept 12). This concept provided a simple way for users to align the image properly. The team has already confirmed, through the development of a proof-of-concept model, that this concept is viable and that the “bear ears” are NOT visible on the button once assembly is complete.

Alignment difficulties were also addressed by the design of a linear tracking system (Figures 30 and 31) for the button maker dies. Incorporation of this element eliminates rejects due to misalignment caused by the swivel action of the two dies.

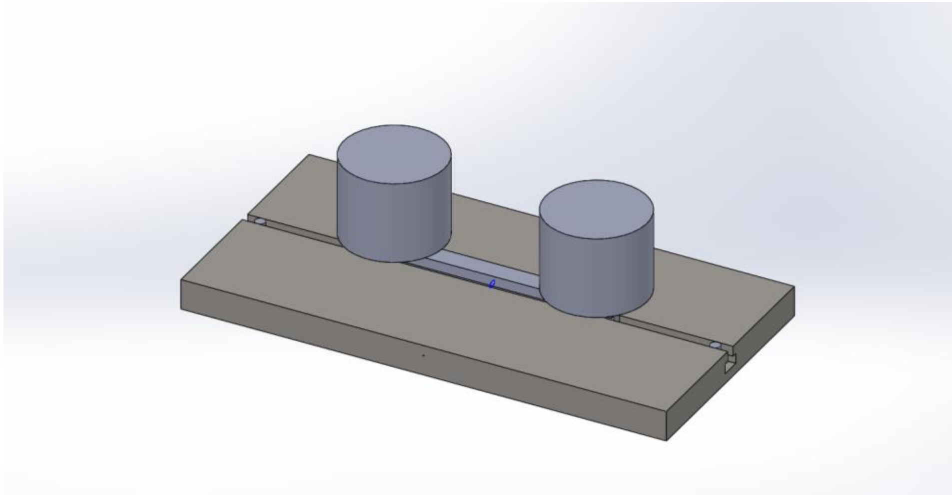


Figure 30: Linear Die Arrangement

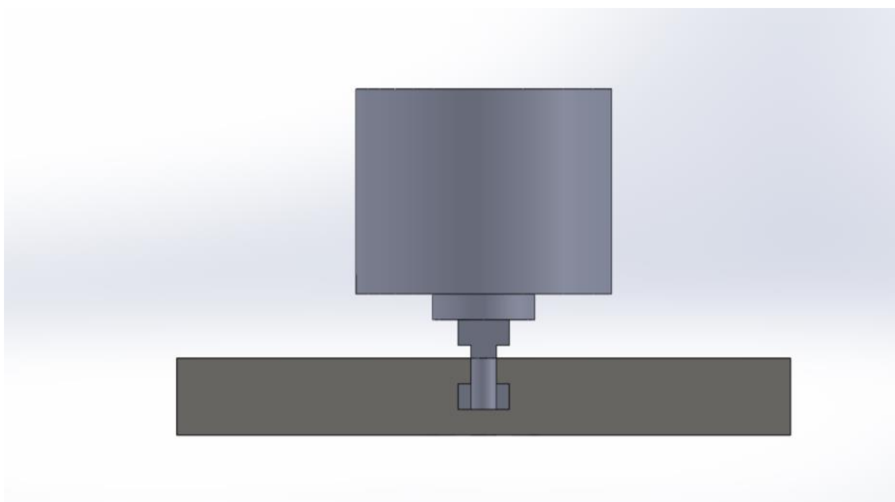


Figure 31: Side View of Linear Arrangement and Die Tracking System

6 IMPLEMENTATION

The team has completed several steps of the implementation of our chosen designs. Prototypes were constructed in December of 2015 and these are described in Section 6.1. Since that time, several deficiencies have been identified in the designs and changes have been made to concepts in order to make the devices more easily manufactured and to reflect the recent input of the customer contact, Justin Cartwright. The manufacturing completed thus far and plans for upcoming manufacturing are detailed as well as the results of a Design of Experiment process.

6.1 Prototyping

The team approached the implementation and embodiment of our final designs by generating two different types of prototypes: proof-of-concept (or a "works like" model) and an industrial design prototype (a "looks like" model). The three areas on which the team focused for this portion of implementation were to create a model of the geometry and size of the actuation system, the viability of the “bear ears” solution for alignment, and the ability of an arbor press to deliver the force needed to cut the images from the sheet.

To determine if an arbor press will deliver enough force to cut through multiple sheets of paper, a small cutting die was purchased and mounted to an arbor press at a team mate’s workplace (Figure 32). This setup was capable of cutting a single circle through a magazine (or 50-60 pages)(Figure 33). This is encouraging, but more testing is needed to establish if the cutting die can be modified to cut six circles from one sheet and through multiple sheets of paper. The purpose of this proof-of-concept prototype was to determine if the necessary force could be delivered by such an approach and this was confirmed.

Figure 32: Proof-Of-Concept for Cutting Process

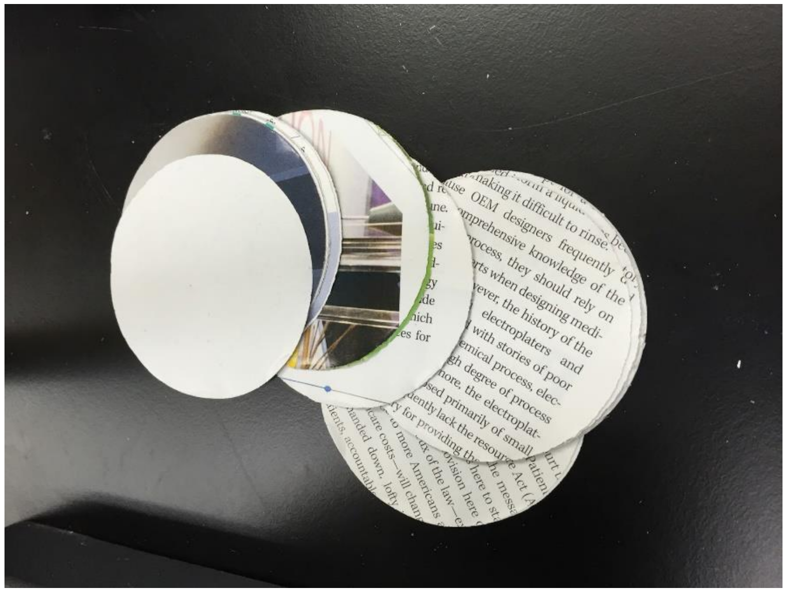


Figure 33: Images Cut for Proof-Of-Concept

The team built an industrial design prototype to represent the foot lever extension and hand crank designs (Figure 34). The team wanted to ensure that adding these features to the button maker would result in a comfortable, stable improvement to the process. The industrial prototype was constructed of scrap wood and hardware and assembled to duplicate the current dimensions of the button maker as well as the features the team is planning to add.

Figure 34: Industrial Prototype for Actuation

The other proof-of-concept prototype the team generated related to confirming the viability of cutting the images into a “bear head” shape (Figure 35). The shape would make alignment in the Button Maker dies much more simple if guides were added to the button maker dies. The team was concerned that adding the “ears” would create excess paper tabs on the back of the button, where the edges were not completely wrapped by the “crimping” action of the button components. A simple test using such a cut shape and the Hozhoni Button maker revealed that the “ears” are completely wrapped around the edge and no excess paper is visible on the back of the button (the “bear ears” were successfully hidden by the crimp, in other words).

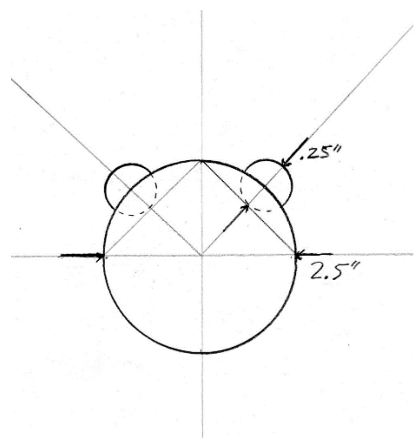


Figure 35: Schematic of "Bear Ears" Concept

6.2 DESIGN CHANGES

After the winter break, the team re-convened to re-assess our selected designs, review the 3-D models, and discuss them with our customer contact, Justin Cartwright. Based on these discussions and meetings, the team made several changes to the designs.

6.2.1 Changes to Actuation

The team, after discussing the designs with the customer contact, decided to change the long lever arm on the button maker gear box to a more compact mechanism. This was due to safety concerns over whether the long lever arm would become a hazard to anyone sharing a space with the button maker itself. The team’s solution was to replace the lever arm with two round handle cranks on either side of the button maker that would be rotated to produce the downward action of the button maker press. See Figure 36 for a 3-D model of this new design.

6.2.2 Changes to Alignment

Based on additional feedback from the customer contact, one major aspect of the alignment system design was changed. While the die will still be rearranged into a linear tracking system, they will no longer be fixed. Rather, one die will rotate on a ratchet-type fixture, which allows for adjustments to be made to the orientation of the die (and thus the image being placed in the button), but with a degree of resistance to prevent unwanted movements or misalignments. This feature was added to address the customer contact’s concern that it is easier for someone with limited dexterity to turn the die, rather than to have to remove the image and attempt to place it in the proper orientation. Figures 37 and 38 show the components for the ratchet system, achieved with a ratchet gear and spring-loaded ball plunger fixed to the die. The team has also replaced the hardware needed for affixing the dies to the linear tracking system: the original design called for the machining of a small “I-beam” shape (Figure 39) to allow movement in horizontal line, but the new design uses "T-slot nuts" (Figure 40) that can be bought off-the-shelf and will minimize additional machining processes.

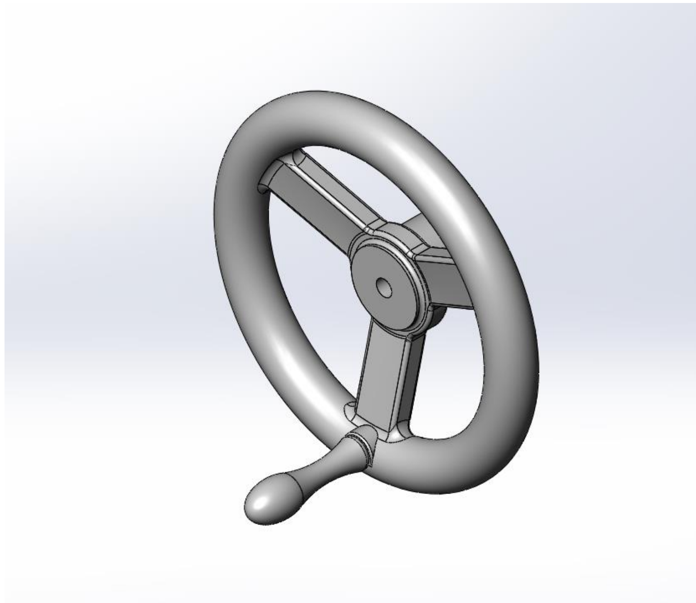


Figure 36: Hand Crank Replacing Arm Lever on Gear Box

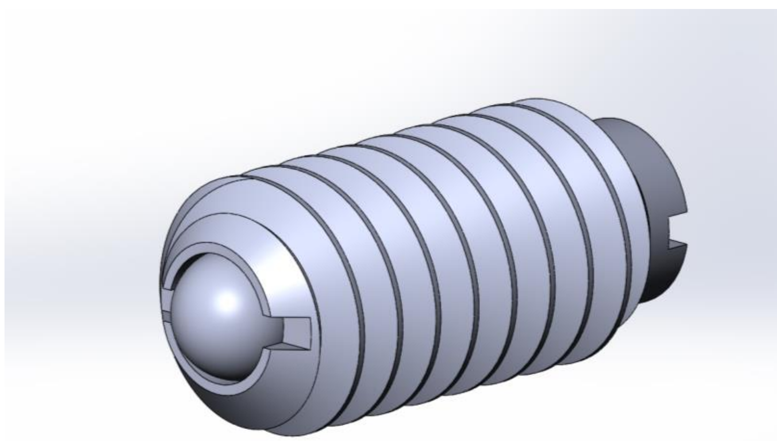


Figure 37: Spring Plunger Pin for Ratchet on Button Maker Die

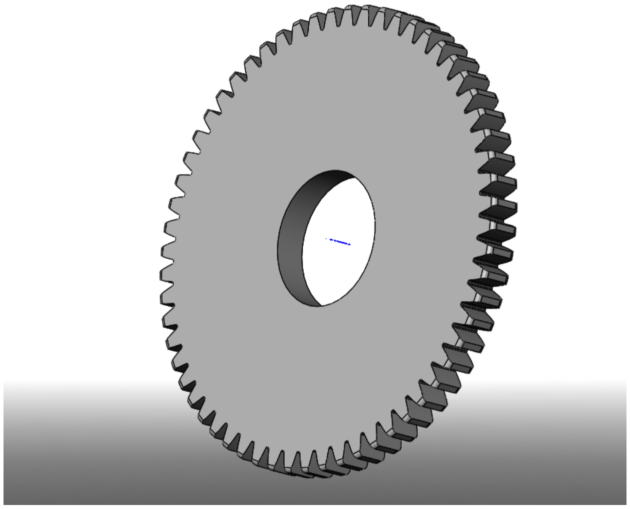


Figure 38: Ratchet Gear for Button Maker Die

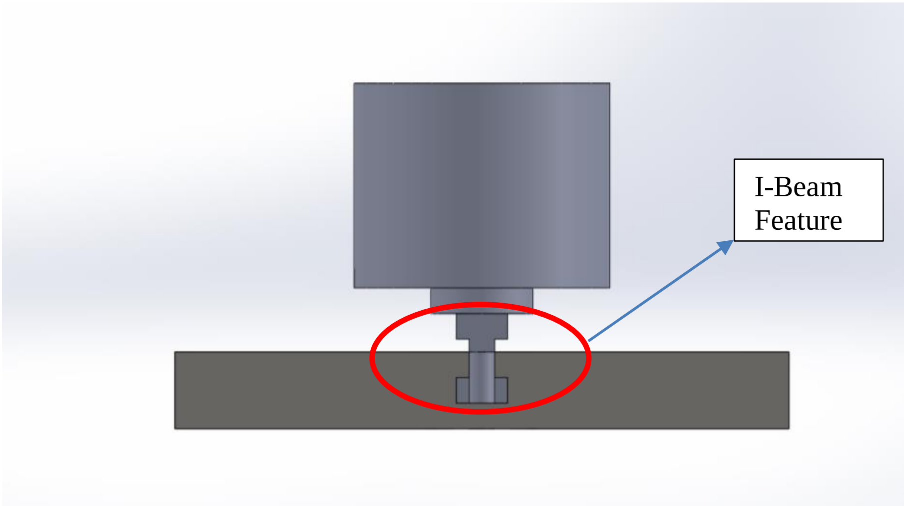


Figure 39: "I-Beam" Component for Linear Tracking

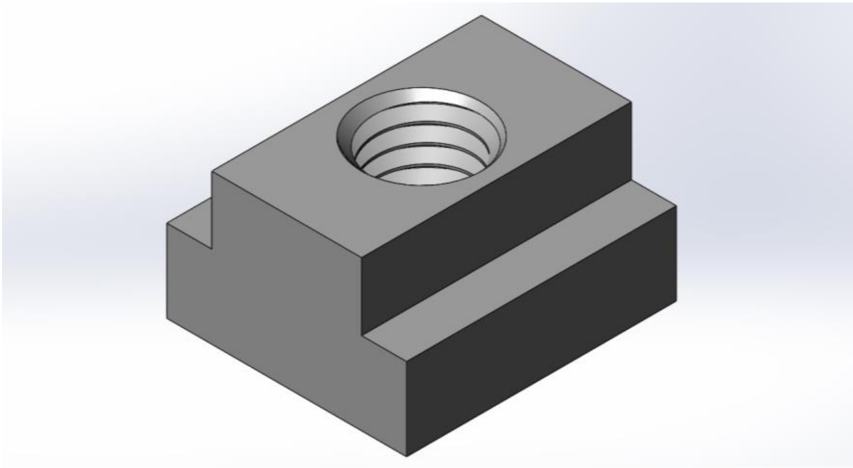


Figure 40: "T-Slot" Nut for Linear Tracking

6.2.3 Finalized Button Maker Design

The finalized button maker design in shown in Figure 41. The model shows the handle crank and gearbox system, the linear die alignment, and the foot extension. Figure 42 shows a closer view of these components.

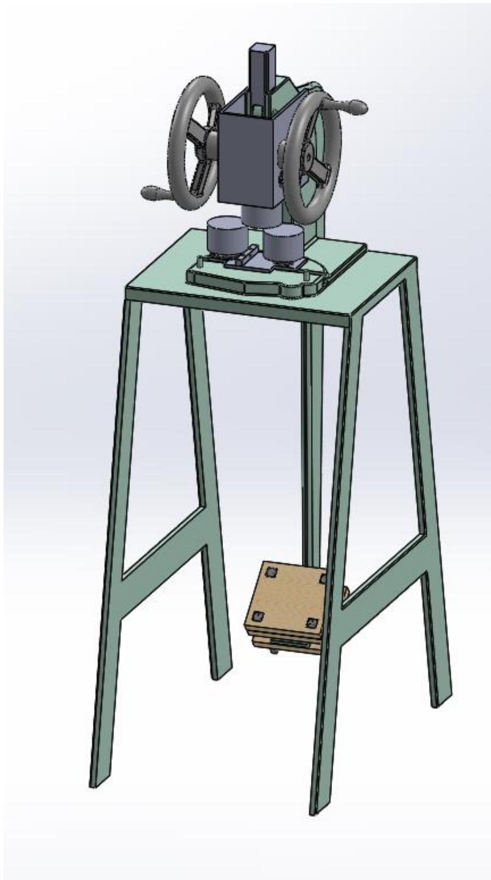


Figure 41: Complete 3-D Model of the Button Maker

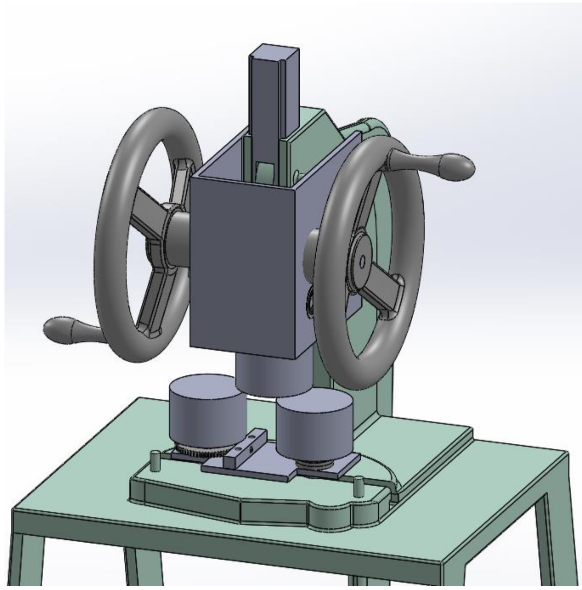


Figure 42: Close-Up Of Hand-Actuation and Linear Die Arrangement

6.3 MANUFACTURING PLAN

The team is constructing three devices/modifications to the current button maker and cutting process, and these devices are being constructed with a combination of off-the-shelf components (which will be used "as-is") and with a variety of raw materials machined to specifications.

6.3.1 Off-The Shelf Components

Table 2 shows the items that were purchased to be used without any additional machining or finishing.

6.3.2 Manufacturing

Table 3 shows the raw materials that have been purchased, of which mechanism they will be a part, and the machining process that are required to manufacture the parts to specification. Those processes highlighted in blue have already been completed. The first machining process to approach completion is the gearbox and assembly has begun on the machined parts.

It should also be noted that the button maker will have to be transported from the Hozhoni Offices to the NAU machine shop in order to install the gearbox, hand cranks, and foot actuator. The team is planning to complete all sub-assemblies before moving the button maker in order to minimize the time that Hozhoni will be without it. The team is discussing dates with the customer contact, but the button maker will tentatively be moved in mid-March and will be returned two weeks later.

Table 2: Off-The-Shelf Components

OFF THE SHELF COMPONENTS		
Description	Supplier	Item Description
	CUTTING	
Arbor Press, Cast Frame	HHIP	Arbor Press 2 ton HHIP
Arbor Press, Shaft Pinion	HHIP	Arbor Press 2 ton HHIP
Arbor Press, Shaft Pinion	HHIP	Arbor Press 2 ton HHIP
Arbor Press, Face plate		
Lever Arm		
Collar		
Handle Cap		
Jib Plate		
Screw, Thumb		
Blade	Joanns	Cutting Blades
	ALIGNMENT	
Dies	Existing	
Spring plunger	McMaster-Carr	Spring Plunger
Base plate	McMaster-Carr	Nylon Block
Pins	McMaster-Carr	Alloy Steel Dowel Pin, 1/4" Diameter, 3/4" Length
T slot nut	McMaster-Carr	
Ratchet Gear	McMaster-Carr	
	ACTUATION	
Smaller Gear	Rush Gear	18 tooth small gear
Larger Gear	Rush Gear	28 tooth large gear
Rack Gear	SDP	8" rack gear
Handle Cap	McMaster-Carr	Ribbed Finishing Plug for Tubing, Fits 3/4" Tube OD and 0.59"-0.7" Tube ID
Handle Crank	McMaster-Carr	
	PENDING PURCHASES	
Bearings	McMaster	
Fully threaded rod	McMaster	
Threaded on one end rod	McMaster	
Washer .5" screw size	McMaster	
Washer .75" screw size	McMaster	
Set screw	McMaster	

6.4 DESIGN OF EXPERIMENTS

The team has designed an experiment to test the effectiveness of the arbor press and modified cutting process: the number of sheets cut through cleanly is to be tested as a function of arbor press lever arm length, number of sheets in the tray, and the thickness of the blades. Due to a supplier error, the wrong blades were shipped to the team and this has prevented the execution of this Design of Experiments (DOE) process. Once the proper blades have been delivered, the DOE will be run and the results analyzed.

Design Of Experiments: Cutting Process

Y = number of images cut per operation
Y = Y (blade thickness, arbor press arm length, number of sheets)
Blade thickness = x_1
Arm length = x_2
Number of sheets = x_3

Table 3: DOE Variables and Values

Variable	Nominal Value	+1	-1
x_1	0.125”	.15”	.10”
x_2	1.25’	1.5’	1.0’
x_3	30	45	15

Table 4: Trials and Variable Values

Trial	Vect.	x_1	x_2	x_3	$Y_1(x)$	$Y_2(x)$
1	d_1	-1	-1	-1		
2	d_1	+1	-1	-1		
3	d_1	+1	+1	-1		
4	d_1	+1	+1	+1		
5	d_1	+1	-1	+1		
6	d_1	-1	+1	+1		
7	d_1	-1	-1	+1		
8	d_1	-1	+1	-1		

An updated Midpoint Report will be delivered upon completion of the DOE, which is expected by March 10, 2016. The team expects that both the thickness of the blades and the number of sheets loaded in the arbor press will have the largest effect on the number of sheets cut.

Table 5: Manufacturing Processes

Cutting								
			size					
Part	**# of pieces**	**Tool/machine**	**Length**	**width**	**height**	**diameter**	**Dates**	**Notes**
2' lever arm	1	Lathe down to .7!	2'			.75"	March 5-15, 2016	
		Band saw					March 5-15, 2016	Cut from 3' to 2'
Base plate	1	Band Saw	11"	8.5"	.25"		March 5-15, 2016	
Top plate	1	Band Saw	11"	8.5"	.25"		March 5-15, 2016	
		Drill press				.125"	March 5-15, 2016	Refer to diagram to see where holes are located
Side walls	2	Band Saw	8.5"	1.5"	.25"		March 5-15, 2016	
	1	Band saw	11"	1.5"	.25"		March 5-15, 2016	
		GMAW					March 5-15, 2016	Weld sides walls to bottom plate to provide walls to align paper
Base to arbor pre	1	GMAW					March 5-15, 2016	Center base plate on arbor press and weld to arbor press
							March 5-15, 2016	
Alignment								
			size					
Part	**# of pieces**	**Tool/machine**	**Length**	**width**	**height**	**diameter**		**Notes**
Base plate	1	Band Saw					March 10-30	Cut to final length
		Band Saw					March 10-30	Cut to final width
		Band Saw					March 10-30	Cut out rectangle from left coner for hard stop alignment
		Band Saw					March 10-30	Cut out rectangle from right coner for hard stop alignment
		Drill press					March 10-30	Holes for holding block and button dies
Holding block	1	Band saw					March 10-30	Cut to final width
		Band saw					March 10-30	Cut to final length
		Drill press					March 10-30	Drill foor ball spring plunger hole and mechanical fasteners
		Tapping die					March 10-30	Tap ball spring hole to hold in place
Button die	2	Drill press				0.5	March 10-30	Drill into bottom of die for shaft attachemnt
		Tapping die				0.5	March 10-30	Tap one of the dies so that it can srew on and be fixed
Arm Actuation								
			size					
Part	**# of pieces**	**Tool/machine**	**Length**	**width**	**height**	**diameter**		**Notes**
Input shaft	1	Lathe					February 15-March 15	turn to size
		Drill press					February 15-March 15	key slots and crank pins
		Band saw					February 15-March 15	cut to size
Output shaft	1	Lathe					February 15-March 15	turn to size
		Drill press					February 15-March 15	key slots
		Band saw					February 15-March 15	cut to size
Housing plate L	1	Band saw					February 15-March 15	cut to size
		Drill press					February 15-March 15	holes for shafts
Housing plate R	1	Band saw					February 15-March 15	cut to size
		Drill press					February 15-March 15	holes for shafts
Housing plate T	1	Band saw					February 15-March 15	cut to size
Housing plate B	1	Band saw					February 15-March 15	cut to size
		GMAW					February 15-March 15	Weld all housing plates together

6.5 IMPLEMENTATION COSTS TO DATE

Table 6 displays a summary of all costs to date. The team has enough funds left to cover costs associated with UGRADS in April (such as the cost of presentation materials). By far the most expensive materials purchased thus far have been the gears and handle cranks for the gear box and hand actuation, but some of the costs have been offset by taking advantage of donated/scrap materials at the NAU machine shop. Refer to the complete Bill of Materials in Appendix A3.

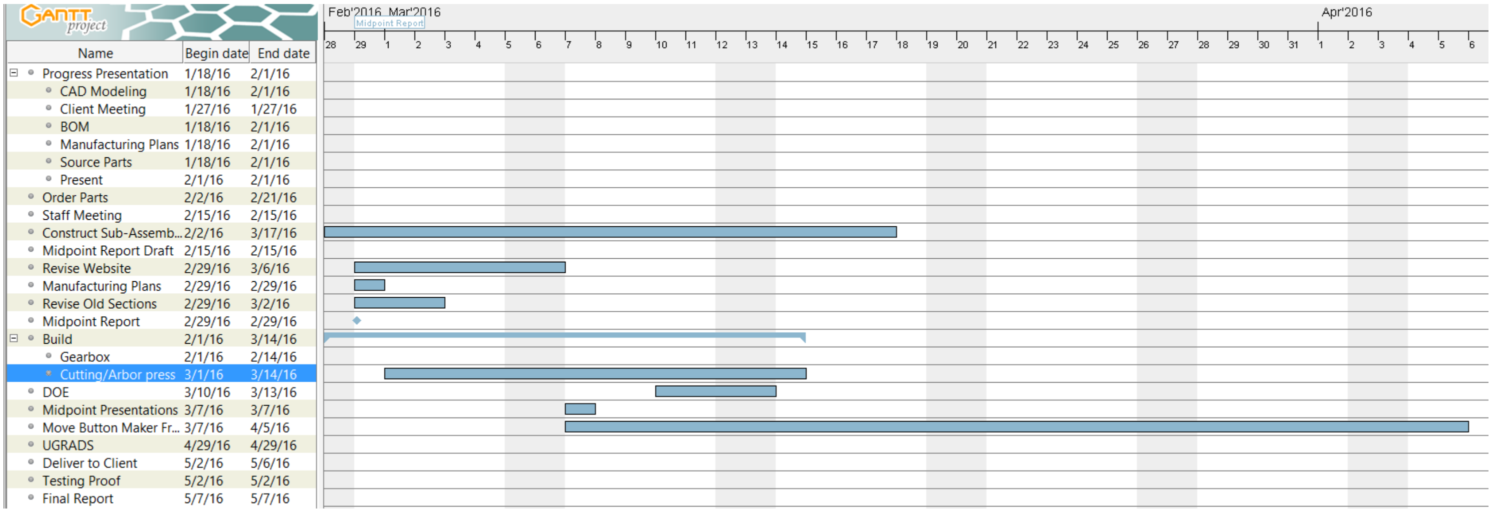
Table 6: Summarized Costs To Date

COST SOURCE	TOTAL COST TO DATE
Prototyping	$21.37
Cutting Process	$275.94
Alignment	$85.89
Actuation	$802.07
TOTAL COST	$1185.27
REMAINING FUNDS	$314.73

6.6 Updated Schedule

The Gantt Chart (Table 7) shows all tasks for the Spring Semester and approximate dates. Currently the team is on schedule but is at risk of falling behind on manufacturing. Several teammates have signed up to complete the NAU Machine Shop training to assist the one team member with Machine Shop access. This should enable the team to accelerate the manufacturing process.

Table 7: Gantt Chart



Name	Begin date	End date
Progress Presentation	1/18/16	2/1/16
CAD Modeling	1/18/16	2/1/16
Client Meeting	1/27/16	1/27/16
BOM	1/18/16	2/1/16
Manufacturing Plans	1/18/16	2/1/16
Source Parts	1/18/16	2/1/16
Present	2/1/16	2/1/16
Order Parts	2/2/16	2/21/16
Staff Meeting	2/15/16	2/15/16
Construct Sub-Assemb...	2/2/16	3/17/16
Midpoint Report Draft	2/15/16	2/15/16
Revise Website	2/29/16	3/6/16
Manufacturing Plans	2/29/16	2/29/16
Revise Old Sections	2/29/16	3/2/16
Midpoint Report	2/29/16	2/29/16
Build	2/1/16	3/14/16
Gearbox	2/1/16	2/14/16
Cutting/Arbor press	3/1/16	3/14/16
DOE	3/10/16	3/13/16
Midpoint Presentations	3/7/16	3/7/16
Move Button Maker Fr...	3/7/16	4/5/16
UGRADS	4/29/16	4/29/16
Deliver to Client	5/2/16	5/6/16
Testing Proof	5/2/16	5/2/16
Final Report	5/7/16	5/7/16

7 REFERENCES

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APPENDICES

A.1 Pugh Charts

Pugh Charts were compiled for each of the three areas of design focus: Actuation, Cutting Process, and Alignment. Each team member scored the concepts against the criteria, and the average of the individual scores were taken, giving a ‘+’, ‘-‘, or ‘S’ for each concept against each criteria. Top scores are highlighted in blue and were then scored in a Decision Matrix.

Table 8: Pugh Chart, Actuation

CRITERIA \ CONCEPTS	ADD EXTENSION TO FOOT LEVE	ATTACH ARM LEVER TO FOOT LEVER	PULLEYS FOR ARM ACTUATI	ATTACH HAND CABLE TO FOOT LE	HAND CRANK WITH GEA	BICYCLE CRANK	ADD WHEEL FOR ARM ACTUATION	U SHAPED BAR WITH HANDLES MOUNTED TO FOOT LEVER
Safety	"++++" = +	"++++"	S-+S	----	**DATUM**	"++++"	S+++	S+++
Reliability	"++++" = +	"++++"	----	"++++"	**DATUM**	"++++"	S++S	S++S
Efficiency	"+--S" = -	"++++"	----	"++++"	**DATUM**	"++S+"	S+SS	S++S
Force needed to operate	S+S = S	----	----	----	**DATUM**	"+++S"	S-S-	-+S-
Limb Extension Required	+	----	S+++	----	**DATUM**	"S+SS"	S+S-	----
Cost	"++++"	S-+-	S-SS	"+-SS"	**DATUM**	S-SS	S---	"++++"
Part Count	"++++"	"+-+"	S---	"+-SS"	**DATUM**	---	S--S	"+++"
Σ+	5	4	1	2		4	1	5
Σ-	1	3	4	3		1	1	1
ΣS	1	0	2	2		2	5	1

Table 9: Pugh Chart, Cutting Process

PUGH CHART: PATTERN CUTTING										
CRITERIA \ CONCEPT	ARBOR PRESS	GIANT "HOLE PUNCH"	CIRCULAR MULTISIZED	HOLE PUNCH WITH LEVE	GRAPHIC CUTTER 1	GRAPHIC CUTTER	LASER CUTTER	HANDHELD CIRCLE CUTTER (crank)	HANDHELD CIRCLE CUTTER (Punch)	SCRAPBOOKING CUTTER
Safety	**DATUM**	+ +	+ +	+ +	S S	S S	- -	- -	+ +	+ +
Reliability	**DATUM**	S -	S S	S -	S S	S S	+ +	+ +	+ -	- -
Efficiency	**DATUM**	S -	- -	S -	S S	S S	+ +	- -	- -	- -
Time to Align	**DATUM**	S -	- -	- -	+ S	+ S	+ +	S S	+ -	+ +
Number of Steps to Align	**DATUM**	+ S	- -	S S	S S	S S	+ +	+ +	+ +	+ +
Sheets cut per Operation	**DATUM**	- -	- -	S S	- -	- -	+ -	- -	- -	- -
Preparation Required	**DATUM**	S -	- -	S S	- S	- S	- -	+ +	+ +	+ +
Patterns Cut Per Operation	**DATUM**	- -	- -	S S	- -	- -	+ S	- -	- -	- -
Cost	**DATUM**	- +	+ +	- +	+ +	+ +	- -	+ +	+ +	+ +
Σ+		2	2	1	1	2	5	4	4	5
Σ-		6	6	2	2	3	3	4	3	4
ΣS		1	1	7	6	4	1	1	2	0

Table 10: Pugh Chart, Alignment

PUGH CHART: DIE ALIGNMENT										
CRITERIA \ CONCEPT	AXIS SYSTEM	KEY SLOT	AUTOMATED	CHANGE DIE SHAF	REVOLVER PROCES	LINEAR ARRANGEME	SWIVEL BACK BUTTOI	COLOR AIDS	CUTTER IMPARTS A FEATURE	CHANGE BACK FIXATION, ALLOWING BACK TO ROTATE
Safety	-+++	S+S	S+-	**DATUM**	S+S	S++	"+++"	"++-"	S++	"+++"
Reliability	"+---"	S-S	S+-	**DATUM**	S-S	S++	"+++"	"+--"	S--	"-+s"
Efficiency	"+---"	S--	S++	**DATUM**	S-+	S++	"+++"	"+--"	---	"-++"
Time to Align	"----"	---	S++	**DATUM**	"+-S"	S+S	"+++"	---	S--	"+++"
Number of Steps to Align	S+SS	-++	S-+	**DATUM**	S+S	S+S	"+++"	"+--"	---	"+++"
Cost	S+SS	S-S	---	**DATUM**	"+--"	S++	"+++"	"+++"	"+-+"	"+++"
Part Count For Alignment Syst	S+SS	S+S	---	**DATUM**	"+--"	S+S	"+++"	"+++"	"+-+"	"+++"
Works with current inventory	"+++"	"+-S"	---	**DATUM**	"+--"	"+++"	---	"+++"	"+-+"	"++"
Σ+	2	1	2		0	5	7	4	4	7
Σ-	3	2	3		3	0	1	4	4	0
ΣS	3	5	3		5	3	0	0	0	1

A.2: Decision Matrices

The top five scoring concepts from The Pugh Charts were scored in a decision matrix. One decision matrix was generated for each of the three design focus areas.

Table 11: Decision Matrix, Actuation

		CONCEPTS				
CRITERIA	**WEIGHT**	*Extend Foot Lever*	*Attach Arm Lever to Foot Lever*	*Bicycle Crank*	*Hand Crank with Gears*	*Bar Mounted to Foot lever*
Safety	0.2	9	9	9	9	8
Reliability	0.15	9	9	9	9	9
Efficiency	0.15	9	5	9	9	8
Force Needed to Operate	0.15	9	7	8	8	5
Limb Extension Required	0.15	9	3	5	8	4
Cost	0.15	9	7	6	6	7
Part Count	0.05	9	8	5	5	7
Sum, Raw Score (0-10)		63	48	51	54	48
Weighted Score		9	6.85	8.05	8.05	6.9

Table 12: Decision Matrix, Cutting Process

		CONCEPTS				
CRITERIA	**WEIGHT**	*Arbor Press*	*Laser Cutter*	*Handheld Circle Cutter (Crank)*	*Handheld Circle Cutter (Press)*	*Scrapbookin g Cutter*
Safety	0.12	8	7	6	8	9
Reliability	0.11	8	4	7	6	3
Efficiency	0.11	8	8	4	4	8
Time to Align	0.11	7	7	4	3	4
Steps to Align	0.11	7	7	3	3	6
Sheets Cut per Operatior	0.11	8	1	1	3	1
Patterns Cut Per Operatic	0.11	7	9	1	1	9
Preparation Required	0.11	7	7	7	8	7
Cost	0.11	6	2	10	9	7
	1					
RAW SCORE, SUM		66	52	43	45	54
WEIGHTED SCORE, TOTAL		7.34	5.79	4.79	5.03	6.03

Table 13: Decision Matrix, Alignment

CONCEPTS						
CRITERIA	WEIGHT	*Change Die Shape*	*Linear Arrangement*	*Swivel Back Buttons*	*Color Aids*	*Change Back Fixation*
Safety	0.14	8	8	5	8	8
Reliability	0.12	8	8	8	4	8
Efficiency	0.12	7	7	6	4	7
Time to Align	0.13	8	9	9	5	9
Steps to Align	0.15	8	7	8	4	8
Cost	0.12	6	8	10	10	10
Part Count	0.12	7	6	10	10	10
Compatible with Current Inventory	0.1	8	10	0	10	10
Sum	1					
SUM, Raw Score (0-10)		60	63	56	55	70
WEIGHTED TOTAL SCORE		7.52	7.82	7.15	6.73	8.69

A.3 Bill of Materials

Cutting

Drawing Part #	Description	Supplier	Item Description	Item #	Lead Time	Units	Cost per unit	# needed	Total
	Arbor Press, Cast Frame	HHIP	Arbor Press 2 ton HHIP	8600-0033			$175.09	1	175.09
	Arbor Press, Shaft Pinion	HHIP	Arbor Press 2 ton HHIP	8600-0034					
	Arbor Press, Shaft Pinion	HHIP	Arbor Press 2 ton HHIP	8600-0034					
	Arbor Press, Face plate								
	Lever Arm								
	Collar								
	Handle Cap								
	Jib Plate								
	Screw, Thumb								
	Arbor Press, Ram	Midwest Metal Warehouse	Carbons Steel Grade 50			ea	$1.00	25.43	$25.43
	Table Plate	McMaster-Carr	Wear-Resistant Black Nylon Sheet, 7/64" Thick, 12" x 12"	8540K125		ea	$12.47	1	$12.47
	Blade	Joanns		2412914		ea	$12.59	5	$62.95
								Total Cost	**275.94**

Alignment

Drawing Part #	Description	Supplier	Item Description	Item #	Lead Time	Units	Cost per unit	# needed	Total
	Dies	Existing							
	Spring plunger	McMaster-Carr	Spring Plunger	3408A73		ea	$3.62	2	$7.24
	Base plate	McMaster-Carr	Nylon Block	8539K171		ea	$33.26	1	$33.26
	Pins	McMaster-Carr	Alloy Steel Dowel Pin, 1/4" Diameter, 3/4" Length	98381A540		25 pk	$5.40	1	$5.40
	T slot nut	McMaster-Carr		94750A584		ea	$3.17	2	$6.34
	Ratchet Gear	McMaster-Carr		6832K66		ea	$33.65	1	$33.65
								Total Cost	**$85.89**

Foot Extension

Drawing Part #	Description	Supplier	Item Description	Item #	Lead Time	Units	Cost per unit	# needed	Total
1	Foot Pad	Existing		NA	NA	NA	$0.00		$0.00
2	Bottom Plate	Home Depot	3/4 in. x 4 ft. x 4 ft. BC Sanded Pine Plywood	205999854	1 day	4x4 ft	$24.98	1	$24.98
3	Middle Plate								
4	Top Plate								
5	Threaded Bolt	McMaster-Carr	Grade 5 Steel Square Head Bolt, 1/2"-13 Thread, 5" Long, Fully Threaded	92327A317			$7.17	4	$28.68
6	Wing nut	McMaster-Carr	316 Stainless Steel Wing Nut, 1/2"-13 Thread Size	93575A035			$5.60	4	$22.40
7	Traction Tape	McMaster-Carr	Abrasive Antislip Tape, 4" Width x 30' Length Roll, Black	6970T151		30ft roll	$26.40	1	$26.40
								Total Cost	102.46

Hand Actuation

Drawing Part #	Description	Supplier	Item Description	Item #	Lead Time	Units	Cost per unit	# needed	Total	
	Box Plate	Midwest Metal Warehouse	1/4" plain carbon steel			ea	$25.43	1	$25.43	
	Output Shaft	Midwest Metal Warehouse	3/4"Carbon Steel	3/4 rd 304 annealed		ea	$7.39	1	$0.00	donated
	Input Shaft	Midwest Metal Warehouse	3/4"Carbon Steel	3/4 rd 304 annealed		ea	$7.39	1	$0.00	donated
	Smaller Gear	Rush Gear	18 tooth small gear	S10C9Z-024H018		ea	$39.27	2	$78.54	
	Larger Gear	Rush Gear	28 tooth large gear	S10C9Z-024H072		ea	$69.26	1	$69.26	
	Rack Gear	SDP	8" rack gear	A1C12-Y242		ea	$35.44	1	$35.44	
	Handle Cap	McMaster-Carr	Ribbed Finishing Plug for Tubing, Fits 3/4" Tube OD and 0.59"-0.7" Tube	9283K12		100 pk	$11.69	1	$0.00	
	Lever Arm	Midwest Metal Warehouse	24" lever arm plain carbon steel	3/4 rd 304 annealed		ea	$29.56	1	$29.56	
	1045 Steel Rod 1' 3/4"	McMaster-Carr		8924K1		ea	$23.00	1	$23.00	
	Steel Plate	McMaster-Carr	0.25"*12"*3' A34	1388K177		ea	$168.42	1	168.42	
	Handle Crank	McMaster-Carr		6026K158		ea	$134.98	2	269.96	
								Total Cost	699.61	

Total Project Cost **$1,163.90**

STILL TO BE BOUGHT

Drawing Part #	Description	Supplier	Item Description	Item #	Lead Time	Units	Cost per unit	# needed	Total	
	Bearings	McMaster		6384K74	$ (12.30)	######		4	12.3	12.3
	Fully threaded rod	McMaster		90322A147	$ (3.09)	######		1	3.09	3.09
	Threaded on one end roc	McMaster		97042A524	$ (6.71)	######		1	$ 6.71	6.71
	Washer .5" screw size	McMaster		93286A049	$ (5.50)	######		1	$ 5.50	5.5
	Washer .75" screw size	McMaster		98023A121	$ (7.48)	######		1	$ 7.48	7.48
	Set screw	McMaster						2		
								Total Cost	35.08	