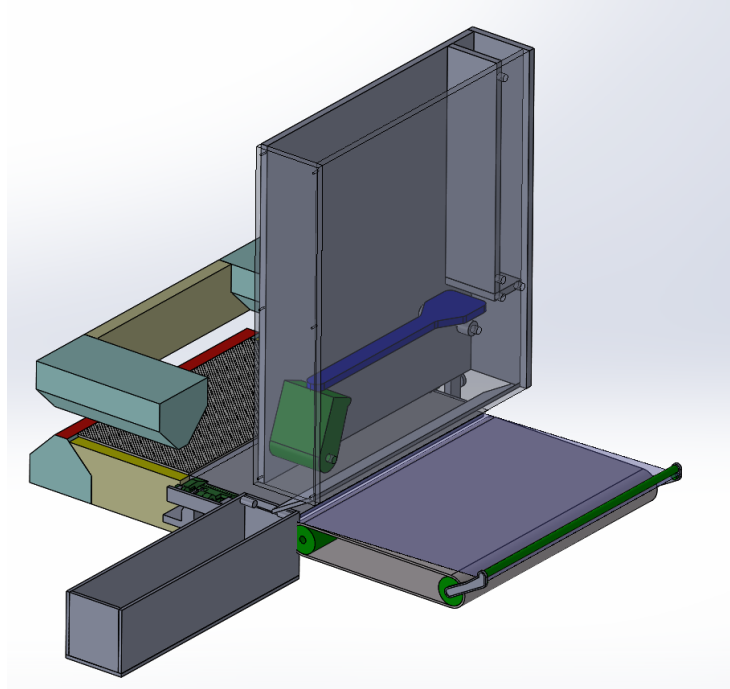


Design and Fabrication of an Automated Packaging System for A-Leg-Up



Department of Mechanical and Aerospace Engineering
Mechanical Engineering Program
University of California, San Diego

Instructor:

David Gillette

TA:

Young Woo Seo

Group 16:

Brunner, Griffin

Huynh, Dai

Ismail, Ali

Ng, Jerry

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Background

A-Leg-Up is a small company based out of San Diego, named after their central product. The company was founded in 2011 by David Blackford. The A-Leg-Up was designed to provide a stable and comfortable platform to perform such tasks as pedicure, applying spray, foot powder or lotion, trimming nails or putting on socks and shoes. Not only does it assist those with hip, knee or back problems, but anyone wishing to be more comfortable in performing these tasks. The long handle also provides an easy-to-reach shoehorn. Currently, to fulfill orders, the company packages each A-Leg-Up manually by inserting, sealing and cutting each unit by hand. This method is tedious and time consuming, significantly slowing down the rate of production. The scope of this project is to create an automated packaging system that helps speed up packaging times as well as simplifying the process. The goal was to create a system that should be able to dispense, wrap, and seal each A-Leg-Up unit automatically.

Review of Existing Solutions

Given the nature of the project, there are thousands of existing solutions that were potentially capable of being referenced for the final design. As such, it was important to figure out which designs would lead to the most beneficial results for the project at hand. The company's small nature meant that most large scale, room-sized automation systems that could run for 24 hours a day and move thousands of parts an hour were not an option. Instead, the existing hand packing system was referenced, wherein polytubing was rolled out to the appropriate length, filled by hand with the product and insert, sealed off by an impulse sealer, and cut to length. The weaknesses of this solution, namely its tedious product and insert insertion process, were then accounted for and minimized, if not eradicated altogether, in the final solution. The vast majority of the automated steps gained inspiration from the existing automated solution, and then were tweaked to work somewhat like the automated assembly line solutions, albeit on a smaller scale.

Statement of Requirements:

Sponsor Requirements:

- Semi-automated. Requiring as little human interaction as possible.
- Packages more than 80 units of product per hour
- Easily taken apart and reassembled
- Mobile to the extent that in parts it can be relocated
- Components are easily replaceable
- Low-cost
- Packages at least 30 units of product before requiring refilling of any dispensers or containers

Statement of Deliverables:

- Rough CAD designs of all components include: plastic feeding, products dispenser, folding manipulation, 3 sides sealing.
- Required materials for first prototype of the products dispenser: wood, steel bars,...
- Choices of plastic roll's size and choice of motors.

Impact on Society

The finished product is likely to have an overall minimal impact on society, as it is being designed specifically for the product being distributed by A-Leg-Up, and cannot be used specifically by other companies wishing to automate their packing system. Indeed, those companies that seek such a goal may be better off inventing their own packaging system as done here, since this system was specifically optimized for the A-Leg-Up product and its insert. The plastic being used is not substantially eco-friendly, but the client base, while growing, is still markedly small enough that, since the amount of plastic used has not actually increased, there is little to no net eco gain in materials cost. The design has been optimized to work purely on electrical power, and as such has the potential to run completely on clean energy, assuming the electrical power distributor being used has switched to purely green energy.

The automated packing system will have one substantial impact on society, and that is a subtler one, as its creation will enable the distribution of product at far higher rates than ever before, and thus will allow the company to distribute the product as fast as they are theoretically being ordered, up to and including a max product distribution rate of 480/hour, 6 times the current max rate of 80/hour. If the marketing aspect of the company does their job, then this increased capable distribution rate can be capitalized upon and the product can be shared with more and more consumers who may find their struggles alleviated, thus making a better life for all those impacted.

Applicable Standards

As noted in the Appendix, **Heat Sealing** article, ASTM Standards **F88** and **F1886** can be used to test the seals created by the impulse sealer at the end of the packaging process. **Standard F88** can be used to test the strength of the seal by measuring the force required to open the seal. In addition, this standard identifies the mode of specimen failure. Additional failure criterion may be added to this standard with regards to what the project requires. **Standard F1886** can be used to visually test the seal by observing how many channels and openings in the seal are in the specimen.

In addition, ASTM Standard **F2097-16** is a standard for design and evaluation of medical packaging. This standard can be used to test the tensile properties of the plastic sheet being used for packaging, through **Test Method D882**. Several of the tests mentioned in this standard cannot be used for this project due to the expensive nature of these tests with regard to manufacturing, which is not applicable to medical devices.

Appendix

Individual Components Analyses

Plastic Folding

Given the nature of the asymmetrical three-seal design, it was important to further investigate how exactly the plastic would be folded in this solution. While this problem could be tackled in numerous ways, some design solutions offered more elegance and effectiveness than others. The setup for this portion of the design problem is as follows:

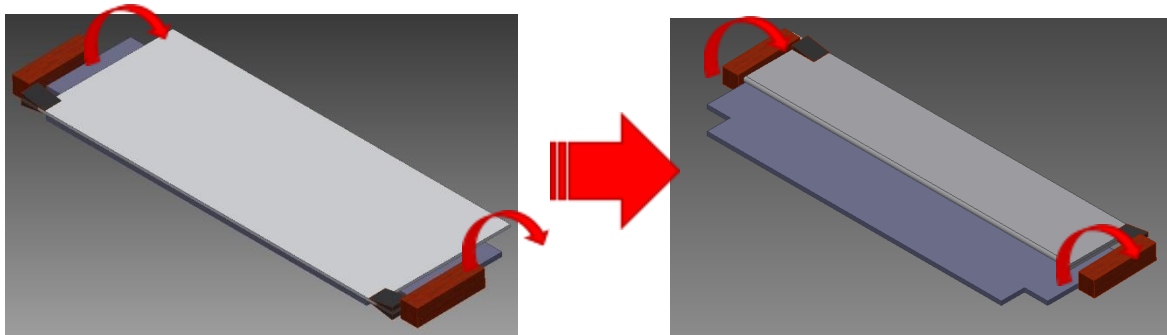


Figure 1. Before and After of Design Challenge.

Two jaws, as seen in Figure 1, rotate from 0 to 180, holding the end of the plastic. The design solution needs to allow room for this arm to rotate, and provide appropriate resistance for the cutting tool, along with allowing for easy disposal of the spare material post cut. It must be a robust design solution that will work reliably indefinitely.



Figure 2a. Jaw Design

2b. Typical Vacuum Table Design

2c. Guide Design

This simple yet critical design problem led us to discuss 3 key possible solutions. The first, and most obvious solution, is two mechanized jaws, as seen in Figure 2a. These would hold the plastic at the pivot point once the material was in the right place, and allow for a simple timed actuation of the jaws to hold or release the part. Just because this solution is the most obvious, however, does not make it necessarily the best.

The second solution, seen in Figure 2b, involves a vacuum table placed underneath the plastic that holds a large portion of the plastic down while the arm lifts the rest of the plastic over the part to provide a quality seal. This solution is more complicated and nuanced in its approach, as it theoretically allows for appropriate resistance for the cutting blade and has no ‘moving parts’, but does require the use of a vacuum that needs to gain and lose suction at a relatively high rate, and may not hold well around the rotation point due to the vacuum’s natural distributed load compared to the point based loads of the other designs.

The third and final solution considered here is that of a nonmoving guide. As seen in Figure 2c, this part would sit idle and lead the plastic into the appropriate place (with some elevation if the plastic has some curling due to its pre-wind) while also providing a pivot point for the plastic that would allow it to rotate easily and freely. This solution has no physical hold on the part, which is beneficial for the easy disposal of scrap, but does require a modification to the design of the lifting arms, so that material does not stray where it should not. This design also, unfortunately, provides little cutting resistance.

These designs are not inherently at odds, and the ideal design solution may incorporate elements of each of these designs. This analysis, instead, shall look at the benefits of each design, and attempt to determine what the best design could be, given all of the factors.

	Ease of Fabrication	Cost	Reliability	Hold Strength for Rotate	Hold Strength for Cut	Maintenance	Noise	Speed / Efficiency
Jaws	~	~	+	+	~	~	~	~
Vacuum	-	-	~	-	+	-	-	-
Guide	+	+	-	~	-	+	+	+

Looking at the above table, it’s easy to compare each of these designs. In this chart, “+” means the most ideal value in the category, while “-” means the least, and “~” means the middlemost in the category. Clearly, while both the Jaws and Guide solution have the potential to be best in show, the Vacuum solution lags the furthest behind, being the best in only one category and the worst in others. As such, this design does not seem to be the ideal one to follow. Nor does it seem logical to try and incorporate it into any other part of our design, as the cons of its design seem to recommend it not be used in any design that is focused on completing our task efficiently.

The other two designs lead us to a more important spot: which design should we follow suit with? The Jaws promise the most reliable solution, with a strong hold on the part that enables a quality and accurate rotation with no slippage, with a single downside being its not ideal hold on the part for cutting. The Guide solution, meanwhile, is by far the most cost effective and easy to make, but doesn’t guarantee the highest quality hold on the part for cutting or rotating.

Our final proposed solution is a modification of the Jaw design that enables the best quality cut to be made, while gripping on the part along a long plane, as can be seen in Figure 3. This will give the part the best cuts possible without adding significant amounts of complexity. The main pitfalls we will have to avoid with this design are any amounts of pre-wind in the plastic that cause it to want to bunch up, which is a factor we will have to analyze once we get our hands on some of the plastic, as it could be a massive amount of tension or basically none.

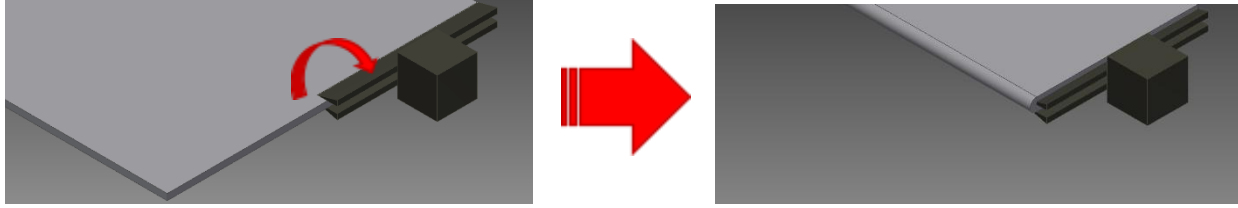


Figure 3. Extended Jaw Solution.

Arm Loading

The load on the motor is based on the weight of the arm and the weight of the plastic being lifted. Future analysis will allow us to determine the actual weight distribution of the components and determine which motor should truly be sufficient. For our analysis, we will assume the weight of the jaws is relatively negligible, along with the mechanism that controls them, as use of hydraulics could make the portion of the mechanism that is actually mounted to the arm relatively light if using the right fluid. However, in order to make the assumption that we use hydraulics, we have to make sure that hydraulics can provide enough resistive force to prevent the slipping for the material.

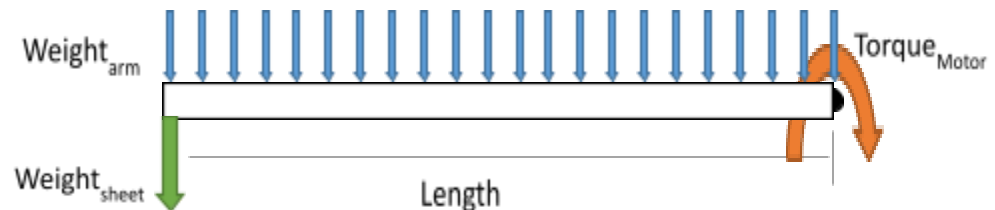
Assuming we use 4mm by 20in by 8in LDPE (our ideal size), if we reference the weight of 4mm by 48in by 1200in from Uline, which rates said roll at 6 lbs, we can determine the weight of the ideal sheet.

$$\frac{Weight_{sheet}}{Weight_{total}} = \frac{Volume_{sheet}}{Volume_{total}} \therefore Weight_{sheet} = \frac{4mm * 20in * 8in}{4mm * 48in * 1200in} * 6 lbs = .167lbs$$

To design with an adequate factor of safety, we will assume the jaw is put into a situation where its holding force must be equivalent to the weight of the entire sheet, which should be sufficient force to hold the bag during normal operation. If we assume the jaw is made of a similar plastic, such that its coefficient of friction was approximately .3, then this would imply that the force applied by the hydraulics must be:

$$N = \frac{f}{\mu} = \frac{.167lbs}{.3} = .55lbs$$

Applying a load of .55 lbs is easy with DC motors, and as such it is totally reasonable to expect that we could use a motor to resist any force applied by the sheet. For our lifting motor strength calculations, if we assume the weight of the arm is consistent throughout, we can use the following diagram to illustrate the situation:



From that diagram, if we assume the arm is made out of wood (per the sponsor's request), with a density of $23 \text{ lb/ft}^3 = .0133 \text{ lb/in}^3$, and we make the arm $1\text{in} \times 1\text{in} \times 4\text{in} = 4\text{in}^3$, we can find the approximate motor torque we need:

$$Torque_{motor} = \int_0^{Length} \frac{Weight_{arm}}{Length} * x * dx + Weight_{sheet} * Length = \int_0^4 \frac{4 * .0133}{4} * x * dx + .55 * 4 = 2.201 \text{ lb} * \text{in}$$

This is actually a pretty sizeable amount of torque required for a DC motor, as they typically range from .46 to 1.6. However, even the smallest motor could easily overcome this value with a gear ratio of 6, still maintaining a speed of 780 rpm which is far more than sufficient for our needs.

References

<http://www.tribology-abc.com/abc/cof.htm>

<https://www.uline.com/Product/Detail/S-11175/Plastic-Sheeting/Clear-Poly-Sheeting-4-Mil-3-x-100>

http://www.engineeringtoolbox.com/wood-density-d_40.html

<http://www.moog.com/literature/MCG/moc23series.pdf>

<http://www.tk560.com/vactable4.html>

Plastic Feeder

Project Introduction:

In the scope of this class, my team will be working on designing and building the automated packaging and sealing system for A-Leg-Up. The system will take process from rolling out the poly tube, cut them off with a fixed length, insert the cardboard holder together with the A-Leg-Up into the plastic bag and seal its 3 ends.

Individual Component:

My Individual component analysis is about the Feeding and Cutting of the plastic sheet. The plastic here is the single sheet plastic. The process using the single sheet plastic of feeding and cutting will take place of steps: Pull out the plastic sheet from the roll, lay it down on the flat surface (conveyor belt)

The result of the combination of all above 2 steps is a complete wide opened sheet of plastic and ready for the inserting products steps.

Analysis:

Apparatus:

_____ The plastic is sold and prepared as a roll. The one we decide to use is the Clear Poly Sheeting.

Dimension: W 3' x L 200'.

Weight: 7.61 Lbs.

Assume the thickness of the sheet is 0.02'.

The roll originally will be held on a roll dispenser (as shown on the picture). The dispenser has $r_{in} = 0.5'$

$$V_{\text{plastic roll}} = 3' \times 200' \times 0.02' = 12 \text{ in}^3$$

$$V_{\text{plastic roll}} = 3' \times \pi \times (r_{\text{plastic roll}}^2 - r_{\text{dispenser}}^2)$$

$$\Rightarrow r_{\text{plastic roll}} = 1.234 \text{ inch}$$

The radius of the plastic roll is 1.234 inch = 0.0313436 m.



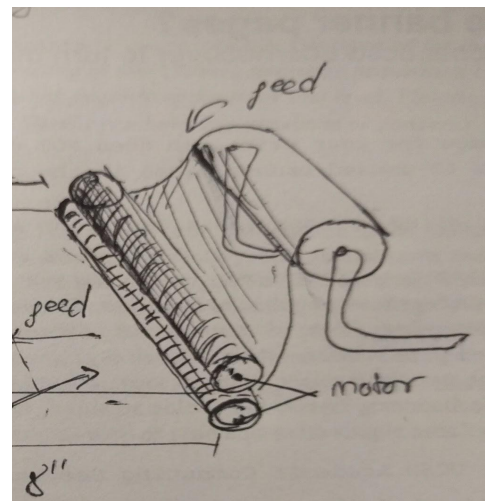
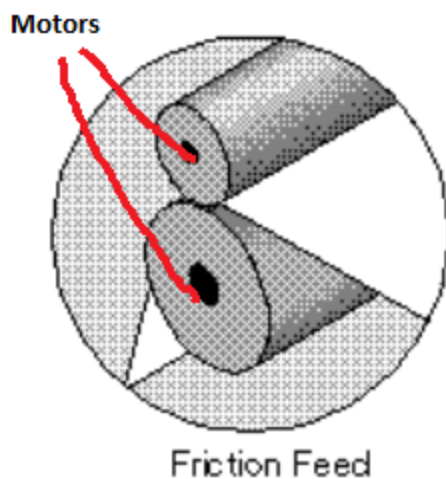
____Rollers are used as well in the transition step, either to provide the pulling to the plastic sheet or just control the direction of the plastic feeding.

The roller is made from Stainless steel 301 with dimension:

$$r_{\text{roller}} = 0.25 \text{ inch}, V_{\text{roller}} = 5.837 \times 10^{-5} \text{ m}^3, m = 0.46 \text{ kg}$$

Method 1: Friction feeding with 2 rollers:

The Plastic Sheet will be pulled out using friction feeding by 2 rollers: top and bottom. The rollers are coated with an adhesive(can be some sticky/high friction like the pro-grip sheet) layer to enhance friction. 2 motors are used to control the movement of 2 rollers and also control the amount plastic sheet has been pulled out. The plastic sheet is then pulled on a flat, horizontal surface, level with gaps between 2 rollers for 8 inches. The flat surface can be the conveyor belt.



We have: Torque = Inertia x angular acceleration

$$T = I * \alpha$$

$$\text{Where } I_{\text{plastic roll}} = \frac{1}{2} * \text{mass} * (r_{\text{out}}^2 + r_{\text{in}}^2) = 1.974 \times 10^{-3} \text{ kg.m}^2$$

$$I_{\text{roller}} = \text{mass} * r_{\text{roller}}^2 = 2.58064 \times 10^{-5} \text{ kg.m}^2$$

$$F = 2 * F_1 \Rightarrow T_{\text{roller}} = T_{\text{plastic roll}} / 2 * r_{\text{roller}} / r_{\text{plastic roll}}$$

Assume the angular acceleration of the plastic roll is 0.5 ft/s^2

Then the torque needed for the motors on the roller is $T_{\text{roller}} = 2.1875 \times 10^{-5} \text{ N.m}$

Due to the choice of the plastic sheet is to be decided hence the needed force for the choice of motor is still in queue but we do know the torque needed is $2.1875 \times 10^{-5} \text{ N.m}$

Pros: this method is not hard to do, the hardware needed is simple and inexpensive.

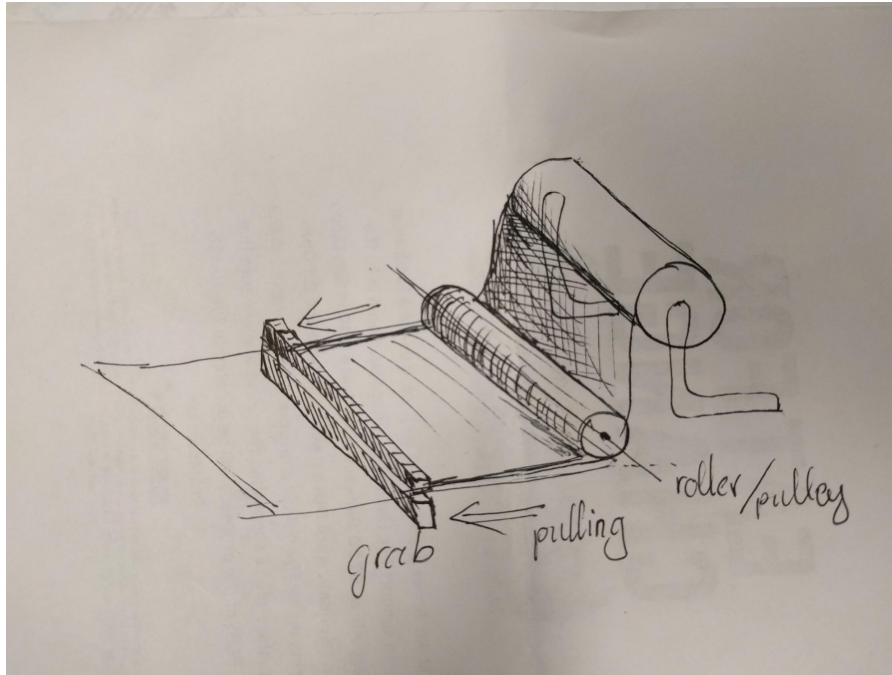
Cons: Every time we need to change the plastic sheet roll or start the system, we need an initial setup that is manually put the sheet between the rollers and attach its end to the arm (in the sealing and cutting part.)

Method 2: Using an arm to grab and pull the plastic sheet:

_____ In this method, the hardware is the same as method 1 but there is only 1 roller and it functions as a pulley only. The roller helps to direct the feeding direction to the same horizontal level as the flat surface. The pulling force is produced by the pulling grabbing arm.

Using the calculations from Method 1, due to the only pulling force in method 2 is from the grabbing arm, the required pulling force is:

$$F_{\text{pull}} = T/r_{\text{plastic roll}} = 0.022607\text{N}$$



Pros: The control only need to apply on the grabbing arm. The setup and hardware for the pulley/roller is much easier. The arm can be used as the same arm in the folding and cutting process. The roller does not need to be coated with adhesive layer.

Cons: The arm acts as the only pulling component, it does both pulling and folding actions, thus a stronger motors and more complicated control is needed for the motor applied on the grabbing arm.

Conclusion:

2 methods have proved their pros and cons themselves. Even the decision has not been made for the choice of the material but base on the cost benefit, easy to make and precision in operating, the most optimized design comes out to be the 2 rollers friction feeding and the single plastic sheet.

Heat Sealing

Overview

In this report, three different sealing methods will be analyzed for deeper understanding. Three common types of heat sealing that will be analyzed are impulse sealing, hot bar sealers, and continuous heat sealers. First, the analysis will state the functional requirements to keep in mind for the project. Afterwards, this analysis will cover the properties, possible benefits, possible complications, and the cost of each sealing method. In addition, the required ASTM standards to test the seals produced by the sealing methods will be provided. Finally, a decision will be made as to which sealing method meets the functional requirements of the project and is best fit for the project.

Analysis

Functional Requirements:

The packaging system must be mobile, low cost, and relatively easy to reassemble. This project is meant to be an intermediary step before the sponsor moves on to outsourcing the packaging process to a third party. Considering this, the sealing method chosen must be **low cost, mobile**, and create a 4 inch seal with **LDPE films**.

Method 1:

Impulse heat sealers, seen in **Figure A.1**, are a type of heat sealing based on heating for short period of times, only when current flows through the heater. Materials are held between the jaws of the sealer with pressure and friction during the sealing process. Typically, the sealer is made of one to two heating elements composed of nichrome placed between rubber and a release surface. The nichrome heats up when current runs through it, rising to a set temperature, applying heat to the material placed between the jaws of the sealer. The actual sealing occurs due to the materials melting, and then cooling together when the heat is removed.

Method 2:

Hot bar sealers, seen in **Figure A.2**, are a type of heat sealing similar to impulse sealers. Instead of drawing power for a small time period, hot bar sealers continuously draw power and are temperature controlled. Hot bar sealers are composed of, as the name suggests, one or more hot bars that make contact with the materials, causing them to heat up and melt together.

Method 3:

Continuous heat sealers, otherwise known as Band type heat sealers, are significantly different from the two previous mentioned sealing methods. Continuous heat sealers, seen in **Figure A.3**, utilize conveyor belt systems with hot and cold regions to heat and cool the material placed between the two belts. The hot and cold regions are created using a heated jaw pair and a cooled jaw pair.

Table 1: Heat Sealing Comparison:

Type	Pros	Cons	Cost Estimate
Impulse	- Low energy cost - Specifically good for PE and PP - Fast sealing process - Mobile - No warm up time	- Requires maintenance and part replacement often - Has one set length of seal	Initial Cost: \$215 Replacement parts cost: \$18
Hot Bar	- Variable temperature control - High life expectancy - All thermoplastic films can be used - Very good for thicker films - Mobile	- High energy cost - Has one set length of seal - Significant warm up time	Initial Cost: \$277.50 Replacement parts cost: \$18
Continuous (Band)	- All thermoplastic films can be used - Can create seals of varying lengths - Fastest sealing process - Fast warm up time	- High energy cost - Requires part replacement due to moving belts - Not mobile	Initial Cost: \$675 Replacement parts cost: \$65

Lastly, seals created by heat sealing can be tested as noted in **Table 2**.

Table 2: ASTM Standards

Standards	Description
F88	Seal Strength
F1886	Visual Inspection of Seal

Conclusion

Based on this analysis, impulse heat sealing seems to be the best fit for the project. The continuous heat sealer goes far beyond the specifications in terms of sealing, but does not meet all the functional requirements. The hot bar sealer meets the functional requirements, but the constant power consumption makes it an inefficient choice for the project when compared to the impulse heat sealer, which is fast on start up, mobile, and low-cost. Considering the use of this project is temporary, complications and maintenance to the impulse heat sealer is relatively insignificant.

References

- <http://www.innovativetechnologyconferences.com/files/public/Gates.%20Jan2013.pdf>
- <http://www.toss-gmbh.de/en/industrial-products/general-notes/thermal-impulse-sealing.html>
- <http://www.sealersales.com/faqs>
- <http://www.sealersales.com/bandsealers>
- <http://www.sealersales.com/directheatsealers>
- https://www.uline.com/BL_2254/Tabletop-Poly-Bag-Sealer-Impulse-with-Cutter

Appendix

Figure A.1: Impulse Heat sealer with cutter. Image taken from Uline

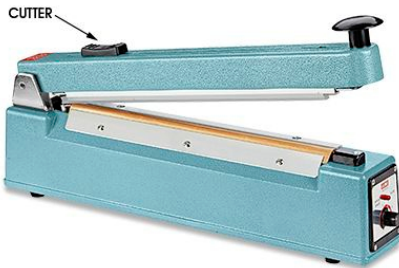


Figure A.2: Hot bar sealer. Image taken from Sealer Sales



Figure A.3: Band type heat sealer. Image taken from Sealer Sales



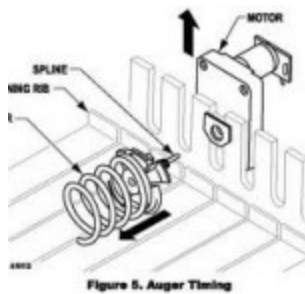
Product Dispenser

Overview

This report will analyze several different dispensing mechanisms to feed the A-Leg-Up as well as its cardboard backing to the packaging step in the system. The dispenser should be able to hold 20-30 units at a single time as per request of the sponsor. It should be able to dispense one unit at a time and send it to be packaged and only dispense another unit once the prior unit is complete. To avoid complexity of two separate dispensers, both the A-Leg-Up and cardboard backing will be stocked and dispensed together. Factors that will be taken into consideration in this analysis are ease of use to restock, cost of component, dispensing time, and reliability.

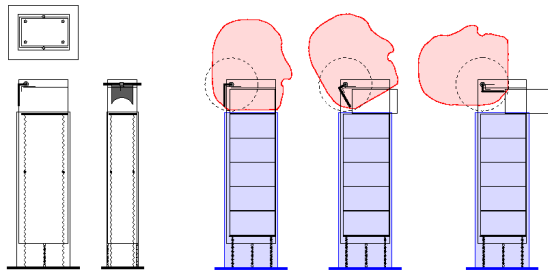
Analysis

Method 1: Vending Machine Style



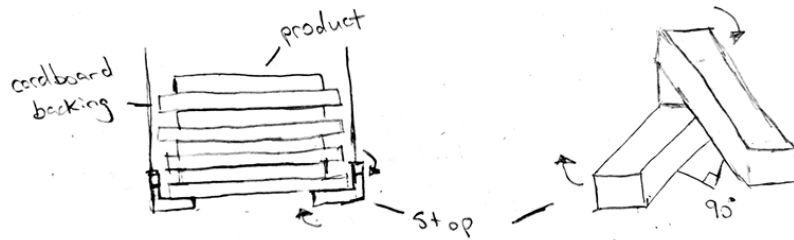
The vending machine style dispenser uses a large rotating coil to move units towards the end of the coil. The rotating coil acts as a guide for the product, pushing it towards the end as it rotates since the product moves upwards along the coil. The spacing in the coil acts as holding slots where each product may be inserted.

Method 2: Magazine Style



The magazine style dispenser works by stacking units against a compressed spring. When the magazine is fully loaded, the spring is fully compressed. The units in the magazine are held down by a stop so the spring will not decompress and release all the units. Units can be dispensed one at a time from the top the stack by releasing the lock and sliding one out while holding the rest in place. Once a unit is removed, the spring pushes the stack up to the stopper, ready to repeat the process.

Method 3: Lock-Release Style



The lock-release style dispenser works similar to that of the magazine, however it uses gravity to release a single unit at a time instead of a compressed spring. The product is stacked into a column of 25-30 units. 2 levers on the bottom, at each end of the A-Leg-Up, locks the stack in place, keeping it from falling. To dispense a unit, the lever turns 90 degrees to release the unit nearest to the bottom. Simultaneously another lever, that was 90 degrees to the original, turns to lock the rest of the stack. Once dispensed, the levers turn back, dropping the stack down to fill the gap and the process is repeated.

	Pros	Cons	Cost Estimate
Vending Machine	- Each unit has its own holder - Can dispense one unit with ease	- May need to make custom coil to hold A-Leg-Up - May be difficult to hold A-Leg-Up and its cardboard backing together - Slow dispensing time	- Coil: \$40 - Motor: \$20 - Casing: \$40
Magazine	- Easy to reload - Can stack A-Leg-Up with cardboard backing - Fast dispensing time	- May be difficult to dispense one unit at a time - Custom spring that is 15" long	- Spring: \$85 - Motor: \$20 - Casing: \$40
Lock-Release	- Easy to reload - Can stack A-Leg-Up with cardboard backing - Gravity powered, less complex - Fast dispensing time	- Lever stop needs to be well timed to prevent all units from falling out	- Motors (2) : \$40 - Casing: \$40

Conclusion

Based on the analysis, the lock-release method is the best option for a dispensing mechanism. It meets all the requirements as far as dispensing the A-Leg-Up with its cardboard backing with ease and being relatively easy to restock. It is the least complex of the 3 options since it does

not require custom manufactured parts such as springs or coils. The lever can be 3D-printed making it easy to manufacture. In addition, this method produced the lowest cost estimate.

References

- http://www.ebay.com/itm/ANTARES-COMBO-VENDING-MACHINE-2-LARGE-COILS-12-Count-Free-Ship/131457534013?_trksid=p2047675.c100005.m1851&_trkparms=aid%3D222007%26algo%3DSIC.MBE%26ao%3D2%26asc%3D40130%26meid%3D8d7251b693c9462ca77e598bd3b83168%26pid%3D100005%26rk%3D1%26rkt%3D6%26sd%3D132008294902
- <https://www.thespringstore.com/pc468-4156-15-30-ot-16-000-cg-n-in.html>
- <http://www.robotshop.com/en/cytron-12v-17rpm-1944oz-in-spur-gearmotor.html>