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# ArcWorks Straw Cutting Device & Process Improvement

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## ABSTRACT

The primary goal of the ArcWorks Straw Cutting Device project was to design, build, and deliver a functional straw cutting device to ArcWorks which will be able to cut multiple PPCO straws to desired lengths with minimal deformation and burring. The device will have to follow ISO 9001 guidelines, along with complying with OSHA standards. These straws are used within an assembly process at the ArcWorks facility which provides wash bottle assemblies for customers like Thermo Fisher and Nalgene.

The current process at ArcWorks utilizes one automated machine along with a manual process to cut the raw material straws to the appropriate lengths. With the addition of our automated machine an increase in overall productivity at ArcWorks within their wash bottle assembly process will be seen. The inventory levels held within the facility will be able to be reduced because of the increase in productivity. In this paper, the design, manufacturer, testing processes, process improvement opportunities and results will be described in detail.


## NOMENCLATURE

PPCO- Polypropylene copolymer
Scrap Door/ Trap Door- System used to release the cut straws into a bin beneath the table. Part of the height adjustment system.
THATD- Two Handed Anti-Tie Down switch. This was used in our pneumatic actuation system. It will only allow for the system to be actuated if both buttons are depressed at the same time.
OSHA-Occupational Safety and Health Administration
ISO 9001- Quality management standards.
WMS-Warehouse Management System
ERP-Enterprise Resource Planning

## INTRODUCTION & BACKGROUND

Our sponsor ArcWorks, which is a subsidiary of Arc of Monroe County, specializes in subcontract manufacturing services. One of their manufacturing processes is to cut plastic PPCO straws to nine specified lengths.

To accomplish this task of cutting the straws to their specified lengths an automated device is used which cuts up to 10 straws at a time. The automated process currently has some issues with producing a through cut on all 10 straws due to the blades which are currently used. This problem results in the operator initiating the cutting process multiple times to receive an acceptable cut. This repetitive cutting actuation process reduces the throughput capability of the automated machine.

The loading of the machine also takes up a significant amount of time. ArcWorks employs associates who have a wide range of developmental disabilities so any new process or machine will need to be designed to take this into account. Past Multidisciplinary Senior Design teams have worked on projects at ArcWorks in the past on similar processes with varying degrees of success.

**DESIGN PROCESS:**

The design processes began with our team observing the current process utilized at ArcWorks. Through this observation and conversations with ArcWork's representatives their customer needs and requirements were identified.

**Customer Needs:**

- Increase Productivity
- Safety of Machine
- Minimize Physical Exertion
- Reduce Downtime
- Complete through cut of straws on first actuation.
- No deformation of cut straws.
- Straws lie within Tolerance of desired length.
- Minimal debris left in work area
- Inexpensive replacement parts
- Utilize cost effect blades.
- Machine fits on standard table

Once these needs were identified, a set of specifications were created. Most of these specifications identified the current state of the process along with determining a set of future state goals which our proposed machine should be able to meet.

In order to meet all of the desired needs and specs desired by ArcWorks, the proposed Straw Cutting Device had to be composed of multiple systems. These systems would need to interface seamlessly to create the end product (cut straws) required by the downstream assembly processes.

**Systems Identified:**

- Straw Cutting (Blade)
- Pneumatic System
- Safety System
- Straw Loading
- Length Adjustment
- Trap Door
- Frame/ Base
- Debris Removal

**Development:**

Multiple prototypes were designed to utilize a wide range of ideas for completing the task of cutting the straws. Ultimately the chosen design was the most straightforward to manufacture and the most reliable when in operation. The design that was chosen uses a simple carriage system mounted on two parallel shafts. This carriage system moves the blade horizontally through its cutting stroke in a straight back and forth motion.

**Mechanical Design Overview:**

The final design of the machine integrates a number of features both for purposes of safety and functionality. The list of design features, in its entirety, will be omitted for the sake of brevity. However some of the fundamental design considerations and features, will be discussed.

The primary objective in designing the machine was to develop a slide system intended to guide a blade along one vector. This task was accomplished by pairing two linear bearings together on two separate precision linear shafts. These were both sized appropriately for the forces that they would be experiencing.

A carriage was designed to tie our chosen pneumatic cylinder into the sliding assembly. It as serve as a mount for the cutting blade. This carriage was designed to hold the blade at a 45° angle, for optimum utilization of the razor's cutting properties. The carriage uses only two blade mounting screws to allow for quick blade changes.

In order for the cutting blade to be effective, a plate needed to be integrated into the machine as a counter-sheer. This plate was designed with twelve straw holes, in an attempt to increase output. These twelve holes were aligned such that a maximum area of the blade was utilized, and also so that the blade is initiating just one cut at a time. This maximizes the blade's potential, and also ensures that a sufficient amount of force is being applied to the cutting edge. The plate can be seen below in *Figure 1*.

***Figure 1 - Straw Insertion Plate***

**Straw Cutting Blade:**

All of the systems are essential for the machine to meet the requirements. Keeping in mind that the finished product from the device is to produce cut straws, it was essential to focus on the actual cutting system from the start.

As mentioned earlier, the current cutting process was not nearly as efficient as it could be. One of the first noticeable deficiencies in the process was the blade being used. ArcWorks had been utilizing a blade that was comprised of two standard razor blades. These blades were then sent out to be modified to fit into the blade mount that ArcWorks used. This blade configuration also seemed to wear down fairly quickly, requiring replacement nearly every 2-3 weeks. In the picture below, wear marks are evident from where the blade comes in contact with the straws.

*Figure 2 - Current Machine Blade Setup*

The final razor blade design which was decided upon (shown in *Figure 3)* is thicker and longer in overall length than the current razor blades. This means that only one blade is needed to be replaced at a time. This results in shorter downtime. Additionally, the new blades are made from stronger steel. These will withstand the wear of everyday use significantly better than the current machine's razor blades.

A concept of using lathe parting tools was also proposed. The tools would with an edge that was ground to razor sharpness by the precision grinder in the machine shop. Since they are made from high speed tool steel, they would have excellent edge retention. Due to time constraints, the difficulty for ArcWorks to re-sharpen dull blades, and creating new blades if necessary, the idea was discarded. The readily available and easily replaceable longer razor blades were chosen for use in the final design.

*Figure 3 - New Blade used in developed Device*

**Pneumatic System - Design:**

Originally the pneumatic system had three separate types of designs. One was purely pneumatic and the other two were a merging of electrical and pneumatic systems. It was decided, during the course of the first quarter, that a microcontroller would be used to control the electrical system. The following schematic in *Figure 4* shows this "final" design.

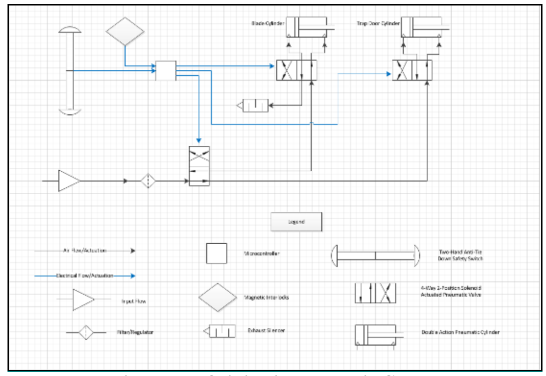

*Figure 4 - Original Pneumatic System*

After thorough consultation, it was decided that a fully pneumatic system would simplify things greatly. Debugging pneumatic switches is easier than determining voltages and current flow, parts are easier to replace, and no amount of programming would be necessary. The following is the schematic of the final pneumatic system.

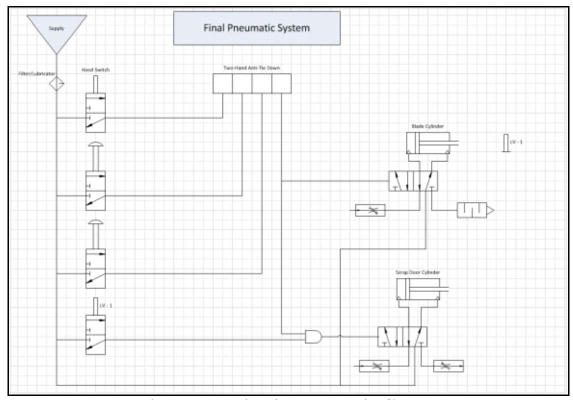


*Figure 5 - Final Pneumatic System*

**Pneumatic System - How It Works:**

A mechanical switch is placed by the lid. When the lid is closed, the pneumatic system becomes active. A two-handed button system, also known as the two-hand anti-tie down (THATD) actuates the blade cylinder. The blade cylinder pushes the blade carriage across the cutting plane and cuts the straws. The blade carriage is attached to a shoulder bolt which hits a mechanical switch. The switch actuates the scrap door, which releases the cut straws. When the buttons are released, everything returns to its original state. A 300 pound-force cylinder was chosen to cut the straws. It only takes about 60 pounds of force (found through testing) to cut an individual straw. One and a half straws are cut through at a time, however, a factor of safety of 5x was applied. The 300 pound-force cylinder was the smallest cylinder which was within these constraints. Seen below in *Figure 6*.

*Figure 6 - Cylinder to Actuate Cutting Blade Carriage*

**Pneumatic System - Safety:**

As mentioned above, certain levels of tamper resistance were embedded into the system to provide the highest level of safety for the customer. The mechanical switch in the lid is one method of prevention. If the lid is opened, the system will not function; all cylinders will stop immediately. The THATD buttons shown in *Figure 7* must be pressed simultaneously and for the duration of the operations cycle. If the THATD is released this will immediately return everything to its "home state"; the blade will be withdrawn and the scrap door will return. Additional precautions involve the lid and plastic enclosures, which prevent cut scrap from flying around, as well as operator's hands from reaching in.

*Figure 7 - Two Handed Anti-Tie Down Setup*

**Hardware Implemented**:

Pictured in *Figure 8* is the quick connection which the device will use to hook up to the air supply. In *Figure 9* the filter and regulator are pictured.

*Figure 8 - Quick Connection*

*Figure 9 - Filter and Regulator Setup*

**Trap Door:**

The Trap Door works in conjunction with the length adjustment function outlined below. It essentially consists of the plate that the straws sit on once they are manually loaded into the machine. This trap door will be actuated when the carriage goes through a full forward range of travel, and the shoulder bolt attached to the carriage compresses the switch located on the opposite side support. Once this switch is hit, the straws will fall down into a collection bin, located under the table. The table will have a hole located directly underneath this area to allow for material collection.

**Length Adjustment:**

The device had to have the capability to produce straws of nine different specified lengths. This is an important functionality which ArcWorks requires due to the range in sizes of the wash bottles assemblies that these straws are used in. To accomplish this task, a system was designed that allows the operator or supervisor to simply unscrew a bolt, slide the trap door assembly up or down to the desired straw length setting, and screw the bolt into the appropriate one of nine graduated tapped holes.

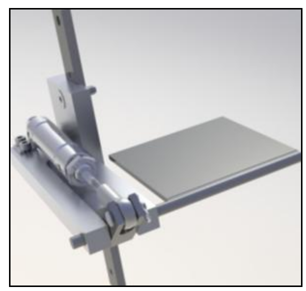

*Figure 10 - Length Adjustment*

**Length Adjustment Backup Plan**

A Delrin plastic block design was also constructed as a backup, if the length adjustment was unable to operate effectively. This would not be ideal for ArcWorks, but it would still allow for the machine to have adjustability for different length straws.

*Figure 11 - Backup Block design used if mechanical length adjustment does not work*

**Machining Methodology:**
The manufacturing process for this project was fairly straightforward. The first parts to be machined were the aluminum side supports, from which the cutting plate, blade carriage, and cutting cylinder are attached. Once the main geometry was machined, the side supports were changed as the design evolved during fabrication, (i.e. bolt hole modifications, and various attachment point additions).

The steel blade carriage was the next component to be manufactured. The blade carriage is made from three separate pieces of steel, which are joined together by welds along their joints. A pre-cut aluminum frame was ordered from mK technologies. They designed and fabricated a frame based on our general design and dimensional specifications. The cutting plate (which holds the straws) and the vacuum attachment piece were created by The Brinkman Lab via their CNC mills and fused deposition modeling rapid prototyping machines, respectively. The acrylic safety shield was fabricated last due to its simplicity and to allow custom fitting to the final dimensions of the machine.

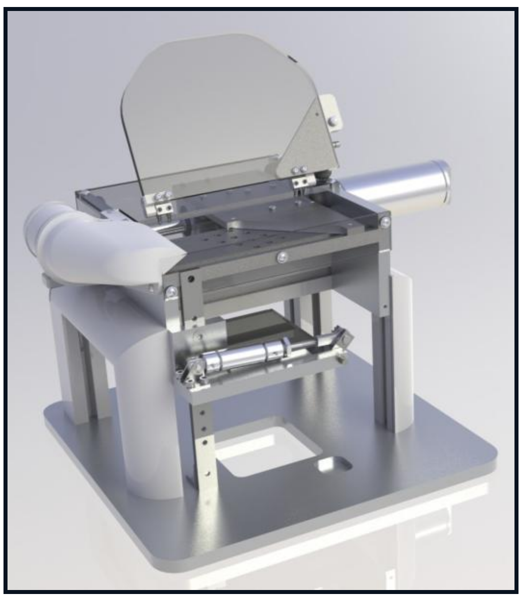

*Figure 12 – Final Design Rendering*

**Straw Loading:**
Originally it was intended for the operators to load the straws into the machine with the use of a cartridge system. These cartridges would be pre-loaded by another operator. This idea could still be perused as an add-on to this project, but due to time constraints and the priority of producing a functional machine, the cartridge loading system was unable to be implemented.

**Debris Removal:**
A vacuum attachment shown in *Figure 13* was designed to be placed on the device to allow for the scrap plastic pieces to be removed after the cut has been made. This attachment was created in the Brinkman lab using the rapid prototype machine.

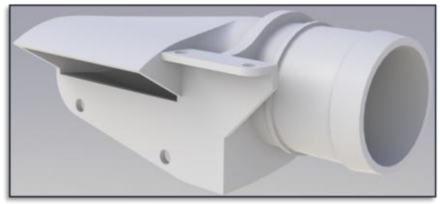

*Figure 13 - Vacuum Attachment*

**PROCESS IMPROVEMENT**

**Efficiency and Throughput**
The process currently in place at ArcWorks provided many areas for improvement opportunities. Many of the 7 forms of waste (transportation, inventory, motion, waiting, overproduction, over processing, and defects were identified. Much of this waste can be eliminated through the implementation of the new proposed Straw Cutting Device. Currently, operators working on the automated machine at ArcWorks are capable of cutting around 700 straws/ hr. on an average day. This is assuming that with one actuation, 10 straws will be cut. With the new proposed machine, 12 straws could be cut in one actuation. With this added capability, along with a reduced load time, efficiency should increase to around 1000 straws/ hr. ArcWorks plans on using both machines in conjunction with each other in the future. This would mean that the throughput potential from using the two separate machines would equal to more than double the current production capability.

A major loss of efficiency is seen when the operator chooses to actuate the system multiple times to make sure all of the straws have been cut. With the new design, the need to actuate the system multiple times should be eliminated. The operators who would be assigned to this station would be highly functional individuals, but it still might be difficult to retrain them to understand that it is no longer needed to actuate the system multiple times.

**Inventory Reduction**
With the predicted increase in production and throughput, the need for excessive inventory will be reduced. Currently 50,000 straws / length are required to be on hand in the warehouse. A box is comprised of 5,000 straws. Ten boxes per length is a significant amount of space required in inventory. Due to the fact that there are no forecasts or ERP systems in place (For when the inventory falls below this level) a production signal is sent to the floor to produce more

straws of the designated length. With the added capability to produce more straws in a shorter amount of time, the requirements for 50,000 straws on hand will no longer be necessary. A figure closer to 20,000 straws or 4 boxes / length will be more than adequate for the new process.

**Warehouse Management**

The reduction of inventory will improve the process at ArcWorks, but, in order for this change to be fully effective, the warehouse needs to have some sort of order to it. Currently there is no warehouse management system and only a few warehouse workers actually know the exact location of particular items within storage. The implementation of a "Warehouse Management System" (WMS) had been discussed in the past, but had never been implemented. A system to track the location of specific items would help the overall efficiency in the system. This implementation is out of the range of our project, but the beginning stages of a WMS could be implemented. An initial step could include labeling designated areas for the specified straw length boxes instead of having the randomized storage.

**Layout Considerations:**

In the beginning the layout and flow of material within the assembly area was observed (*Figure 14*). It was clear that a significant amount of material was traveling back and forth between the storage warehouse and the assembly floor. A U-shaped cellular layout would improve on the material flow within the closure assembly process (*Figure 15*).

This layout was designed to be relocated anywhere within the facility. This is important because our contacts at ArcWorks informed us that they were going to receiving some new products. These would require different machinery and layout of the area in which the current straw cutting and closure assembly would take place.

**Current State Layout:**

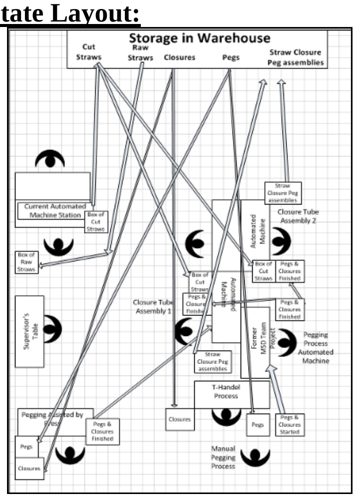


***Figure 14 Current State Layout and Flow***

**Generic Cellular Layout:**

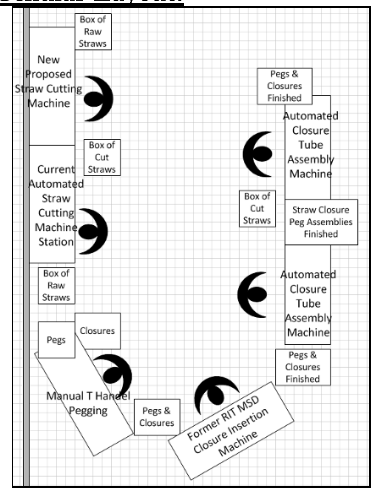


***Figure 15 Possible Cellular Layout***

**Process Capability:**

To get a baseline figure for the current process capability, a variety of cut straws were measured. A capability analysis was completed using the known length tolerance of +/-.02 in. With this figure it was determined that the process was out of control. With further clarification, it was determined that the actual tolerance was +/-.2 in. This made a major difference in our findings. The current process was more than well within the ranges of being a 6 sigma capable process. Going forward, we would have to design our current machine to uphold the same quality standards.

**New Razor Blade Utilization in Old Machine:**

An area for improvement which was not originally identified, was the implementation of the new razor blade option into the old automated cutting machine. The size of the blade is roughly the same as the current standard two-blade mock up. The blade mount on the current machine utilizes a recessed area for the blade to sit that is 4 inches in length. Our new Razor blade option is 4 ½ inches long, so either the blade mount could be modified to accept the new blade, or another shorter blade could be acquired to fit within the current mount.

## RESULTS AND DISCUSSION

Preliminary cutting tests were completed which showed a significant amount of deformation on the cut edge of the straw. The process and setup of the machine was analyzed and it was determined that the carriage was setup in a way which was not completely square. Once this was fixed, more acceptable straight straw cuts were seen, but it seemed as though improvements still needed to be made. Burring was also still an issue and at this point ArcWorks was contacted to get their opinion on whether or not the cut quality was acceptable. The burring which was seen along with the cut which was not fully straight in some instances did not allow Arc Works to accept the cuts which were produced.

In trying to troubleshoot the issue, a theory was developed regarding the blade thickness and design as a potential cause of failure. The theory went as follows: After initiating the cut, the thickness of the blade was causing the portions of the straw above and below the blade to separate not as a result of being severed by the cutting edge, but by being pulled apart by the beveled surfaces. In other words- once the blade cut deep enough that the straw could no longer elastically deform around the bevel of the blade, the straw would fracture, resulting in an unacceptable finish.

A cutting test was performed using the aid of a high speed camera in order to verify this theory. The videos and pictures which were gained from this procedure did indeed show that the straw material was prematurely tearing ahead of the cutting edge. This is the major reason why the quality of the cuts was not acceptable. This test proved that the thickness of the blade which is currently being used on the device is too thick.

The video also showed definitively that the straws were deflecting in the holes. The high speed camera showed that the straws would spin prior to the cut being completed. This rotational motion was produced from the blade hitting the one side of the straw wall before the other. Another consideration is that the blade is currently not sitting completely flush within the mounting plate

Another issue we were seeing was in regard to the length tolerance. We noticed that the straws at the beginning of the cutting cycle were considerably shorter than the last straws cut- somewhere in the neighborhood of a 0.1 inch difference. We deduced that the blade thickness and double bevel on the blade were the cause of this. Once the blade started to travel through the straw, the bottom bevel would cause the blade to push its way vertically since the straws were constrained on the bottom. This meant that each straw it reached would see a cut starting slightly higher than the previous straw's cut, resulting in a gradual step up in straw length. In order to address this issue, we placed a mouse pad on the surface the straws were resting on in order to absorb the deflection and eliminate the variance. This virtually eliminated the issue.

## CONCLUSIONS AND RECOMMENDATIONS

The device is able to cut all of the 12 straws. However the quality of the cuts which are produced are not to an acceptable quality level. It is a credit to the team which had no experience with designing cutting machines in past to come up with a design which is functional. There is room for improvement and possibly an opportunity for future senior design team to take a look at the work which is already complete to determine how the quality of the cut could be increased.

One area of the machine which was not fully functional due to the time constraint and setbacks seen within the group was the height adjustment and trap door system. Due to the size constraint within our machine and the size requirements of the design, difficulty was encountered. Significant amounts of re-designs were required and the time constraint within MSD did not allow for enough time to trouble shoot these designs. In the future more time in the beginning stages of the design should have been allocated to the height adjustment and trap door system. Another resource on the team would have helped in this respect.

**<u>Future Work:</u>**

The Straw Cutting Device project at ArcWorks provides another opportunity for an MSD team to take on a challenge and potentially redesign some components within the system. Ideally a height adjustment and trap door which is fully automated should be utilized. A significant amount of design work was needed for several of the crucial systems within our design and, resources within the team were stretched thin. Future work at Arc Works could pick up from where this project had left off to make adjustments to the system infrastructure which is already in place.

To enhance the productivity and efficiency of the process a cartridge loading device could also be used. This will reduce the amount of time within the process to load the straws into the machine. This idea was originally going to be implemented into our design but due to time constraints and other crucial systems within the system requiring more time to develop, the adequate amount of time to design and build a cartridge loading system was not possible.

## ACKNOWLEDGMENTS

We just want to take this opportunity to thank ArcWorks for their cooperation with this project. We specifically want to thank Wayne Geith for his help and contribution to our team. We would like to thank Dr. Matthew Marshall for his guidance through this MSD process. Special thanks to Roessel with all their help with our pneumatic design and mK Technologies for their extruded aluminum design. We would also like to thank Laird Plastics for their generous donation of Delrin scrap, and The Brinkman Lab for manufacturing several of our essential parts.