

METHOD OF SEED SINGULATION CONCEPT AND TESTING

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ABEN 486/487
Senior Design Project

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May, 2011

ABSTRACT

This project involves the process of designing, developing, and testing the feasibility of an apparatus used to singulate the placement of seeds in a furrow during a planting operation. The equipment incorporated is a linear electronic solenoid that has benefits not capable with current seed metering devices. The design uses a vacuum to assist the electronic solenoid in the movement of each seed kernel. Through developmental stages the apparatus was milled from polyethylene plastic.

Initially the idea was using an electronic solenoid to move a plunger back and forth incorporating both positive and negative air pressure. A new design was modeled using two seed cutouts and gravity to feed the unit. Another was modeled utilizing a double hopper design and two solenoids. Later, a third design was reiterated from the original style using only vacuum. This prototype gives insight of what is possible in the future of seed singulation.

ACKNOWLEDGEMENTS

The team would like to thank Peter Christianson, the collaborator from Titan Machinery, for his guidance, reliability and patience during this project. The group would like to thank him for portraying his knowledge of prototyping and the business aspect for project completion. They would also like to thank him for personally funding this project.

The group would also like to thank Dr. Ganesh Bora, for giving Mr. Christianson the opportunity to come into the class to present this project. Dr. Bora has given the group excellent guidance and has been a useful resource in the ongoing project. The group would also like to thank Dr. Bon for giving us the knowledge in engineering while pursuing our Agricultural Engineering degrees, to successfully complete this project.

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1.0 INTRODUCTION

The senior design project was intended for the group to complete the design of the system, component, or process to meet desired needs in an agricultural system, biomaterials system, or environmental system problem. This report will incorporate necessary engineering, biological, and/or biosystems information using the skills acquired through the engineering courses taken by the students in their engineering curriculum. The requirements are a written report, participating in the Agricultural Technology Expo and an oral presentation. Given the four group members' interests and background in agriculture, the group elected to undertake the seed singulation project because of their knowledge of planting applications and hands on knowledge from being raised on a farm. The group feels the challenges of this project fit their capabilities and would put the uses of their knowledge in engineering to the test.

1.1 Problem Statement

The current methods for seed singulation in row planting equipment is accomplished with a variety of mechanically driven devices, typically driven by a wheel in contact with the ground or hydraulic motors. Providing mechanical power to drive seed metering devices through these methods is a cost effective and reliable solution. It does not allow accurate population counts at a

single row unit level. It does, however, provide accurate population counts over the entire swath of an implement, averaging the population counts of each row unit. Mechanically driven metering devices are also difficult to drive on a per row basis.

The typical method of driving the metering devices is by the use of a common drive shaft powered by a ground driven wheel, varying metering rates in relation to the implements ground speed. Planters could also use a hydraulic motor which controls metering rates by varying the flow rate provided to the motor. Hydraulically driven metering allows the operator to apply seed throughout the field at varying application rates, allowing higher seed rates to be applied in higher yielding portions of the field and vice versa. This variable rate can only be applied to a section of row units and cannot be controlled at each row unit itself. The size of a set of row units is typically around eight row wide sections, meaning that all eight row units must be either on or off and must be planting at the same population rate across the section. It is possible to turn each row unit on or off, but this requires a clutching system at each row. This allows any row to be shut off as desired, but the system to do so is mechanically complicated and expensive. Therefore, this system is rarely present in most planting implement.

A further drawback of the mechanical metering devices is the bulkiness of the system. With such a large space required to accommodate the metering devices, they must be mounted above the actual planting components of the row unit. The seed is then transferred to the furrow created by the opening discs, via a long seed tube. While the seed transitions from the metering device to the furrow through this seed tube, variability in the seed spacing can occur. This variability occurs from bouncing of the seeds and vibrations that are induced on the row unit as it travels through the field. The row unit may hit large clumps of dirt, rocks, or fall into potholes causing a single seed falling through the tube to shift position relative to the other seed traveling through the tube. This variability of seed placement increases as the ground speed of the

planting implement increases, placing a limit on how fast a field can be sowed. The maximum planting speed is defined by a trade-off between productivity of the planting operation and the accuracy of the seed population rate.

The final drawback of the mechanically driven system is the lack of communication of seed placement between row units on an implement. On current metering designs, the system has control over only the seeding population, but not the actual timing and placement of the seed. This means a seed is dropping into the furrow at a constant rate, but the row unit cannot detect the time and place where a seed is being placed relative to its neighboring row units.

Considering an idealistic application, a desired seed spacing of 4 inches; the system would start by placing a seed in a furrow, then the implement would then travel an additional 2 inches and the neighboring row units would each place their seed in the furrow, forming a completely staggered pattern between each row. Currently, this type of seed placement is not obtainable with common mechanically driven metering devices.

Electronically controlled seed singulation devices can address many of the inefficiencies experienced in a mechanically driven seed metering device and have the potential to increase productivity and yield rates dramatically.

2.0 LITERATURE REVIEW

Precision planters differ from other seeding machines in that they have single seed metering devices. According to Hunt (2001), these mechanisms must be able to select as many

as 5000 seeds per minute that are of variable size and shape without causing damage to the seeds that would prevent germination.

Precision planters are designed to provide accurate placement of single seeds at uniform intervals within rows. Most precision planters included seed plates for metering seeds up until the mid-1960s, when plate-less planters were developed, and now, there are several mechanisms available for metering seed.

According to Srivastava et al. (2006), the horizontal seed plate planter was the most popular precision planter until the mid-1960s. In this type of planter, the seed plates contained cells designed to hold single seeds. As the plate rotated in the bottom of the seed hopper, seeds would fill these cells. Excess seeds would be removed by the use of a brush or scraper. The seed would be forced out of the cell by a spring-loaded knockout as each cell passed over the seed tube. Several seed plates were available for different types of seeds.

The finger pickup planter was introduced in the late 1960s and was the first plate-less planter to be widely used. In this type of planter, the metering device uses several spring-loaded fingers that are mounted on a vertical disk. This disk then rotates in a seed hopper and as each finger passes through the bottom of the seed hopper, it picks several seeds. Each finger then passes over an indentation which causes them to collect only a single seed as the rest are transferred back into the seed hopper. The finger then passes across an opening where the seed is dropped onto a transfer belt and transported to the seed tube (Srivastava et al., 2006).

The air planter was the next major innovation in precision planting. This type of planter uses a ground driven seed drum that is pressurized by a fan. Seeds are gravity fed into the drum from a central hopper. The drum has several rows of perforated holes, and as the drum rotates, seeds are held in the perforated holes by differential pressure. When the seeds come near the

seed tubes, the differential pressure is removed and the seeds fall through the seed tubes where they are carried to the planting units by escaping air (Srivastava et al., 2006).

The next innovation was the pressure disk planter which differs from the air planter in that it has separate seed hopper for each row. Seeds are gravity fed from the hopper to the metering device where they are held in place by differential pressure. As a cell approaches the seed tube, the air supply is cut off and the seed falls down the tube. Vacuum-disk metering works similarly. The only difference is that the pressure differential is supplied by creating a vacuum on one side of the disk (Srivastava et al., 2006).

Planters that meter individual seeds provide the most precise control of seeding rates, however, according to Hunt (2001), field tests of planters show substantial variability of seed spacing in a row. This variability can be attributed to several factors. Some cells in a seed meter may fail to fill or may contain more than one seed due to variation in individual seed size. Also, in ground driven metering devices, wheel slippage can affect the seeding rate.

Several studies have been performed on the performance of row-crop planters, as well as new devices for improving single seed selection. Previous experimenters studying vacuum planters have used several kinds of seed pickup elements, such as nozzles, drum perforations, vacuum plate, and suction ports on a wheel periphery (Persson and Sial, 1984). In studying the design of vacuum nozzles, Sial and Persson (1984) found that air pressure required for seed pickup should increase with the fourth power of the pickup height, nozzles with an entrance cone were least sensitive to changes in pickup height, and pickup of more than one seed per nozzle occurred much more frequently if the pickup height was less than one seed diameter.

Halderson (1983) evaluated four commercial row crop planter units for their seed metering ability in selecting single edible bean seed and how the seed was spaced in the furrow.

The testing was done using five varieties of ungraded edible bean seed. From his research, Halderson (1983) found that (a) none of the planters examined could maintain seed selection accuracy within 5% with ungraded edible beans as planting speeds were varied from 1.6 to 8.0 km/h, (b) all planters could achieve 95% accuracy under certain conditions – primarily low speed, (c) as planting speed increased, accuracy tended to decrease, and (d) precision of seed spacing in the furrow could best be described as random under the conditions of these tests, although there were differences between machines.

3.0 PROJECT RATIONALE

Mechanically driven seed metering devices currently perform their function efficiently and are a good solution to the problem of metering rates as seed is planted, but there are many shortcomings and voids that could be filled with a substantial change to the metering process. A

proposed solution to fill these voids can be accomplished with an electronically driven and controlled actuation system to meter seed. A successful operating system addresses the problems stated above and be able to improve or add the following features to a planting implement's seed metering device:

- Reduce the overall length of the seed tube.
- Provide accurate metering of seed rates equal to or better than current metering devices.
- Reduce the overall size of the metering device and place it closer to the ground.
- Eliminate the mechanical components required to drive current meters and clutch systems necessary to control the units on a per row basis.
- Improve compatibility between row units on seed placement and seed population rates through electronics.

The following sections explain the afore mentioned features in detail stated about improving the functionality and advantages of incorporating electronic control into seed metering devices.

3.1 Improved Seed Metering Accuracy

Development and design of an electronically actuated seed meter would have the capability to meter seed population at a level equal to that of current equipment or devices available on the market. Yet, during development of a new seed metering device the team focused on improving metering accuracy above current standards. The improved accuracy of the new seed metering device will make it more marketable to farmers.

To improve metering accuracy, the focus was to eliminate seed doubles or blanks as the seed is placed in the furrow. A double is an instance when two seeds are allowed to pass through

the metering device at one time which results in two seeds being placed in the furrow adjacent to each other. A blank is an instance in which the metering device did not pick a seed and results in a blank or skip in the furrow where no seed is placed.

3.2 Reduced Overall Size

A further rationale for the development of an electronically controlled metering device is the potential to reduce the overall size of the metering device. The seed meter has the potential to reduce its overall size greatly with the incorporation of electronic actuation in the system. In current equipment, a major limiting factor on the size of the meter is the vacuum plate seed disk required to accomplish the singulation process. These vacuum disks work in cooperation with negative air pressure to pick and place single seeds into the seed tube. The average size of these vacuum disks is approximately a 1/4" wide disk with a diameter of 10". Incorporating such a large component into the design limits the placement of the seed meter to areas above the actual working components of the row unit. A large seed tube is then required to transfer the seed from the singulation device into the furrow opened by the seed disks.

With the incorporation of electronic components into the metering device, the bulky seed disk can be eliminated from the design. Removing this size limiting component from the design can allow the singulation device to be much more compact, allowing the metering device to be installed in a variety of new locations on the row unit. The intention of a new design is to reduce the size of the device to allow it to be mounted between the seed disks. Having the metering device mounted in this location allows the length of the seed tube to be reduced. The new placement of the device requires a seed tube length of approximately 3-6 inches, compared to the current lengths which vary between 18-24 inches.

3.3 Elimination of Mechanical Components

Incorporating electronic components into the metering device, the large mechanical components that are currently used in the seed singulation and metering process could be eliminated. The major size restraining component that is eliminated is the seed disk, but the elimination of this component also removes the drive mechanism necessary to power the seed disk. This includes the common drive shaft that would power a section of row units, the variable rate adjustments, and the hydraulic drive motor or ground powered drive wheel/sprocket system.

With the mechanical drive system eliminated from the new metering device, a new source of actuation power is necessary. To power and drive the future design, the focus is to use electronic solenoid actuation, leaning towards electric actuators of either rotary or linear displacement. Incorporation of electronic solenoids to power the metering device gives the ability to break away from the common drive system. Powering each metering device individually eliminates the need for clutching devices on the row units to shut off each device. This allows control of the planting units on a row-by-row basis without the need for the expensive and complex clutching components. With each row unit individually controlled, the electronic control system is able to verify that the required amount of seed is going down that seed tube independently from other rows. Once coupled with GPS, it will allow precise placement of seed along with eliminating costly overlap, therefore, reducing overall seed usage.

3.4 Compatibility Between Row Units

The final and most significant benefit that is gained with electronic actuation is the ability of compatibility between row units. Currently the methods of metering and seed singulation are only capable of controlling the rate of seed placement. It is unknown exactly when a seed is being placed into the furrow. With the electronic system controlling placement, it can be

determined when a seed is placed in the ground. For example, when the solenoid is energized, the system activates moving a seed to the seed tube and it is determined exactly when that seed is placed in the furrow.

Allowing the system to control the exact point of seed placement, planting patterns can be created in the field during seeding operations. This is beneficial as the current method of planting rows, as shown in Figure 1, does not take full advantage of the available tillable land.

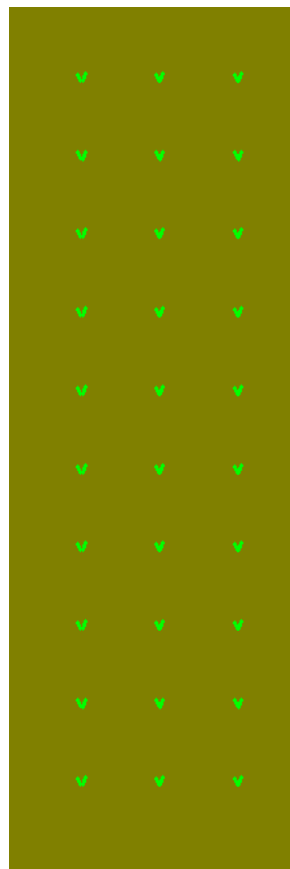


Figure 1 – Sketch of Standard Row Spacing for Grain Crop

With an electronically controlled metering system, it is possible to create patterns, such as the ones in Figure 2 and 3. Figure 2 is a pattern known as twin rows, two rows are placed very close together staggering the placement of the plant in each of the “twin” rows. It takes a greater advantage of the tillable land than the standard rows, but it still has the ability to work the

field down the rows. This is somewhat desirable because it does not require any extensive overhaul on existing equipment and implements.

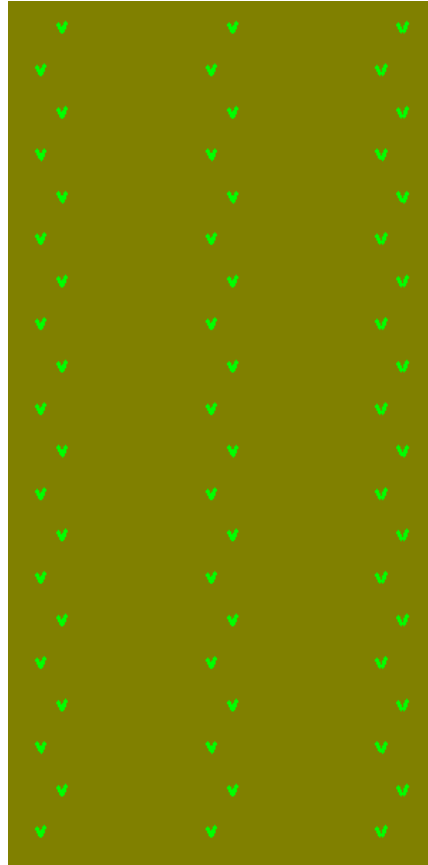


Figure 2 – Sketch of Twin Row Spacing for Grain Crop

Figure 3 depicts a planting pattern known as true equidistance spacing. With this pattern, every plant in the field is at equal spacing from all neighboring plants. This is the most efficient placement of seeds in the field and will also result in improved crop yield. The only drawback to this pattern of placement is that with certain crops it is the norm to plant and tend the crops in rows. Corn, for example, is traditionally planted in rows. Platforms for harvesting corn are

designed to harvest in rows only, and would not work for harvesting corn planted in a true equidistance pattern.

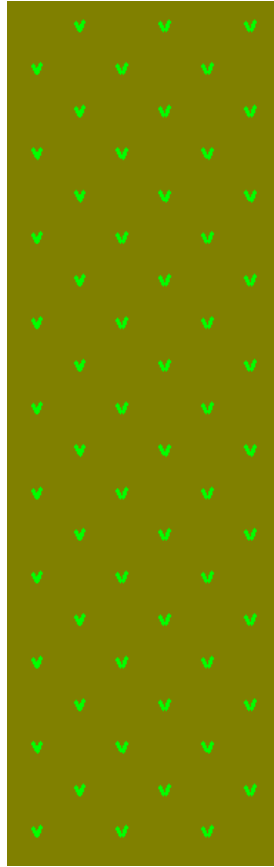


Figure 3- Sketch of True Equidistance Spacing for Grain Crop

3.5 Objectives

The main objective of this project was to study and develop the concept of electronically controlled seed singulation. The specific objectives are stated below:

- To use electronic actuation in conjunction with gravity, positive and/or negative air pressure to singulate seed
- To reduce the overall size of the metering device, allowing a more compact design with the intention of mounting the metering device closer to ground preferably between the seed discs, reducing the overall length of the seed tube.
- To allow for the future capability of communication or collaboration between row units allowing precise and accurate placement and seed patterns to be created during planting operations.

4.0 MATERIALS AND METHODOLOGY

Table 1 is a weighting table consisting of the important factors and weights for each of the prototype designs. The group has decided on the following weighting system for all designs. Using these tables the group has selected which design will be most feasible.

Criteria	Weight (%)
Safety	15
Ease of Use	15
Portability	5
Durability	15
Standard Parts	10
Cost	10
Probability of Successful Function	30

Table 1 – Selection Criteria for Weighting System

Starting with the most heavily weighted design criteria, “Probability of successful function,” a very high level of weight is applied. This is because as many of the brainstormed ideas can be visually analyzed and several of the design shortcomings and flaws are apparent, so this is defined as a preliminary test stage. Safety, ease of use, and durability were the next highest weighted items. After defining the needs of the customer, the group learned the customer wants a device with interchangeable parts that could be quickly and easily added or exchanged to an existing housing without much trouble or hurting himself. The design has to be durable as it has life cycles of well over 50 million through a single planting season. Next, standard parts and

cost are second lowest in the criteria. The main purpose of development for the seed singulation concept is to determine the functionality and feasibility of such a solution. Cost and standard parts are not critical components of prototype development, which is why the group has given them a low weight. Finally, portability is not as critical, as a successful functioning of the device and would have the ability to be simply installed in an existing row unit design which is accounted for in the ease of use criteria.

Some very common principles were taken into account when designing a sustainable product. A non-toxic product which requires little energy to produce should be used if at all possible. The group is choosing a polyethylene plastic that is formed from recycled materials. In this way, the product is safe from harming the environment, or the health and safety of others, since the product is non-toxic.

Manufacturability of the product was accounted for to keep the price of the final product low enough for the economy to support the new products. The product is manufactured out of a recyclable material and then molded into the shapes desired. Once molded together, the design can be easily assembled and installed onto the machine. If a problem occurs, the parts are easily serviceable. The design allows it to be disassembled and replaced easily since it is affordable enough to do so. The product is designed and manufactured to withstand multiple years of use to consider it a sustainable component otherwise people will not continue to purchase the design. The economics of this design will be mainly the prototyping costs since the design is cheaper to produce than what is being used currently. Since this product is cheaper to produce than what is currently in use, it would be unethical to charge a much larger price for the new product. The economy has to be able to afford the newest and greatest for a reasonable price.

5.0 DEFINITION AND EVALUATION OF ALTERNATIVE DESIGNS

After brainstorming and doing analysis of all the different iterations for electronic seed singulation, the group decided on three preliminary designs they thought to be feasible enough to prove the concept of electronic seed singulation. The preliminary designs are listed below.

5.1 Preliminary Design 1

The first basic design is constructed around a circular plate with two pie cut-outs in it (refer to figure 4). The seed from the hopper of approximately 3” by 3” falls through the .75” diameter outlet of the hopper (This can be seen in the top portion of figure 6). The hopper is attached to the access cover of the actuation box. The access cover is attached with pegs which protrude from the bottom of the access cover. A linear actuator is mounted inside the actuation box. One end is mounted to the side of the box and the other to the bottom of the pie plate. The pie plate is also mounted in the actuation box so as to allow horizontal rotation from the linear actuator. The pie plate is mounted above the bottom of the actuation box, directly above a two-hole cutout, to allow the seeds to fall into the seed tube (figure 7) as the pie plate is actuated. A brush is attached to the access cover directly above the center and in contact with the pie plate to eliminate doubles.

The linear actuator extends to rotate the plate approximately 25 degrees horizontally to allow one seed to fall into slot one of the pie plate, resting on the bottom of the actuation box. As the seed is waiting in slot one, slot two is allowing a seed to fall into the seed tube. The actuator then retracts to allow the seed in slot one to fall, and a new seed to load into slot two. The above process is one cycle. The cycle continues simultaneously. The rate of actuation for the cycle is variable with ground speed.



Figure 4 – Metering Component of Pie Plate Design

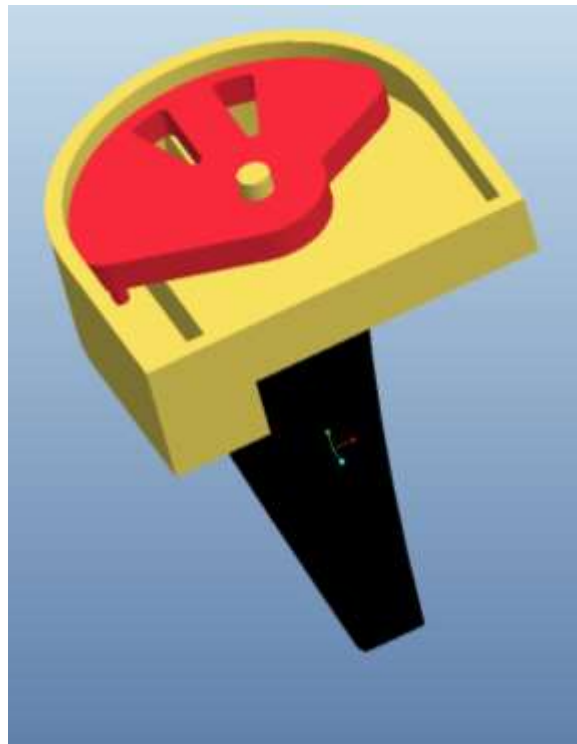


Figure 5 –Pie Plate Design with Access Cover/Hopper Removed

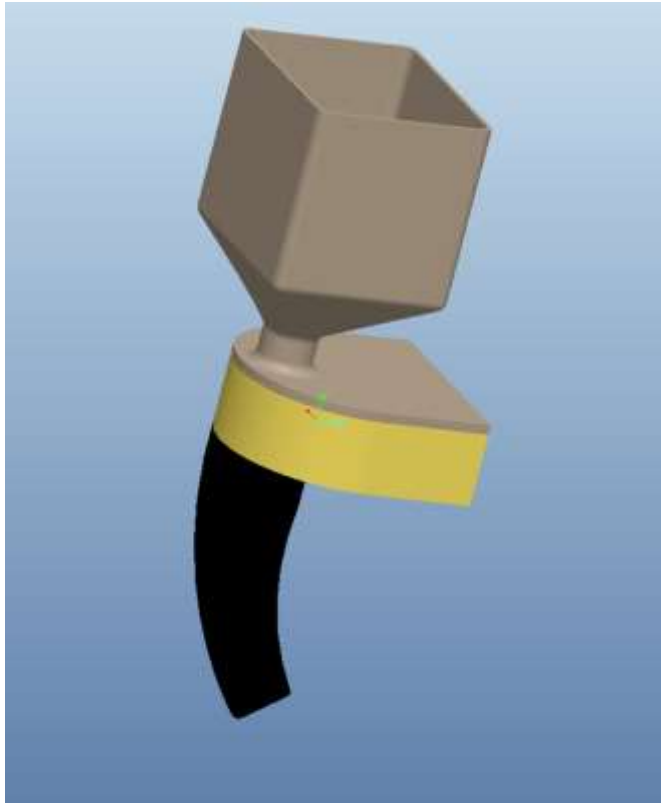


Figure 6 – Pie Plate Design with Seed Hopper Assembled

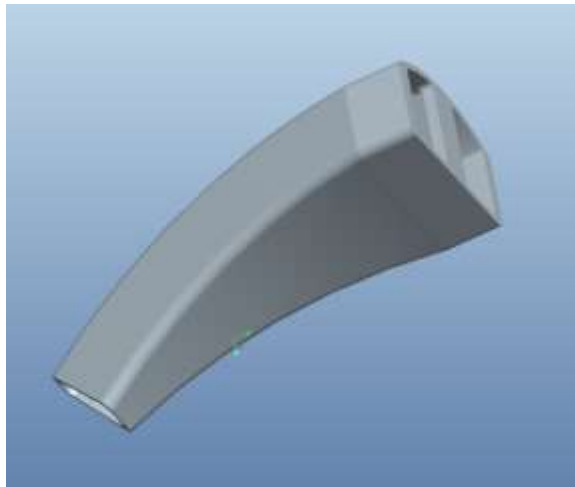


Figure 7 – Seed Tube of Pie Plate Design

5.1.1 Materials Required

The materials needed for this design include ultra-high molecular weight polyethylene (UMHW-PE) or similar plastic for the seed hopper, actuation box, pie plate, linear actuator and the seed tube. Also a small, thin bristle brush is needed to help eliminate doubles.

For this design, a level of 8 of 10 is chosen for the safety. Precautions are taken to avoid pinching fingers while putting the access cover on. Ease of use is rated with a 9 because the operator simply pulls the top cover off, and can pull the pin holding the pie plate on to change pie plates for different seed types. Portability is given 3 as the design may not be easy to remove and reinstall quickly or easily by the customer without having to take apart other components of the planter. Durability scores 7 because, although the design does have moving components, the rotating disc should not be subject to major stresses or wear. Standard parts get 6 because each component will need to be manufactured through plastic molding. The only part that could possibly be purchased from suppliers is the linear actuator. Cost is given 7 because the plastic molded parts are relatively inexpensive. The linear actuator is the main cost. Lastly, probability of success with this design receives 8. This seed metering system has a high chance of success because the seeds are piled up on the pie plate, and with the pie plate design and location in the actuation box, only one seed is allowed to fall into the seed tube.

5.2 Preliminary Design 2

The second design is a double hopper design which can be seen in figure 8 below. With this design, the actuator is double acting. Double acting means when the actuator is pushing a seed into the seed tube on one side, the other side is open allowing a seed to sit in staging until the actuator comes back, pushing the seed down the tube. The reason for using two hoppers is to help singulate the seed before it drops into the seed tube. This also means the actuator only has to

move half as fast since there are two seed tubes. A negative air pressure is used to allow only one seed to fall once the actuator moves and allows the seed to fall into the staging area. The seed is held in the staging area by a brush-like material between the seed and the seed tube. The actuator has enough power to push the sliding mechanism, which pushes the seed through the brush, allowing it to fall down the seed tube.

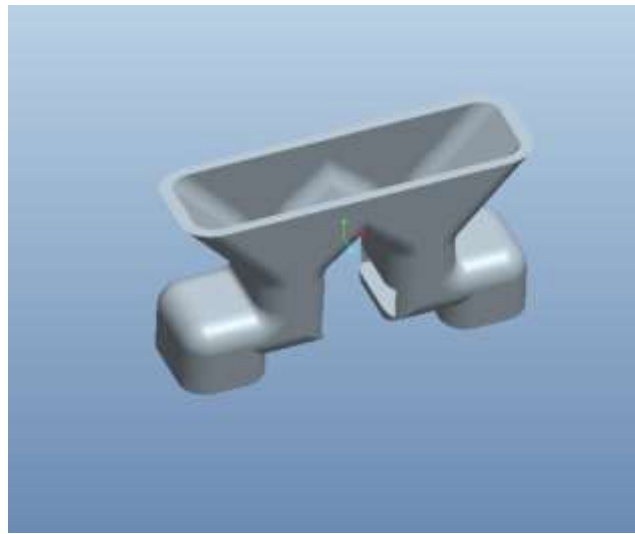


Figure 8 – Double Hopper Design

For this design, a level of 9 of 10 was chosen for the safety. The users are around the seed meter when it is not in operation; this is why safety has very low weight. Ease of use is rated with 9 because the operator does not have to do anything with the meter itself while it is in operation. Portability scores 3 as the design will need to be fairly large and may not fit in the installation location desired by the customer. Durability receives 8 because, although the design does have moving components, the sliding mechanism is not subject to major stresses or wear. Standard parts get 6 because each component needs to be manufactured through plastic molding. The group can use existing seed tubes. The linear actuator is purchased from suppliers. Cost scores 7 because the plastic molded parts are relatively inexpensive. The linear actuator is the most costly

component. Lastly, probability of success with this design scores 8. This seed metering system has a high chance of success because the seeds are singulated into a single row, then pushed out the seed tube by the sliding mechanism controlled by the linear actuator.

5.2.1 Materials Required

The materials needed for this design include (UMHW-PE) for the seed hopper, sliding mechanism, seed tube, and a linear actuator. The group needs a small amount of brush-like material for prototyping.

5.3 Preliminary Design 3

The third design consists of a single hopper and sliding plunger design. Figure 9 is a 2-D model of the design. The seed is singulated down into a small pile where the electronically controlled plunger uses vacuum to hold a single seed into a cutout on the end of the plunger. With this design, small areas are cut into both the plunger and the housing, as can be seen in the following figures, so in certain areas of the stroke there is vacuum applied to the seed plunger, in turn, pulling a seed into an area notched out of the end of the plunger. When the solenoid retracts, at a certain point the vacuum is cut from the plunger, therefore dropping the seed down a hole cut in the housing, and dropping the seed down the seed tube. The solenoid is attached to the plunger on one end, with a spring that retracts the plunger back towards the end of the solenoid. Vacuum is applied to the top of the housing as shown in the figures below.

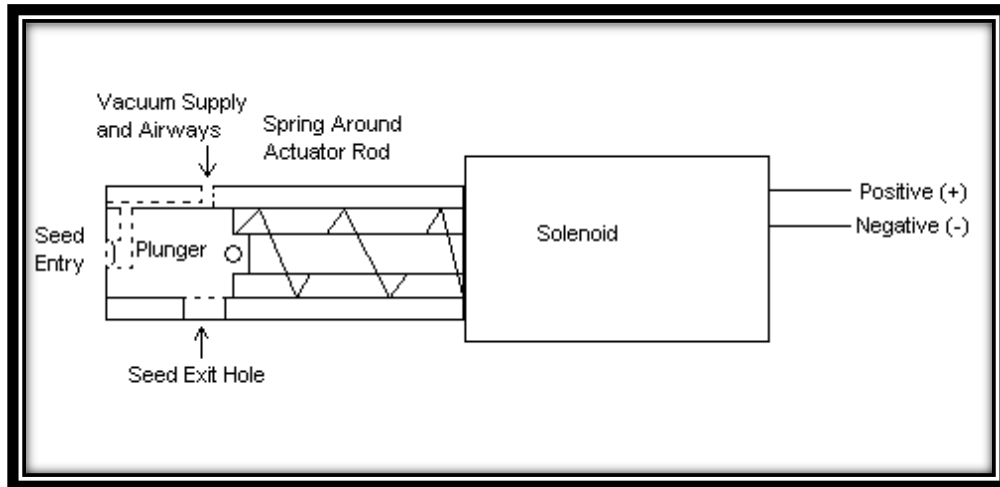


Figure 9 – 2-D Model of Plunger Design

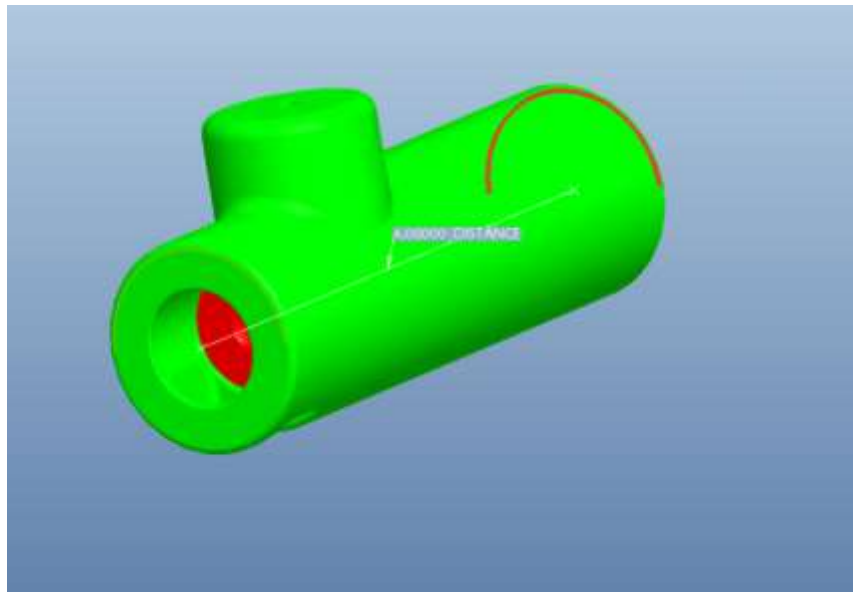


Figure 10 – Plunger Housing and Plunger Assembled

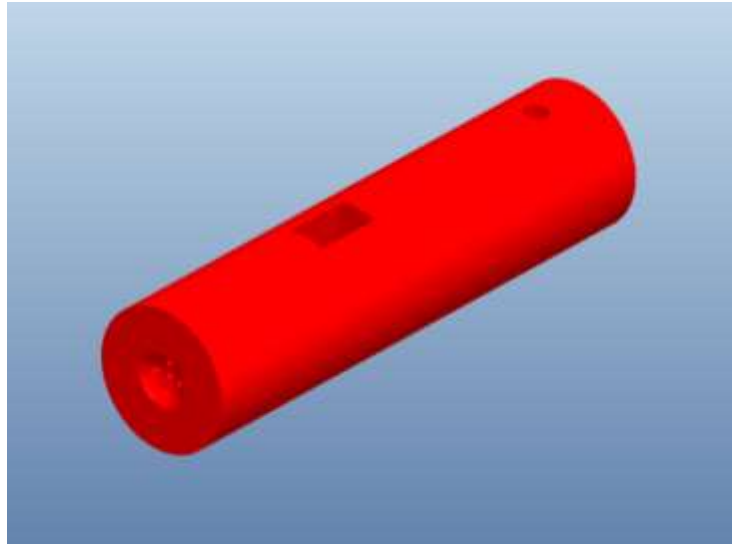


Figure 11 – Plunger of Seed Singulator

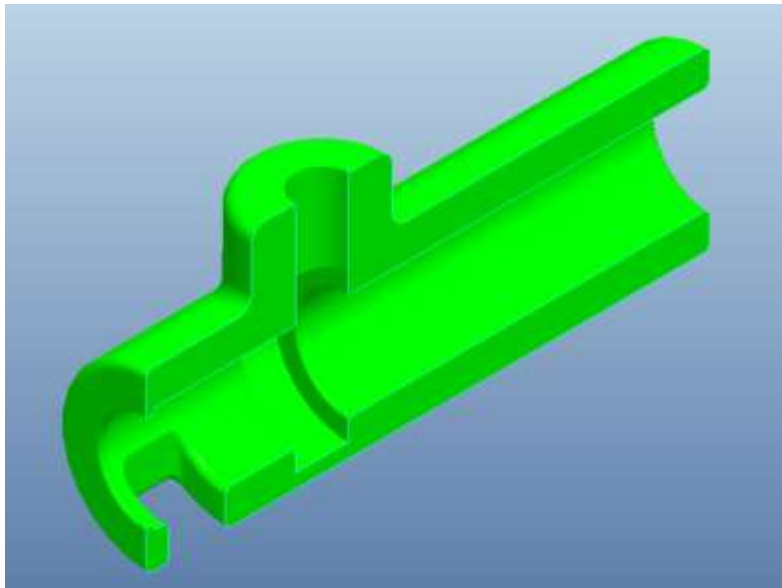


Figure 12 – Section View of Plunger Housing

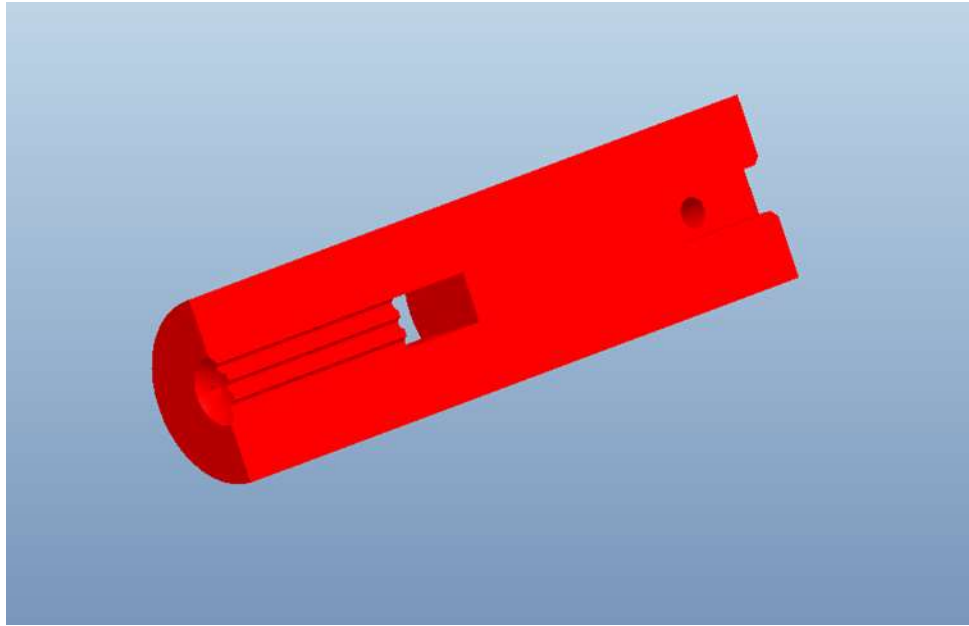


Figure 13 – Section View of Plunger

For this design, a level of 9 of 10 was chosen for the safety. The users are only around the seed singulator when it is not in operation; this is why safety has very low weight. Ease of use is rated with 9 because the operator does not have to do anything with the meter itself while it is in operation. Portability scores 5 as the design is not very big, but with the amount of moving parts, it is tough to easily transport by hand. Durability receives 8 because, although the design does have moving components, the sliding mechanism is not subject to major stresses or wear. Standard parts get 6 because each component needs to be manufactured through plastic molding. The group uses a standard, off the shelf actuator. The cost area scores a 9 because the plastic molded parts are relatively inexpensive. The linear actuator is the most costly component. Lastly, probability of success with this design scores 9. This seed metering system has a high chance of success.

5.3.1 Materials Required

The materials needed for this design include (UMHW-PE) for the seed hopper, plunger and housing, the seed tube, and linear actuator. A spring is the only other component needed to construct this prototype.

Table 2 shows a comparison between all three prototype designs and their score per weight for each specific criterion.

Criteria	Weight (%)	Design 1		Design 2		Design 3	
		Value	Points	Value	Points	Value	Points
Safety	5%	8	40	9	135	9	135
Ease of Use	15%	9	135	9	135	9	135
Portability	5%	3	15	3	15	5	25
Durability	20%	7	140	8	120	8	120
Standard Parts	10%	6	60	6	60	6	60
Cost	10%	7	70	7	70	9	90
Probability of Successful Function	35%	8	280	8	240	9	270
Total Points			740		775		835

Table 2 - Total Scoring of the Concepts

After doing the above analysis and weighing the safety, ease of use, portability, durability, standard parts, cost, and probability of successful function, the group is going to move forward with testing for the plunger design (preliminary design 3).

6.0 BUDGET

The funds spent throughout the project are explained below. The group came up with a proposed budget and presented the budget to the collaborator. Once the budget was approved, the group purchased the necessary supplies throughout the design and development of the project. The total expense of the project was \$211. 12. That value was reduced further, as the solenoids which were not used were returned.

Description	Unit Cost	Quantity	Total Cost
1/4 inch Outside Diameter Tubing (100ft)	\$ 9.58	1	\$ 9.58
Vaccum Gage	\$ 9.58	1	\$ 9.58
1/4 inch Male Elbow	\$ 2.64	2	\$ 5.28
1/4 inch Tee Connector	\$ 4.17	1	\$ 4.17
1/4 inch Female Connector	\$ 4.17	1	\$ 4.17
Solenoid; Coil Power Cont:11.5W; Stroke Length Max:0.8"	\$ 52.26	1	\$ 52.26
Solenoid; Coil Power Cont:8W; Stroke Length Max:0.5"	\$ 23.35	1	\$ 23.35
Solenoid; Coil Power Cont:13W; Size:2.25 x 1.25	\$ 37.13	1	\$ 37.13
Solenoid; Coil Power Cont:17W; Size:2.50 x 1.50	\$ 42.48	1	\$ 42.48
Shipping cost	\$ 8.28	1	\$ 8.28
Switch, Single Pole, Almond	\$ 0.69	1	\$ 0.69
Cap, PVC Pressure, 2", 3016	\$ 2.99	1	\$ 2.99
Boring Tools, H.2.L.B. 7/16"	\$ 3.50	1	\$ 3.50
Tap, Pipe, 1/8-27 NPT, 9520	\$ 5.69	1	\$ 5.69
Assorted Springs	\$ 0.25	4	\$ 1.00
Sales Tax, 6.5%	\$ 0.97	1	\$ 0.97
			\$ 211.12

Table 3 - Budget

7.0 RESULTS

Initial calculations were performed to determine cycle speed of the seed metering device when operating under conditions required in a planting operation. When referring to the cycle time, this is the time needed to move the plunger into the seed mass, pick a single seed out of the bunch, pull the plunger back with seed, and drop the seed into the seed tube. Data from these calculations can be found in Table 4. The assumptions made to perform the calculations were; a standard 30 inch row spacing and a planting speed of 4 mph. From these assumptions calculations could then be performed to determine seed spacing, seeds/second, and cycle time

Cycle Time vs. Seed Population

Assumptions:

30 inch row spacing
6272640 in²/acre
4 mph planting speed

seed/ac	seed spacing (in)	seed/second	cycle time (ms)
1,000	209.1	0.3	2970
2,000	104.5	0.7	1485
3,000	69.7	1.0	990
4,000	52.3	1.3	743
5,000	41.8	1.7	594
7,500	27.9	2.5	396
10,000	20.9	3.4	297
25,000	8.4	8.4	119
50,000	4.2	16.8	59
75,000	2.8	25.3	40
100,000	2.1	33.7	30
125,000	1.7	42.1	24
150,000	1.4	50.5	20
175,000	1.2	58.9	17

Table 4 - Cycle Time vs. Seed Population

7.1 Lab Testing

Lab testing was performed on each revision of the plunger style housing. Early testing was performed to determine feasibility of the design and capabilities of the solenoids themselves. Testing was then performed on later revisions to determine the functionality of the vacuum systems and design improvements.

7.1.1 First Revision of Plunger Style Design

The first revision of the plunger style design incorporated the largest solenoid purchased and a spring with the weakest spring constant. The plunger and housing were machined out of UHMW-PE using a lathe. These components were integrated with the solenoid and fixed to a block of wood to perform testing. A Programmable Logic Controller (PLC) was used to consistently cycle voltage supplied to the solenoid. A program was developed for the PLC that allowed the user to select the desired cycle time of the solenoid.

With the PLC integrated into the control system testing was performed to measure stroke length and its relationship to the supply voltage and also the cycle time. The data points measured during this testing can be found in Figure 19. The results from this testing were used to determine feasibility of the concept and also features that would help develop later revisions of the design. One key finding from this testing was even with our most powerful solenoid it could not actuate the full required stroke length of 0.5 inches at a cycle time necessary to plant at high seeding rates required during soybean planting. Although this cycle time can be improved with the usage of a more ideal spring that do not require as much force to compress. It was also discovered during this testing that as the supply voltage was increased the force applied by the solenoid increased as well. All of the solenoids purchased for our testing purposes were rated for 12 volts. When a supply voltage higher than this was applied to the solenoid the output

performance of the solenoid is improved but this higher supply voltage decreases the life expectancy of the solenoids. From the manufacturers specifications the solenoids perform reliably to 25+ million cycles, so for our testing purposes using a supply voltage higher than the rated voltage had minimal impact on our testing.

A second test was also performed to verify the functionality of using vacuum and machined porting to pick a seed and then cut the vacuum as the plunger actuates to full stroke dropping the seed out of the exit hole. The test was performed using supplies available in the campus lab integrating a vacuum cleaner to provide negative air pressure and $\frac{3}{4}$ inch fuel line to transfer the air flow to the housing. With even this crude setup the system was able to successfully pick a seed and as the plunger was physically moved by hand to a full stroke length the supplied vacuum was cut off and the seed dropped out the exit hole.

7.1.2 Springs

The spring constant determines the force required to compress the spring. As these constants increase, it also increases the force required by the solenoid to retract the plunger. The springs obtained for testing were an off the shelf product obtained from a variety bin that contained no specification of each individual spring. The criteria for the springs used during testing were that the dimensions of the spring needed to have a large enough inner diameter to fit over the plungers of the solenoids, but an overall diameter small enough to slide inside of the machined housing.

7.1.3 Functional Vacuum System Development

With the success of this vacuum system, designs were developed for a system with more functionality. Some key aspects of this improved vacuum system include:

- Push-to-Connect Fittings
- PVC Cap
- Pressure Regulator
- Pressure Gauge

The push-to-connect fittings allowed for components to be quickly connected and disconnected and also if future modifications are necessary components can be added or removed with no tools. A PVC cap was used to mate the system with a vacuum cleaner. A fitting was threaded into this cap to allow the entire system to be removed from the vacuum when not in use. A needle valve pressure regulator was tied into the system with one end open to atmospheric pressure. As this regulator was throttled up or down, the applied vacuum pressure could be adjusted. A vacuum gauge was also installed to allow users an instantaneous readout of the vacuum pressure. Figure 14 shows the layout of vacuum system.

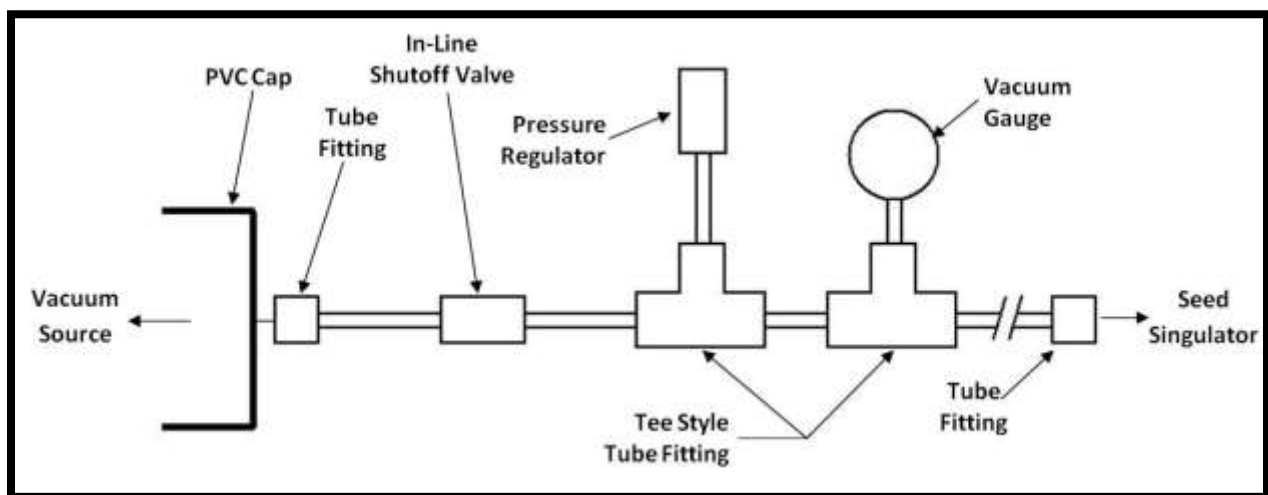


Figure 14 – 2-D Model of Vacuum System

7.1.4 Second Revision of Plunger Style Design

After a brainstorming session with the collaborator some future design changes were made to this reiteration of the prototype. The changes included:

- Designed Around Our Smallest Solenoid
- Smallest Available Spring Used
- Reduced Housing Size
- Reduced Plunger Length
- Integrated Vacuum System

Many of the changes were made to the design in an attempt to achieve the most compact assembly. One key change to the design was the incorporation of our smallest solenoid that mounted with a threaded front face. This eliminated the need for a platform to mount the solenoid and housing/plunger assembly to. With a threaded face, the solenoid could be directly threaded into the housing of the singulation device, allowing the whole device to mate neatly together as a single assembly. Figure 15 shows the entire assembly mated together, while Figure 16 depicts the assembly broken down into its component pieces.



Figure 15 – Second Plunger Style Prototype, Full Assembly



Figure 16 – Second Plunger Style Prototype, Component Breakdown

The prototype was coupled with our PLC control system and the new vacuum system to test the functionality of the prototype. It was found during this testing, that the smallest solenoid was not strong enough to overcome the force of the return spring used in the design. The spring used was our weakest available spring meeting the size requirements of the plunger and housing. This test was performed at several supply voltages ranging for 12-30 volts with a cycle time of 2 seconds. Even with a supply voltage of 30 volts, the max voltage we could supply from our power source, the solenoid could not overcome the spring force.

Testing was also performed to verify the functionality of the improved vacuum system. We were able to prove that vacuum could be transferred successfully through the entire transfer system and through the porting of the housing and plunger to create a point of the front face of the plunger that could pull seed. When the plunger was actuated, manually, the porting of the housing and plunger come out of alignment causing the vacuum to be cut thus dropping the seed out of the exit hole. The vacuum created on the front face of the plunger was weaker than expected though. The system was able to produce under the best conditions, 4 inches of Hg. The team was hoping to achieve a vacuum with pressure closer to 10 inches of Hg. Although the pressure produced was weaker than desired it was still strong enough to pull a seed against the front face, hold the seed in place, and drop the seed out of the exit hole during a manually actuated stroke. The vacuum may have been weaker than expected because of leakage between the plunger and the housing. The probable cause was a result of poor manufacturing of the prototype components during milling. This problem has room for improvement with improved tooling as well as machining experience, as the team produced these prototypes with minimal knowledge.

7.1.5 Third Revision of Plunger Style Design

Even though much of the second revision was a failure, we were still able to produce a single neat assembly and a very compact design. We decided to continue improving on this design and incorporating the following changes into the third revision:

- Integrates Our Strongest Threaded Solenoid
- Smallest Available Spring Used
- Plunger Stroke Length Increased
- Porting Size For Vacuum Transfer Increased

This next revision incorporated our strongest solenoid that still included the threaded front face. To produce more output force this solenoid had larger overall dimensions requiring the housing of the seed singulation device to be increased to allow for the solenoid to mate properly with the assembly. With the housing size increased, the size of the plunger could be increased as well. With a larger plunger, the vacuum porting was able to be increased as well. This was done in attempt to improve the vacuum pressure produced at the front face of the plunger. Also, incorporating the larger solenoid also gave us an improved overall stroke length of the plunger, from 0.45 inches in the second revision to 0.59 inches in the third revision. Figure 17 shows the entire assembly mated together, while Figure 18 depicts the assembly broken down into its component pieces.



Figure 17 – Third Plunger Style Prototype, Full Assembly



Figure 18 – Third Plunger Style Prototype, Component Breakdown

The first stage of the tests performed on the third revision was to prove the functionality of the system being able to actuate with the springs available. For this stage of testing a second spring was used, this spring was “customized” from a spring with a weaker spring constant. The dimensions of this weaker spring did not meet our needs as this spring was designed to fit inside of a 0.25 inch hole, where our application required the inside diameter of spring to be at least 0.625 inches. To achieve this, the spring was carefully uncoiled to meet the dimensions required. It was not the ideal off-the-shelf spring we would have desired but it proved to function well enough to perform some tests.

During the actuation tests stroke length was measured in relation to three variables; spring strength, supply voltage, and cycle time. The charted trends that can be found in Figure 19 showed that with the weaker spring the solenoid could actuate at a full stroke length with a supply voltage of 15V up to 200 millisecond cycle time. At this point, the stroke length began to decrease as cycle time was decreased. This testing was performed again with a supply voltage of 18 volts and again 24 volts. At 18 volts the plunger was able to actuate a full stroke length at a cycle time of 100 milliseconds. The results were the same at 24 volts. What happened that limited the cycle time at the higher voltages was an incidence where the plunger would actuate a full stroke during the first cycle, but as the plunger was then being returned to second stage of the cycle, the plunger could not physically move fast enough to the return to the initial position before the control program switched the solenoid back to the powered state. So as the plunger would be at half stroke the solenoid would switch back on pulling the plunger back to full stroke, effectively “latching” the plunger inside of the housing.

Testing with the off-the-shelf stronger spring showed that the system could not actuate to a full stroke at supply voltages of 15 & 18 volts, it showed a decreasing stroke length as cycle time was decreased. When tested at 24 volts the plunger would actuate a full stroke length up

until a 100 millisecond cycle time, at which point the solenoid would “latch” the plunger again and stroke length would be decreased. All measured data points can be found in Appendix A.

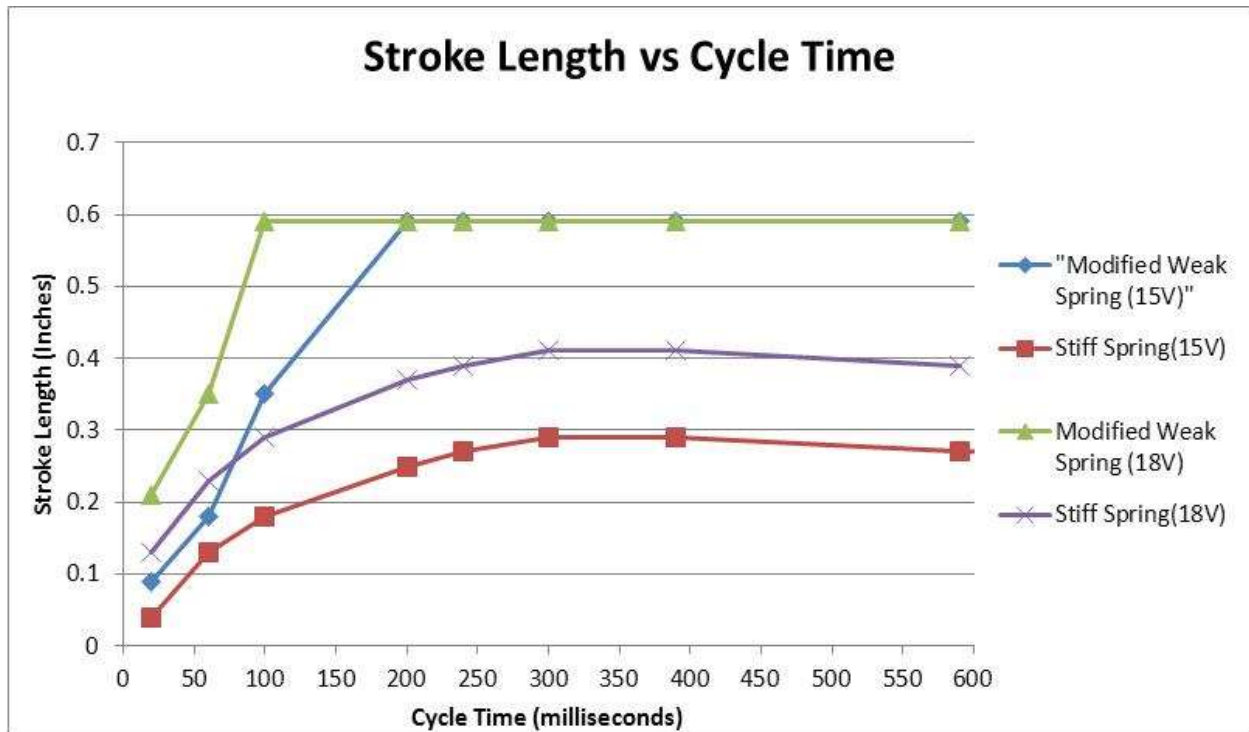


Figure 19 – Stroke Length vs. Cycle Time Comparing Different Voltages and Springs

The most ideal configuration discovered during the stroke length actuation test had the following parameters:

- 100 millisecond cycle time
- 18 volt supply voltage
- Modified weak spring

This same configuration was to be used when the seed singulation device was integrated with the vacuum system, to prove the capability of the system to pick and place seed. Although to demonstrate the concept, a cycle time of 2 seconds was used for this test. With the third revision of the prototype, the improved manufacturing allowed the max vacuum pressure to increase slightly to 4.5 inches of Hg, which was the vacuum pressure used during testing. This test showed that at this slow speed, if a seed was delicately placed against the front face of the plunger, the vacuum would hold the seed in place until the plunger reached full stroke; at this point, the vacuum was cut and the seed would drop out of the exit hole. This testing did demonstrate the capability to pick and place seed, but a single seed had to be delicately directed to the vacuum area. The vacuum produced was not strong enough to pick a single seed out a mass of available seeds.

8.0 RECOMMENDATIONS FOR FUTURE WORK

Further research and development will be needed on this project to help prove the concept. A new vacuum design is needed. Springs need to be researched to find something with a lower k value. The system needs to find its capabilities of actually planting a crop at speed.

8.1 Vacuum System

A new vacuum system needs to be implemented. The system the team utilized did not produce the air volume needed to pull seeds and hold them adequately. A new system similar to what is currently used on vacuum planter systems should be utilized. Tubing size needs to be researched to find the proper volume needed in order to do the job of pulling and dropping seeds.

8.2 Springs

The return springs for use in the solenoid need to be further researched. The team had a hard time finding springs to implement in the test stages that were not homemade. The springs with the smallest k value found worked, but were very violent on the return stroke. The voltage needed to be turned up in order for the solenoid just to be able to pull the plunger in with these stiff springs. Springs with a smaller k value still did the job of returning the plunger, and the voltage could be turned down to a reasonable level. With high voltage levels, the solenoids would get hot, decreasing life and performance.

8.3 Actuation Speed

Soybeans are planted at a high seeding rate. Wheat is planted at an even higher rate. In order for this concept to be implemented into such areas more research will need to be done on design work. For example, a planter utilizing 30 inch wide rows traveling at 4 mph planting

soybeans at even 100,000 seeds per acre will require a cycle time of 30 milliseconds per row. With a single solenoid moving soybean seeds at this cycle time, there is no way the plunger will physically move seeds that fast. That rate is approximately 34 seeds per second. This is very difficult if not impossible to accomplish with a single solenoid picking one seed at a time. This is true especially when this concept is to be implemented at a faster seeding rate than normal due to its increased accuracy potential.

9.0 CONCLUSION

At the end of the project, the data and working designs helped to prove that the concept of using electronic actuation to singulate seeds is viable. With a working concept, it may be possible after being refined to replace the existing design with the newfound idea.

The group developed the design to a point of having a solenoid selected for the application, plastic parts molded and assembled, and getting the unit small enough to be placed low to the ground in between the seed discs. The unit was tested to prove that the design of electronic actuation is feasible. Some major features of the completed design are:

- The group proved that electronic linear actuation can be used for seed singulation.
- Used electric current in conjunction with gravity and negative air pressure to move seed.
- Reduced overall size of a metering device to allow row unit placement closer to the ground between the seed discs accommodating a shortened seed tube.
- Electronic control provides the capability for communication between row units.
- The actuator chosen for the final design was cost effective for the customer to utilize.

10.0 REFERENCES

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Appendix A

Data Collected From Actuation Testing On Third Revision

	Voltage (Volts)	Cycle Time (ms)	Stroke Length (inches)
3rd Revision, modified weak spring Full stroke is .59 inch	15	1190	0.59
	15	590	0.59
	15	390	0.59
	15	300	0.59
	15	240	0.59
	15	200	0.59
	15	100	0.35
	15	60	0.18
	15	20	0.09
	18	1190	0.59
	18	590	0.59
	18	390	0.59
	18	300	0.59
	18	240	0.59
	18	200	0.59
	18	100	0.59
	18	60	0.35
	18	20	0.21
	24	1190	0.59
	24	590	0.59
	24	390	0.59
	24	300	0.59
24	240	0.59	
24	200	0.59	
24	100	0.59	
24	60	0.16	
24	20	0.05	

	Voltage (Volts)	Cycle Time (ms)	Stroke Length (inches)
3rd Revision, stiff spring Full stroke is .59 inch	15	1190	0.26
	15	590	0.27
	15	390	0.29
	15	300	0.29
	15	240	0.27
	15	200	0.25
	15	100	0.18
	15	60	0.13
	15	20	0.04
	18	1190	0.38
	18	590	0.39
	18	390	0.41
	18	300	0.41
	18	240	0.39
	18	200	0.37
	18	100	0.29
	18	60	0.23
	18	20	0.13
	24	1190	0.59
	24	590	0.59
	24	390	0.59
	24	300	0.59
24	240	0.59	
24	200	0.59	
24	100	0.59	
24	60	0.5	
24	20	0.3	

Data Collected From Actuation Testing On Third Revision

