Development of an Electronic Seed Singulation Device

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Report
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1. Introduction

1.1 Problem Statement & Rationale

Presently, most row planters use some means of mechanically or hydraulically driven devices to turn seed meter discs that accurately place seeds in rows. Using mechanical or hydraulic devices to turn the seed meters is cost effective and has been implemented for many years. By using these methods, seed populations can be varied across the entire width of the planter by changing the rotational speed of the drive devices. However, the ability to control the population on a single row basis is very difficult using these methods.

The most common and cost-effective method that is used to drive metering devices is to use a ground driven wheel. The speed of the ground driven wheel is directly proportional to the speed of the implement. This wheel either turns a chain or turns a common shaft amongst several row units, that in-turn spins the metering device to effectively singulate the seed. In this type of system, the gear ratios of the drives can be changed by interchanging gears and chains to accommodate different seeding rates for different crops. This method of seed singulation is very simple, but variation of rates is difficult to achieve, as the user is limited by sprocket sizes.

In recent years, using a hydraulic motor to drive the shaft that turns the meters has also become a viable solution. The hydraulic motor is driven by the tractors hydraulic system and the flow can be varied to change the rotational speed of the meters. Precision planting software and GPS are used to change the flow rate and the seed population. This allows the user to vary seed rates in different areas of the field where one would benefit from higher or lower populations. Information for different population zones are developed from yield maps generated using precision software and GPS. The drawback of this system, however, is that rates can only be varied across sections of the implement and not on a single row unit basis. The size of the section of row units that can be controlled depends on the number of hydraulic motors and the size of the implement. It is common to have these row unit sections separated into three zones on the planter: the center, right, and left, with each section having the ability to vary seeding rates. This does not allow each row unit to act individually, which is a major limitation.

Seed placement can also be altered by using row clutches. Row clutches are electronic devices that allow single rows to be turned on or off. This is beneficial when approaching ditches that are not plantable, headlands, and sections of the field where overlap is unavoidable. The row clutches are also controlled by the precision planting software and GPS. Row clutches are very limited however, as they can only run as on or off (binary), with no variation in rotational speed of the meters.

The biggest problem with the current drive devices is presumed to be the inability to control seed populations on a single row basis; however there are also some other issues with the current seeding systems that are limiting seeding capabilities. One of these issues is the physical size of the metering device (ie. disk and vacuum). In a common metering device, a disc is used to singulate seeds. The disc is usually made out of a polymer and can be up to 12 inches (30.48cm) in diameter. This disc has holes in it to hold the seeds and also uses a vacuum to hold the seed in place as the disc spins. The seed rotates on the disc and is brushed or wiped off the disc, and then dropped into a seed placement tube. The seed placement tube places the seed in the furrow. The size of the meter that houses the disc requires a lot of space. It is usually mounted above all the necessary components used to place the seed. This requires that a fairly long seed placement tube (approximately 1 meter) be used to bring the seed into the furrow. This means that the forces of gravity effect the placement of the seed. Things like rocks or rough terrain can cause the row unit to bounce up and down causing the seed to be placed in slightly different locations due to the amount of time is takes for the seed to fall from the disk of the metering device into the furrow created by the planter.

The current disk and vacuum meter drive systems can control seed on a population basis across the planter, but there is no communication between adjacent row units. The actual timing between row units cannot be controlled with the current methods, so optimal seed placement is impossible to achieve. The most effective seed placement is to place seeds so the spacing between each seed and each row is uniform. This allows farmers to take full advantage of all of the land that they have available. Using this method also promotes a greater crop yield.

The disks of the current metering systems have limitations to the speed that they can turn. With a ground driven system, a point is reached when the ground speed of the planter is too great and the disks of the meters cannot turn fast enough to singulate the amount of seed needed to reach the appropriate populations. The hydraulic drive system is limited to the amount of hydraulic flow available from the tractor, which also limits the speed that the meters can turn.

Electronic seed singulation could potentially solve the current problems associated with current singulation devices. One of the biggest advantages would be the ability to precisely control seed placement among rows. By using a method of electronic singulation, the ability to control the placement using precision planting software would presumably become much easier. It is much easier to detect a binary signal from an electronic device compared to using the current methods of measuring seed placement by using an electronic eye or other form. Electric signals also travel extremely fast, so precise control of when a seed is placed or held is easily possible.

Electronic seed singulation would make it possible to eliminate many of the mechanical components in the current metering devices. The hex shaft and ground/hydraulic driven systems would no longer be needed. If one were to use a solenoid or actuator the seed disc could also be eliminated. By eliminating these components it would be possible to make the singulation system much smaller compared to today's metering/singulation devices. This would solve many of the issues associated with current systems by minimizing the effect of gravity on seed placement.

1.2 Impact on Society

The importance of precision seeding impacts the world and society as well. Human population is constantly growing. This increases the amount of food that needs to be produced in order to feed everyone. With precision seeding, the goal is to plant the maximum seed population that the soil can support and to have the maximum yields. Land productivity is not uniform and thus seed populations change relative to the fertility and properties of the soil. With spatial changes in the soil, it is necessary to have each planting row meter seed individually and accurately to the soil's productivity. By having the best seed population the soil can support, yields can be maximized and food productivity increased.

There is a limited amount of land resources on this earth and it must both be used to produce food and house the human population and industry. With precision planting, efficiency increases and maximum yields are achieved thus reducing the amount of land required. Based on the laws of supply and demand, increasing food production decreases food prices making it more affordable to feed the world's population.

1.3 Project Objectives

The main goal of this project is to develop a more precise technique of metering and placing seeds. The specific objectives for this project are to:

1. Reduce the length of the seed tube
2. Reduce the size of the metering system
3. Allow for an individual row unit to operate relative to other row units
4. Eliminate the need for row clutches and mechanical components
5. Provide accurate metering at increased ground speeds
6. Produce equal or better metering of seed rates compared to current systems

2. Literature Review

Precision planting is defined as providing accurate placement of seeds within each row. A precision planter is very helpful because it provides four operations in one step. The precision planter is able to cut a furrow at a set depth, and then place the seeds accurately in the furrow. Once the seeds are placed in the furrows; a set of wheels pushes soil over the seeds and closes the furrow. In most applications a firmer is also used to firm the soil next to the furrow. Previous to the 1960's many farmers used precision planters that utilized seed plates to distribute the seed. The plates had cavities that were sized for each seed and only one seed could fall into the cavity. When the seeds passed by the seed tube a knockout device would push the seed out of the cavity into the seed tube (Buckmaster et al., 2006). The current precision planting method is very similar to the old plate method. The current method is still a plate, but the seed is held on the plate using vacuum on one side of the plate keeping the seed in the cavity. The plate is usually mounted vertically next to the seed hopper. The seed is carried from the hopper to the seed tube, and is then wiped from the plate by a brush or plastic plate. On modern planters the plate is commonly referred to as a seed disc.

Precision planters produce the most accurate form of planting. If a precision planter is set up correctly the calculated seeding rate should be very close to the actual seeding rate. Using the current methods it is possible for cells on the seed disc to be empty. It is also possible for more than one seed to fill each cavity on each disc. This can cause the actual populations to differ from the calculated populations. When measuring the efficiency of precision planters the term coefficient of variation is commonly used. The coefficient of variation is number used to rate the effectiveness of the planter. If the coefficient of variation is zero there are no skips or multiples and the seed spacing in each furrow is equal to the desired number (Buckmaster et al., 2006).

When planting crops many parameters should be considered. The two most important parameters are the amount of seeds placed per acre, also known as seed population, and row spacing. For Corn, the best yields will be found when seed populations are between 28,000 and 32,000 seeds per acre. Corn row spacing can vary from 20 to 38 inch (0.5 – 0.96 m) rows. The most common row spacing for corn in the United States is 22 and 30 inches (0.56 – 0.76 m) (Farnham, 2001).

When planting soybeans, much greater seed populations are used compared to corn. Soybean populations range from 70,000 to 180,000 seeds per acre. Usually a population of 150,000 seeds per acre is ideal for wide rows and a population of 175,000 seeds per acre is used for narrow rows. Soybeans are commonly planted in rows with spacings of less than 30 inches (0.76 m) (NSRL, 2010).

At present time, there is one company that is using electronic means to singulate seeds. Graham Equipment markets a kit that retrofits a standard D.C. electric motor to each row unit. The D.C. motor eliminates many moving parts on the planter that commonly wear out. The website www.grahamelectricplanter.com, states that each motor has a lifespan of at least 5000 hours. The current listed price of retrofitting each row unit is $950.00 plus the costs of a touchscreen interface. Graham recommends the use of a hydraulically driven alternator to supply the required voltage and amperage to the motors on the row units as most tractors are not capable of producing the required power. Graham provides their own control software and interface to control the electric drives. They claim that their control system has an error of only 0.7% and can change row populations in as fast as 0.2 seconds. This system seems to be a very good option, but its main purpose is to eliminate mechanical components. This system does not have the ability to interface between rows, so the perfect plating arrangement is still not achieved.

A stepper motor is similar to a standard direct current motor in a few ways. The stepper motor uses magnets, bearings, and wires, much like a regular D.C. motor, but it also uses a rotor with teeth. A stepper motor does not use brushes to create motion. It instead uses digital pulses to create movement of the shaft. Each pulse equals one small movement of the shaft, and it generally requires several pulses to create one revolution. When the frequency of the pulses is increased the speed of rotation is increased (*Stepper motor guide*, 2012).

The basic operation of a stepper motor is based off of sequential magnetic pulses that align a rotor when activated. There are generally 4 to 8 magnets activated in one pulse revolution of a stepper motor (A pulse revolution is achieved when all magnets in the cycle have been activated once). Each magnet-rotor tooth pair is misaligned before activation, thus causing rotation of the rotor when the magnet is activated. Each magnet activates, one after the other, aligning a respective rotor tooth to the activated magnet. Due to this design, speeds of stepper motors can be varied as quickly as an electric pulse. See figures 1 through 4 for a visual description.

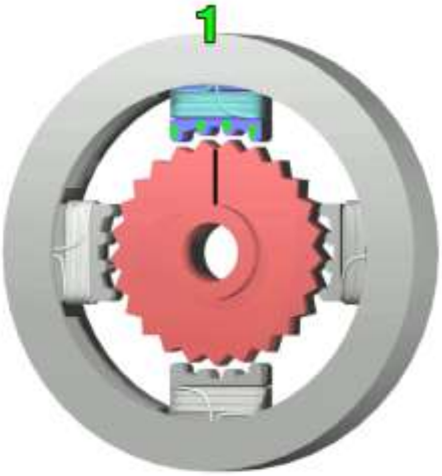


FIGURE 1. THE FIRST MAGNET IS ENERGIZED AND THE TEETH ON THE CENTRAL ROTOR AND MAGNET ALIGN (STEPPER MOTORS, 2007).

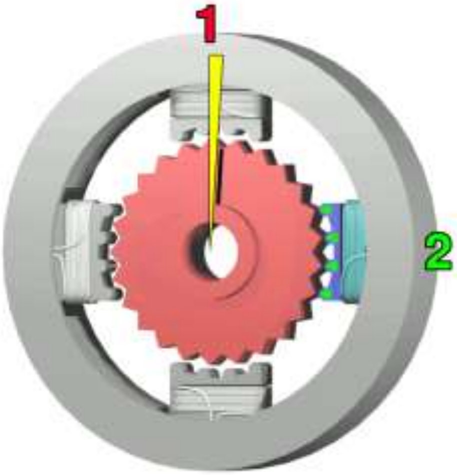


FIGURE 2. THE FIRST MAGNET IS DEACTIVATED AND THE SECOND MAGNET IS ENERGIZED. THE TEETH ON THE ROTOR ALIGN WITH THE TEETH ON THE MAGNET AND THE SHAFT ROTATES THE AMOUNT SHOWN BY THE ANGLE OUTLINED ABOVE (STEPPER MOTORS, 2007).

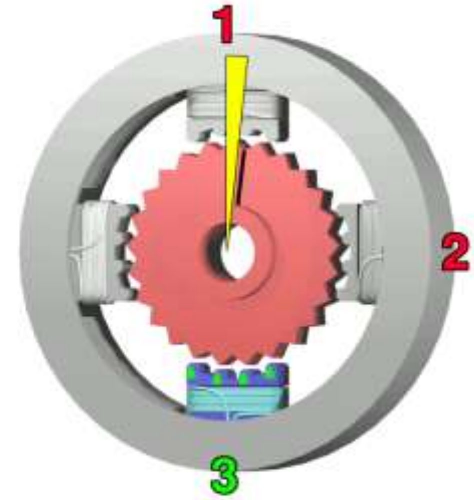


FIGURE 3. THE SECOND MAGNET IS DEACTIVATED AND THE THIRD MAGNET IS ENERGIZED. THE TEETH ON THE ROTOR ALIGN WITH THE TEETH ON THE MAGNET AND THE SHAFT HAS ROTATED THE AMOUNT SHOWN ABOVE (STEPPER MOTORS, 2007).

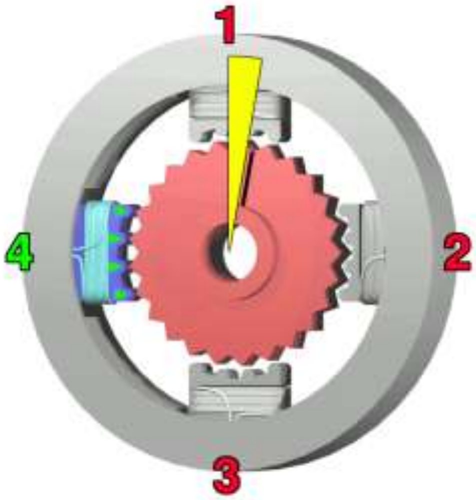


FIGURE 4. THE THIRD MAGNET IS DEACTIVATED AND THE FOURTH MAGNET IS ENERGIZED. THE TEETH ON THE ROTOR ALIGN WITH THE TEETH ON THE MAGNET AND THE SHAFT HAS ROTATED THE AMOUNT SHOWN BY THE ANGLE ABOVE. THIS SEQUENCE CONTINUES AT A VERY RAPID PACE AND A SMOOTH ROTATION OF THE SHAFT OCCURS (STEPPER MOTORS, 2007).

Precise rotational control is possible when a stepper motor is used. The motors can be stopped, started, and reversed very easily because all changes can be made with a digital pulse. It is also possible to lock the shaft in place by energizing all of the coils at the same time. When the shaft is rotating at very low speeds, maximum torque is produced. As speed increases the torque of the motor decreases greatly (*Stepper motor guide*, 2012).

3. Materials and Methodology

3.1 Basics of Theory

3.1.1 Reduce the length of the seed tube:

Presently, seed tubes are required to be very long because hydraulic and ground driven metering systems use mechanical shafts to drive the meter. These shafts are placed at the same height as the frame of the planter, thus requiring a long seed tube to deliver the seed to the ground. By reducing the length of the seed tube, the effects of gravity on seed placement are minimized. The ideal situation for a planter is to have the seed singulated as close to the ground as possible. However, when the seed singulation device is placed close to the ground, other factors must be considered. Plugging of the device in muddy situations, durability of the device in rocky conditions, and longevity of the device in bumpy situations all become concerns when the singulation device is placed near the ground.

3.1.2 Reduce the size of the metering system:

Four designs were considered to replace the current mechanical shaft driven disc and vacuum system that is currently used in virtually all planters. The bulky mechanical driven system was replaced with a much smaller electronic system, thus reducing the overall weight of the planter. Although reducing the overall weight of the planter is important, the main reason for reducing the size of the metering system is to help satisfy the first goal of reducing the length of the seed tube. Reducing the size of the metering system allows for a much larger range of meter placement on the planter.

3.1.3 Establish relative communication between individual row units:

Communication between individual rows allows for seeds to be placed in patterns that are much more economical for the farmer. If each row unit can communicate with the one next to it and an alternating pattern can be created, the space that each seed has to grow in is maximized. The ideal situation would be to have the first row unit place a seed in row one and have the second row unit place a seed halfway between the first and second seeds in row one as seen in figure 5. With fertilizer costs rising, it is important to plant seeds in a manner that will allow for equal and efficient use of soil nutrients. A checkered pattern (as seen in figure 5) allows for even distribution of nutrients to each plant and reduces waste for the farmer.

FIGURE 5 - ALTERNATING ROW SPACING (FRAUENBERG ET. AL., 2011).

3.1.4 Eliminate the need for row clutches and other mechanical components:

By using a system that makes each row unit independent of the other row units, current obsolete features are eliminated from the planting process. This is achieved by driving each row unit electronically, with each row unit having independent variability. This system eliminates row clutches and other mechanical components currently used to vary seed rates. This further reduces the amount of overlapping at the ends of each field. By eliminating row clutches and other mechanical components used in current planting systems; the planter is simplified and its weight is further reduced.

3.1.5 Provide accurate metering at increased ground speeds:

It is assumed that by increasing the speed that farmers can put seed into the ground accurately increases that value of the planting unit to the farmer. With the cost of labor higher than ever, it is essential that all farming processes be done as efficiently as possible. This requires the speed of application to be maximized. This projects objective was to accurately place seed at a ground speed of at least 9.66 kilometers per hour (6 mph). Some current planters are capable of seeding at 9.66 km/h, so this speed was chosen in order that planting speed not be sacrificed for precision.

3.1.6 Produce equal or better metering of seed rates compared to current systems:

Producing a system that increases the accuracy of current metering systems by up to a factor of 10 by electronically metering seeds presumably creates a more valuable product for the farmer. Considering the improvements due to the other 5 objectives, this objective seems more realistic. A 10x increase seems excessive for any goal, but when all the undesirable traits of the current metering systems are accounted for, it is clear that there is a lot of room for improvement.

3.2 Preliminary Work

In 2011, previous work was completed on this project in this senior design class. Several different designs were developed and tested to find a precise way to electronically meter seeds on a planter. The design that the previous group found to work best was to use an electronic solenoid with a vacuum source to hold and singulate the seeds. The design showed that it met the needs for a smaller package and less mechanical parts. After evaluating the previous work, it was found that it was impossible to use the solenoid method to effectively singulate seeds with current technology. Equation 1 was used to calculate the seed rate of each row unit of a planter. In Equation 1, **Q** is the seed rate (seeds/sec), **P** is the seed population (seeds/acre), **S** is the speed of the implement (mph), **L** is width of the implement (ft), **n** is the number of rows that the planter uses (rows), and 29700 is a constant.

The seed rate required was found to be too large for the previous design. The solenoid is not capable of withstanding the high frequency due to the extensive stroke length that is needed. The results of these calculations can be found in figure 6.

Equation 1 $$Q = \frac{P*S*L}{29700*n}$$

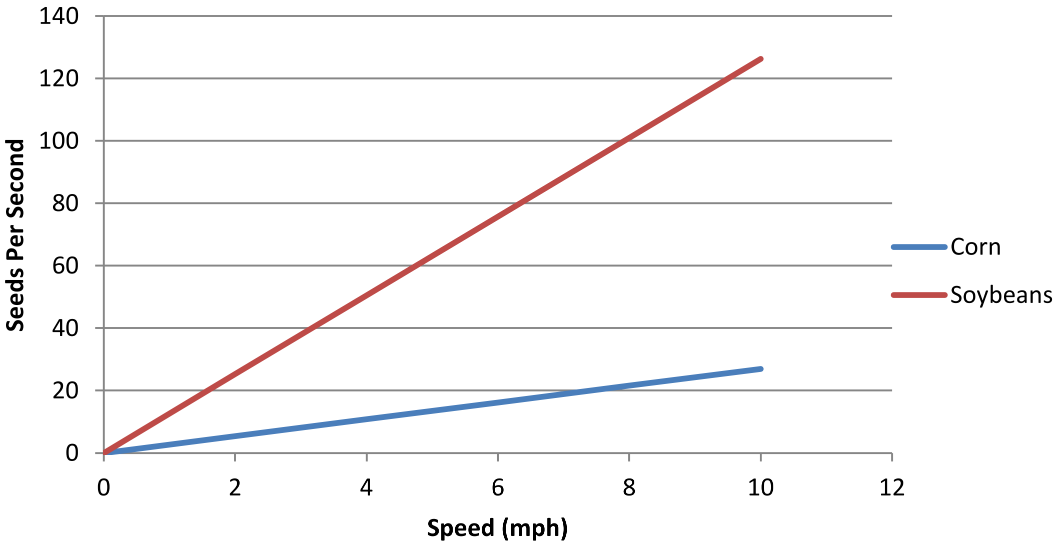


FIGURE 6. SEEDS PER SECOND VS. SPEED. POPULATION IS 32000 AND 150000 SEEDS /ACRE FOR CORN AND SOYBEANS RESPECTIVELY.

3.3 Evaluation of Designs

Four different ideas for an electronic seed singulation device were evaluated and considered for further design and modification. The four concepts include: a straight solenoid connected to a hinged door, a straight solenoid with an arm and perforated sliding separator, a rotating separator similar to a paintball separating device, and an electronic stepper motor retro-fitted onto the current disk meter.

3.3.1. Design # 1: Single solenoid with hinged door to singulate seeds

Figure 7 shows a concept sketch of the hinged door design. In this design only one electric solenoid is used. To allow fast cycling, the plunger on the solenoid is mounted to one end of a hinged door. When the solenoid cycles back-and-forth it opens and closes the bottom of the door. Using a design like this makes it possible to use a very small stroke on the solenoid. The one side of the bottom of the hopper will hold the seed in place and the door will only have to be swung very slightly to allow the seed to drop. Positive air pressure or vacuum can be used to make the seed drop out of the cavity faster. Ideally, the hinge unit and solenoid can be removed as one unit to allow easy service and repair. If the solenoid and hinge unit can be removed as one, it allows for the adjustment of the gap where the seed falls into, so different types and sizes of seeds can be used.

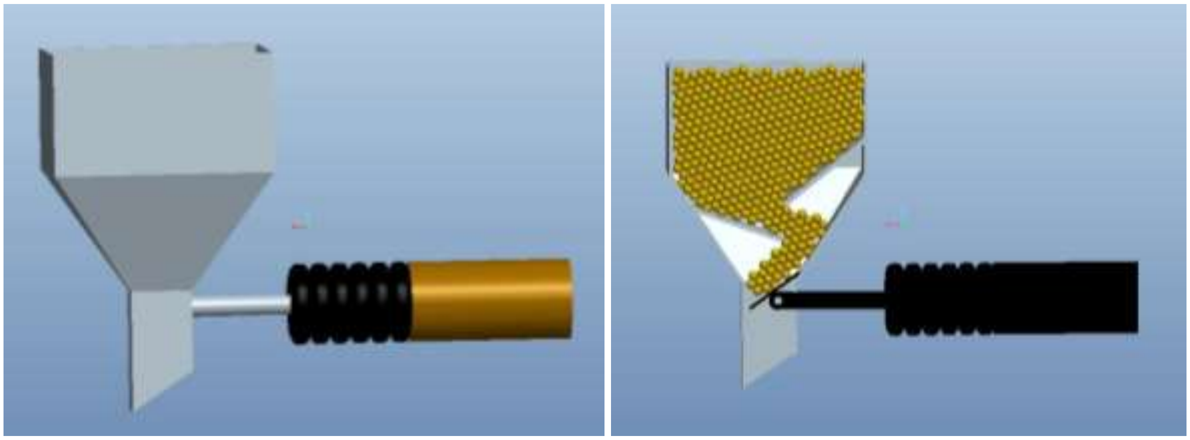


FIGURE 7. SOLENOID CONNECTED TO HINGED DOOR.

This design has simple parts and geometry but manufacturing is more difficult because parts are small and made of plastic. This design allows for a small package to be developed, so mounting the entire unit closer to the ground is simpler, allowing for a very short seed tube.

3.3.2 Design # 2: Single solenoid with perforated sliding "singulator" to singulate seeds

The design of the Solenoid Seed Singulation device as shown in figure 8 is a modification of previous solenoid singulation designs. The mechanical movement of a solenoid arm is used to slide a seed singulator back and forth. Previous designs have one seed for each stroke of the solenoid. In the design shown in figure 8, each stroke counts and drops out two seeds which would reduce the oscillation speed of the solenoid to half of what it would be by taking one seed per stroke. A design factor considered is the speed that a solenoid can singulate seeds, by implementing two seeds per stroke; a higher seed count per second can be reached. This design includes a hopper above the singulator that divides the seed into two shoots, one for each singulator slot. Figure 8 shows the seed boot that delivers the seed to the ground. The unique design has the seeds from each stroke drop in the boot at the same location eliminating the "pin-balling" effect down the boot. The solenoid in the design simplifies the method of singulating and counting seeds. With the solenoid shown in figure 8, one pulse of electricity (on/off) will have the ability to singulate two seeds with each stroke. Other ideas including an electric motor would need to implement variable rate and speed.

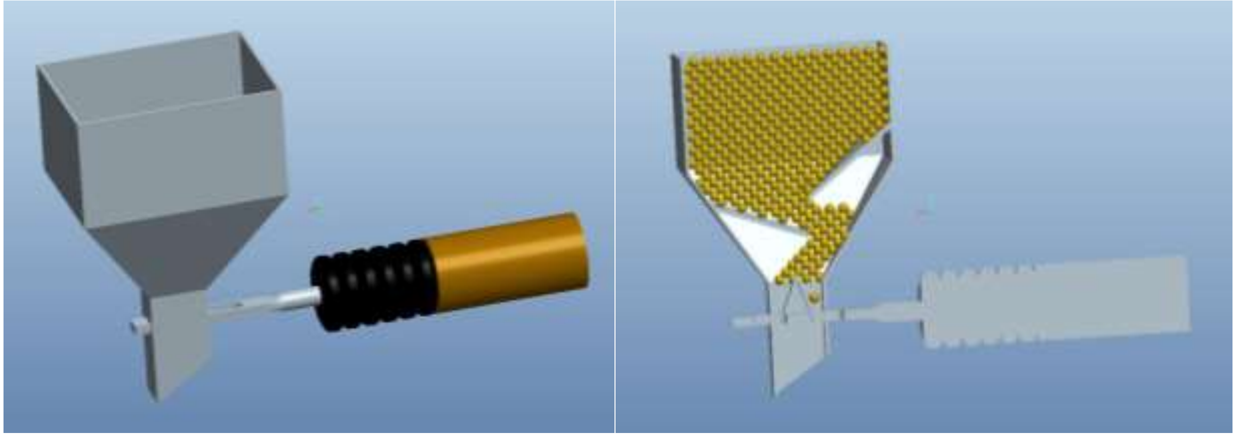


FIGURE 8. PERFORATED SLIDING SEPARATOR.

3.3.3 Design # 3: Rotating separator to singulate seeds

Design 3 is much different than designs 1 and 2, and also deviates from the solenoid design (see Figure 9). This system uses existing rotational separating technology of paintball guns to achieve the desired singulation rate. This design does not require the seed to be filtered into a smaller reservoir like it is in the first concept so the filtering tube of design 1 and 2 would not be necessary, thus allowing for a smaller design overall. The seed is drawn into a seed reservoir, as was done with the first and second concepts, but the seed lies directly on the separation mechanism. The seed rotates in the separation mechanism, shifts downward and then either vacuum draws the seed out of the separation mechanism or positive pressure pushes the seed out of the separation mechanism and into a tube protruding out from the side of the separation unit. The seed is then delivered to the ground. This concept is drawn from the separation mechanism of the Dye Rotor, which has one of the fastest firing rates among all paintball guns (50 balls per second).

FIGURE 9 - ROTATING SEPARATOR OF A PAINTBALL GUN.

3.3.4 Design # 4: Electronic stepper motor

This design does not change the vacuum/disk metering device but it does change how it is driven. Figure 10 shows an electronic stepper motor which is relatively small and portable. The idea behind this concept is to eliminate hydraulic and ground drives and replace it with an electronic drive. By eliminating the ground and hydraulic drives many things can be eliminated including: bearings, shaft, chains, and sprockets. This design can be retrofitted with virtually no adjustments to the current planter, which is attractive to customers. With this design and concept, planting populations are more easily controlled through a GPS unit. Each row unit has a stepper motor attached to it which eliminates the need for row clutches. By using a stepper motor, communication between rows is easily possible, because all that is required is a digital signal. In theory, by alternating rows it is possible to attain equidistant seed spacing among rows. The biggest advantage of using the stepper motor concept is the variation and control that is obtained. The stepper motor considered can operate in 1.9 degree increments which would allow for unprecedented variation control.

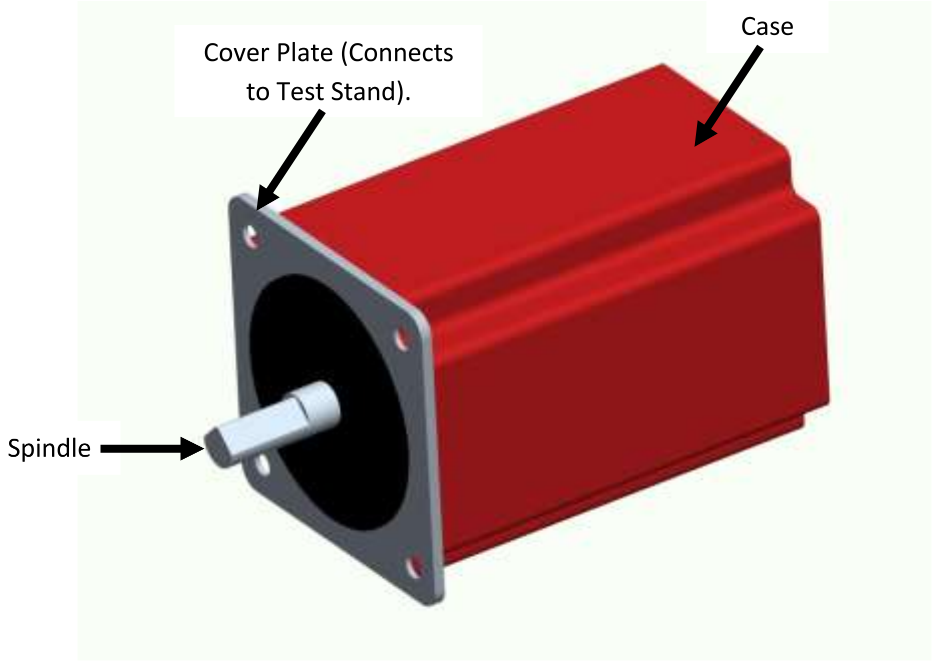


FIGURE 10 - ELECTRONIC STEPPER MOTOR.

All of these designs seem achievable and easily retro-fitted onto existing planters, so all of the concepts were analyzed by certain design criteria including: safety, ease of use, portability, durability, use of standard parts, and cost. Each criterion was given a specific weight and a rating of each criterion was given for each design. Each rating was multiplied by the weight to produce an overall rating for the criteria for each design. All of the overall ratings were added for each concept. The results are shown in Table 1.

TABLE 1. DESIGN CRITERIA

Design Criteria					
Criteria	Weight (%)	Design 1	Design 2	Design 3	Design 4
Safety	**5**	9	9	9	9
R X W		45	45	45	45
Ease of Use	**30**	7	7	8	9
R X W		210	210	240	270
Portability	**15**	7	9	8	5
R X W		105	135	120	75
Durability	**25**	6	7	8	9
R X W		150	175	200	225
Standard Parts	**5**	9	7	4	9
R X W		45	35	20	45
Cost	**20**	8	6	6	4
R X W		160	120	120	80
Total	**100**	715	720	**745**	740

As seen in table 1, all of the designs were given a high **safety** rating due to the lack of hazard of all three. Designs 1 and 2 were both given the same rating for **ease of use** due to their similar singulation style; however Design 3 was given a higher rating because of its simple rotating design. Design 4 was given the highest ease of use rating since it is virtually readily fitted onto current planters. As for **portability**, Designs 1 and 3 were given a decent rating but Design 2 outdoes Design 1 and 3 because of its ease of implementation. Design 4 is a heavier design and requires additional parts so a low portability rating was given. Design 4 is the most **durable** option since it eliminates the extension of the solenoid arm and incorporates a heavy duty design. Designs 1 and 2 utilize **standard parts** pretty well, whereas Design 3 does not; however Design 4 is ready to purchase and thus the highest standard parts rating was applied. The **cost** of Designs 2 and 3 are virtually equal, while Design 4 has a higher cost. Design 1 is overall, less expensive.

The results show that Design 3 is the best option based on the requirements for this project. Since this design eliminates the use of a solenoid, it is possible for the entire unit to fit into a smaller package. This allows for the unit to be mounted where it is needed.

Based on the design criteria and the feasibility of each project, the paintball separation mechanism was further considered. The Dye Rotor design consists of 5 main components as shown in figures 11 and 12: the **Rotor (1)**, **Abutment (2), Sloping Bottom (3), Planetary Gear System (4),** and **Motor (5).** Seeds flow directly on top of the rotor. The rotor separates the seeds that are piled above it. The separated seeds fall onto the sloping bottom, which is sloped towards the center of the mechanism. This slope allows the seeds to be helped to the center by gravity. The seeds are also collected and brought to the center by the abutment which turns in the opposite direction of the rotor. The seeds then fall out of the bottom of the device into the soil.

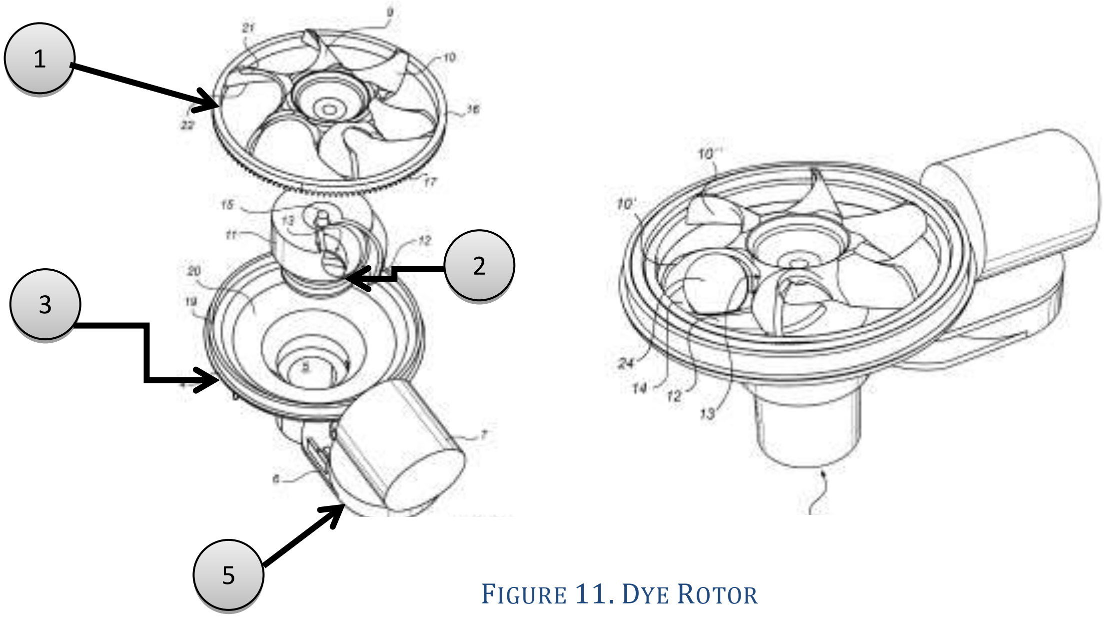


FIGURE 11. DYE ROTOR

Source: Dye Rotor U.S. patent No. 266349.

The whole mechanism is driven by a motor that runs a planetary gear system. The planetary gear system allows for the rotor and the abutment to be run in different directions, and also allows for the speeds of each to be varied while running off of a simple system. See figure 12 for a closer look at the system.

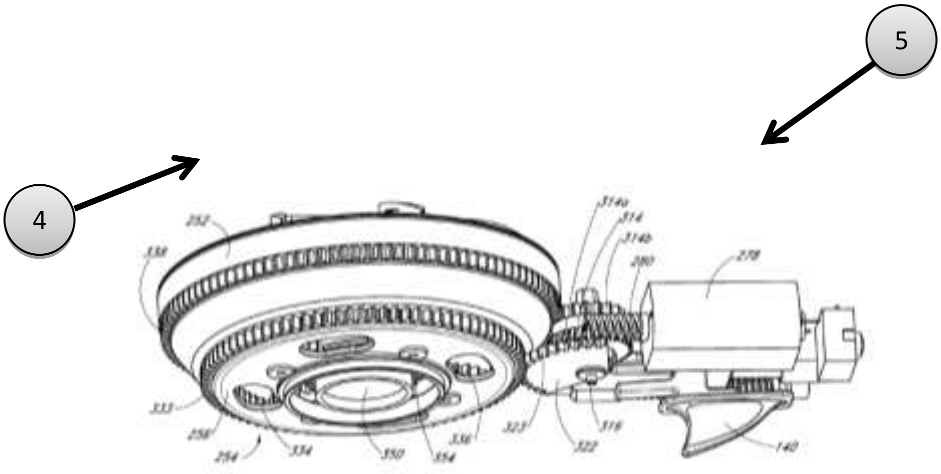


FIGURE 12. MOTOR DRIVING PLANETARY

Source: Dye Rotor U.S. patent No. 95942.

The Dye Rotor design would be scaled down to work on soybeans and a separate rotor would need to be created for corn. The main obstacle is the variety of seed shapes within a sample of seeds. If the rotor design is capable of separating seeds of slightly different sizes and shapes, the design could be a success but with further review, no seed sample can match the uniformity of manufactured paintballs. The shape of corn seed does not allow the Dye Rotor to singulate seeds without shearing or grinding them. There are also variations in the size of corn seeds. Seed size variation is targeted at 3/64” (1.19 mm) within each bag (www.asgrowanddekalb.com). If a corn seed has a diameter of ¼” (6.35 mm) then the variation of seed size per bag is roughly 18.5%. Soybean seeds are also known to have size differences in every bag. These size differences make the Dye Rotor’s technology a poor choice for this application. Since the Dye Rotor concept fails to prove viable due to inability to handle non-uniform seeds, the electronic stepper motor concept was implemented even though it was not the best option in the design analysis provided in table 1.

3.4 Preliminary Design

The design is to add a stepper motor to a planter unit as its driving component. A stepper motor was chosen by matching the torque required to turn a Case 1200 series planter unit and the output torque specified on the motor. By fully loading the metering unit and using a torque wrench, it was determined that the largest torque needed to turn the planter unit was 768 oz- in (48 in-lb, 5.4 N-m). Torque is calculated using equation 2, where **Tq** is the torque (in-lb), **F** is the force on the lever (lb), and **LA** is the length of the lever arm (in).

Equation 2 $$Tq = F * LA$$

The speed at which the stepper motor is expected to turn also was calculated. The Case 1200 series planter unit uses a #48 (48 holes per disk) seed meter disc to meter corn. For every revolution of the disc, 48 corn seeds are singulated and metered. A #130 (130 holes per disk) disc is used to meter soybeans. Using equation 3, **S**, the speed at which the motor turns (rev/sec), is calculated. **Q** is the seed rate (seeds/sec) calculated in equation 1, and **d** is the number of holes in the disc (disc #). The stepper motor is required to operate between 0 and 1.5 rev/sec.

Equation 3 $$S = Q/d$$

A test stand was built to mount a Case 1200 series planter unit and the stepper motor on it. The stand was made to quickly attach the planter unit with just two pins. The motor and the electrical drives were mounted directly to the stand to keep all the components in one place, making the stand easily portable. A coupler was made to connect the motor shaft to the meter shaft. This prototype test stand was used to verify that a stepper motor can drive a planter unit and offer the user complete variable control while maintaining acceptable singulation rates.

3.5 Materials Required

5 components are required for a stepper motor system. A **power source** (the power outlet in the wall) provides alternating current (A.C) to the power supply. The **power supply** converts the A.C. power into direct current (D.C.) power that can be easily used by the **microstepping drive**. The microstepping drive takes the input power from the power supply and converts it into a digital signal that the **stepper motor** can use to create motion. A **personal computer (PC)** is also used in the system to program parameters in the microstepping drive. All of the components were purchased from Automation Direct, a company that specializes in motion control. A power flow diagram of this system is shown in figure 13.

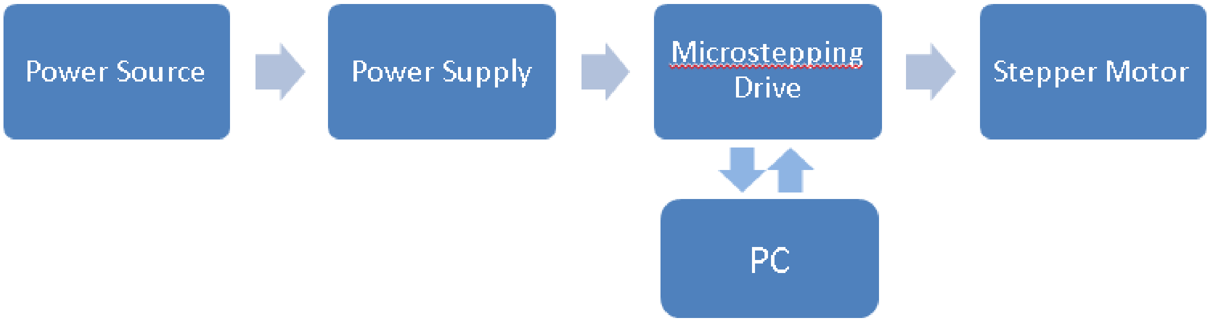


FIGURE 13. POWER FLOW DIAGRAM OF STEPPER MOTOR SYSTEM.

3.5.1 Power Source

The A.C. power source was provided by an 110V wall outlet.

3.5.2 Power Supply

In order to power the stepper motor, a power supply (Figure 14) is needed to take the power source and change it into a current and voltage that the stepper motor can use. For simplification, the power supply used is an 110V wall outlet (AC current). Although this will not be the power source on an agricultural planter, choosing a wall outlet gives the test stand portability to be moved and used in any room. In a real application a power take off (PTO) or hydraulically driven alternator would need to be used to generate power for the planter. The power supply (STP-PWR-7005) was selected from automationdirect.com because it was specifically made to run a NEMA 34 Triple Stack stepper motor. Its input is 120/240 VAC and outputs 70VDC at 5A. Other power supplies have been considered, but this one was guaranteed to work with the stepper motor purchased.

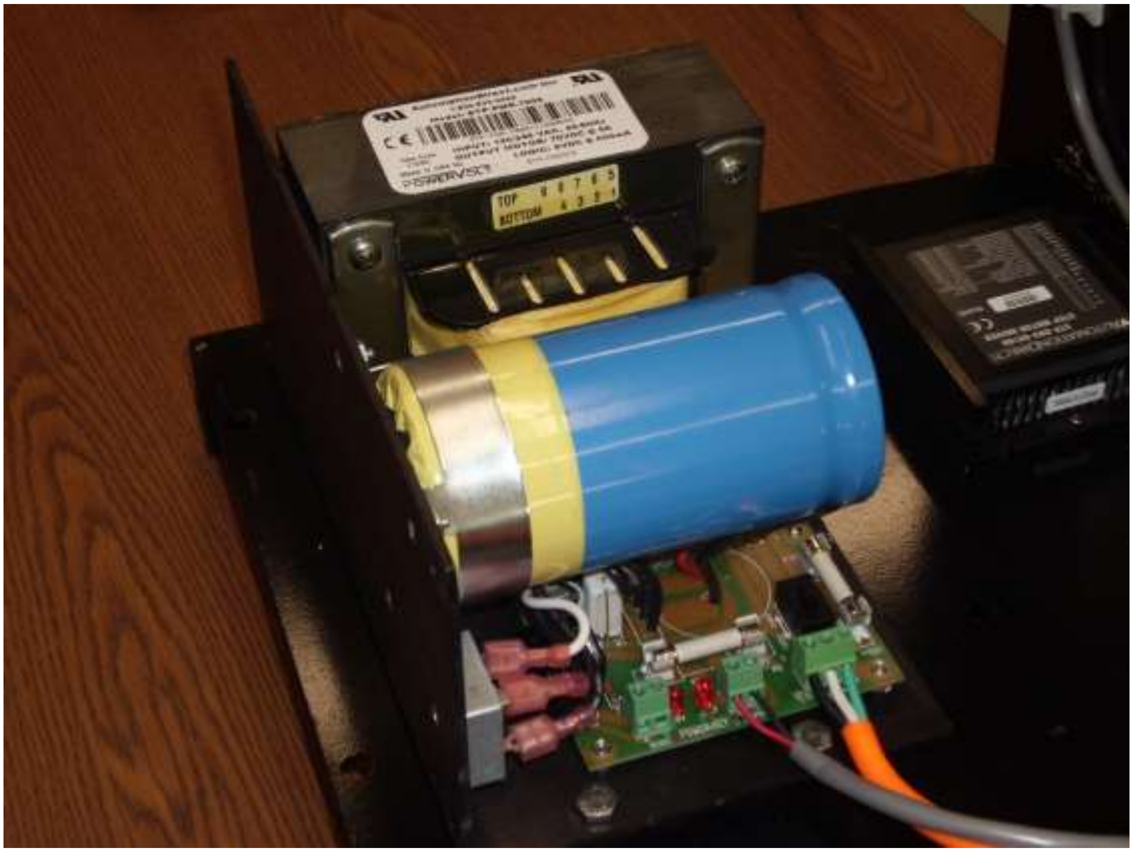


FIGURE 14. POWER SUPPLY USED TO CONVERT A.C. TO D.C.

3.5.3 Microstepping Drive

To convert the power from the power supply into a useable signal for the stepper motor, a microstepping stepper motor drive was used (Figure 15). The microstepping drive (STP-DRV-

80100) was selected because it worked well with the stepper motor and power supply and it was equipped with easy to use software. The microstepping drive provides up to 10 A of current at 80 VDC. The drive requires an input of 24-80 VDC. The drive allows the user to change the minimum and maximum rotational speeds, and the step rate of the stepper motor. It also allows inputs to be added to turn on or off the stepper motor. These inputs can be a potentiometer, a toggle switch, or a proximity switch. The microstepping drive also allows the user to monitor the speed of the stepper motor in real time, which was very helpful for this application.

FIGURE 15. MICROSTEPPING DRIVE

3.5.4 Stepper Motor

A NEMA 34 triple stack model stepper motor (Figure 16) was chosen for its hi-torque capabilities. A triple stack stepper motor has 3 rotors in line on the main shaft of the motor.

Having three rotors instead of one allows for higher torque outputs to be achieved, thus a triple stack stepper motor is ideal for the high torque application of singulating seeds. Specifications for the stepper motor selected can be seen in Table 2.

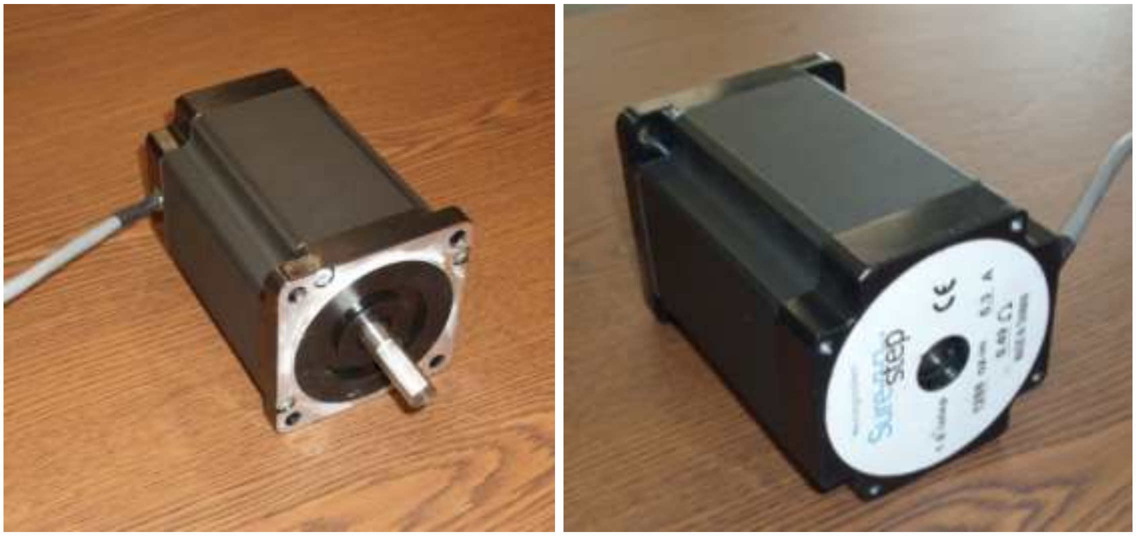


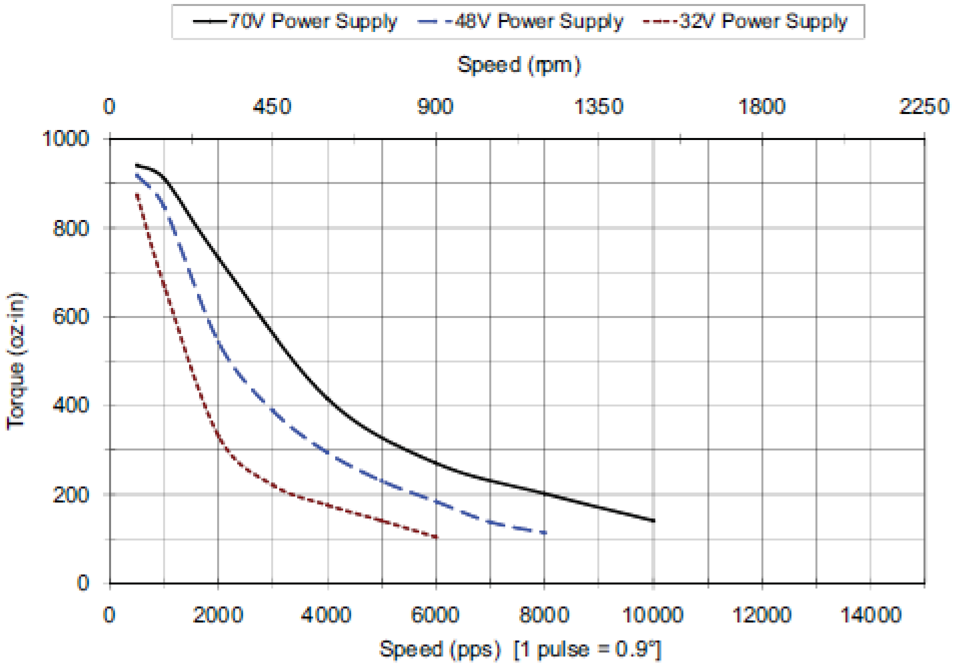
FIGURE 16. STEPPER MOTOR

TABLE 2. STEPPER MOTOR SPECIFICATIONS

Specifications					
Max Holding Torque	1291.77	oz-in	Concentricity	0.051	mm
Rotor Inertia	21.9	oz-in^2	Max Radial Load	17.7	kg
Rated Current	6.3	A/phase	Max Thrust Load	11.3	kg
Resistance	0.49	Ohm/phase	Storage Temp. Range	-20 - 100	°C
Inductance	4.14	mH/phase	Operating Temp. Range	-20 - 50	°C
Basic Step Angle	1.8	°	Operating Humidity Range	55 - 85	%
Shaft Runout	0.051	mm	Weight	4	kg
Max Shaft Radial Play	0.025	mm	Insulation Class	130	°C
Perpendicularity	0.076	mm			

There was some difficulty with specifying a motor for this application as physical size of the motor was important. It was found that the size of a stepper motor directly correlates with the torque output of the motor. A stepper motor also posed difficult because the torque curve decreases greatly as speed is increased, see Table 3.

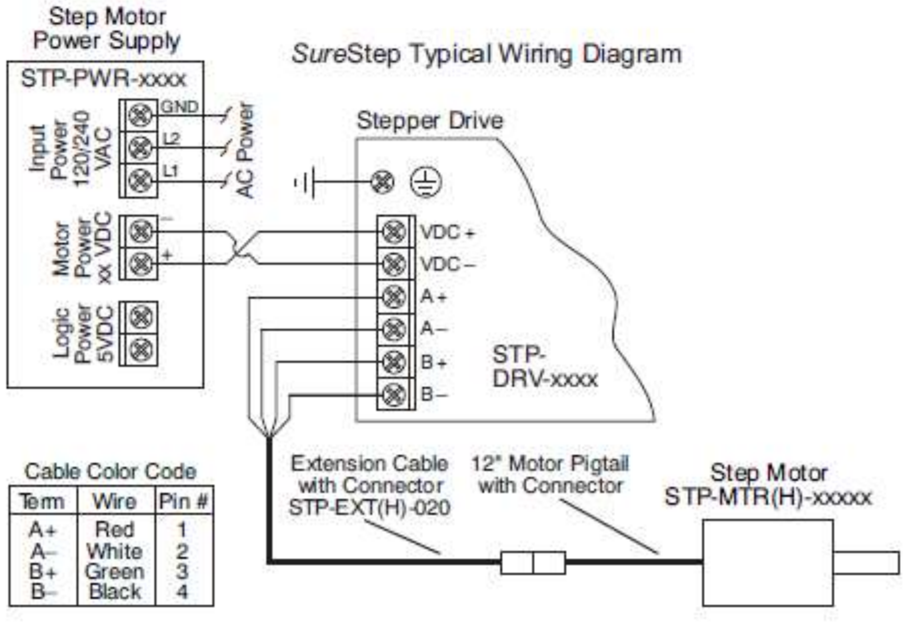
TABLE 3. TORQUE CURVE OF STEPPER MOTOR
SOURCE: AUTOMATION DIRECT (2012)



It was decided that matching or under sizing a motor would be unfavorable. Unforeseen factors such as dirty or wet conditions in the planter may cause a rise in the torque required to spin the planter unit. Having a 1.7 factor of safety was used to account for the varying conditions as well as putting less stress on the motor. Torque required with safety factor included was calculated using equation 3. Where **STq** is torque with safety factor included (oz-in), **Tq** is minimum required torque (oz-in), and **SF** is the safety factor. Since the minimum required torque was 718 oz-in, the safe torque was calculated to be approximately 1230 oz-in.

$$\textbf{Equation 4} \quad STq = Tq * SF$$

Figure 17 shows how the stepper motor is wired to the microstepping drive and the power supply.



Term	Wire	Pin #
A+	Red	1
A–	White	2
B+	Green	3
B–	Black	4

Figure 17. Wiring Diagram
Source: Automation Direct, 2012

3.5.5 Personal Computer

A personal computer (PC) was rented from the ABEN offices for testing purposes. The PC was used to program the microstepping drive and also to monitor the real time speed of the stepper motor while testing.

3.5.6 Precision Planting Stand

Arrangements were made to use the Precision Planting row unit stand (owned by the ABEN department) to test the concepts that were developed. The Precision Planting test stand is used to provide vacuum and seed monitoring capabilities, as it provides adequate control. The stand was also used to monitor singulation rates during testing.

3.5.7 Stepper Motor Test Stand

A new test stand was needed to mount the stepper motor and its required components in order to perform tests so that torque and power readings could be made. The test stand was made out of 1/8 in (3.175 mm) sheet steel that was purchased from Mac’s Hardware in Fargo and can hold all of the components necessary to test the electronic solenoid except for the vacuum. Vacuum was provided by the Precision Planting test stand. The stand was fabricated based off of the Precision Planting stand in order to produce a sturdy frame for testing. The shop in the ABEN department was used to build the stand using the shop tools (welder, drill press, chop saw, etc.).

Pro/Engineer software was used to complete a rendering of the proposed test stand with all of the components installed. The final design was built according to this concept. Figure 18 and 19 illustrate the concept developed. The test stand was designed to act similarly to a Precision Planting test stand. The test stand was needed to test the theory that the stepper motor design could be an effective alternative to hydraulic or mechanical drives without having to implement the concept into an actual planting system. By creating a test stand, the assumptions made were able to be proven and the findings were able to be demonstrated easily. The test stand also saved time by allowing tests to be performed at a convenient location rather than in a field.

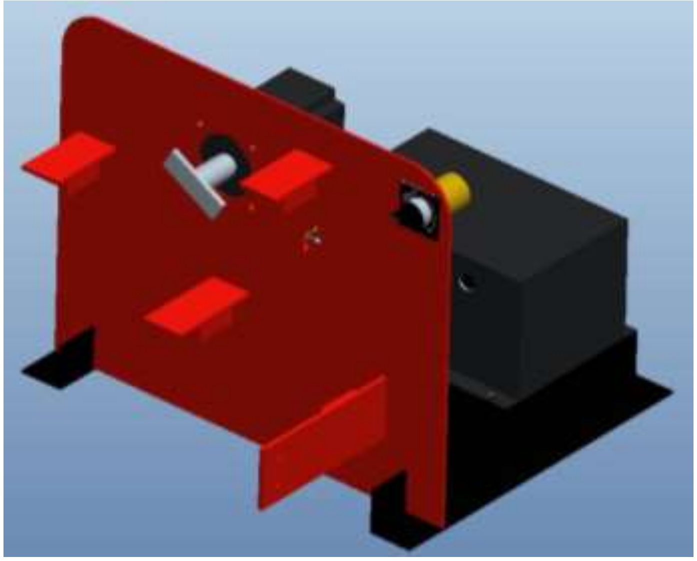


FIGURE 18. FRONT VIEW OF TEST STAND

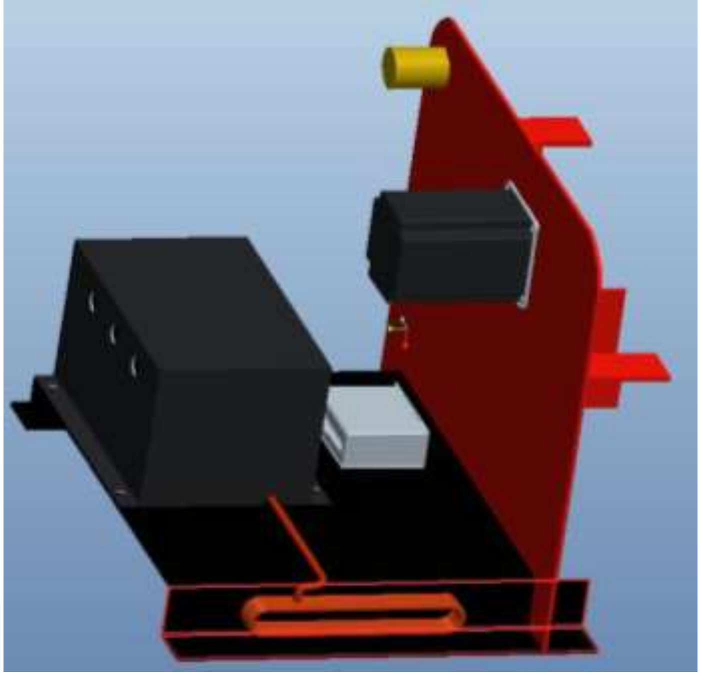


FIGURE 19. BACK VIEW OF TEST STAND

3.5.8 Metering Unit

Titan Machinery donated a Case 1200 series planter row unit to test the control of the stepper motor. The metering unit was needed to put actual loads on the stepper motor while testing. #48 and #130 seed disks were supplied with the row unit in order to test both soybeans and corn.

3.6 Bill of Materials

Table 2 shows the Bill of Materials for this project.

TABLE 4. BILL OF MATERIALS

Shopping list	Description	Price
Stepper Motor*	1288 oz-in NEMA 34, Triple Stack, Bipolar	$160.00
Cable*	20 ft Motor extension cable	$26.50
Stepper Drive*	10A 80VDC Microstepping, Bipolar, 2 Phase	$249.00
Power Supply*	Linear 70VDC 5A	$177.00
Potentiometer*	Dial, 22m 5K Ohm	$39.50
Extension Cord	10ft 110V	$6.50
Steel	36x18” 1/8” plate steel 3’- 1.5x1.5” 1/8” angle iron 18”- 2”w 3/16” thick strap iron 18x24” 18ga plate steel	$25.00
Paint	Red, Black Spray Paint	$10.00
Row Unit	Case 1200 Row Unit	$0.00
Total		$693.50

*Materials Purchased from AutomationDirect.com

3.7 Final Design of the Stepper Motor System with Test Stand

The final design was produced according to the Pro/Engineer renderings of figures 17 and 18. A coupler was manufactured as an adapter from the stepper motor to the Case 1200 row units drive assembly. Figure 20 shows a picture of the coupler. The two bolts shown in figure 20 are used to engage the flat sides of the stepper motor shaft. Figure 21 shows the coupler installed and engaged with the drive on the row unit.

FIGURE 20. COUPLER

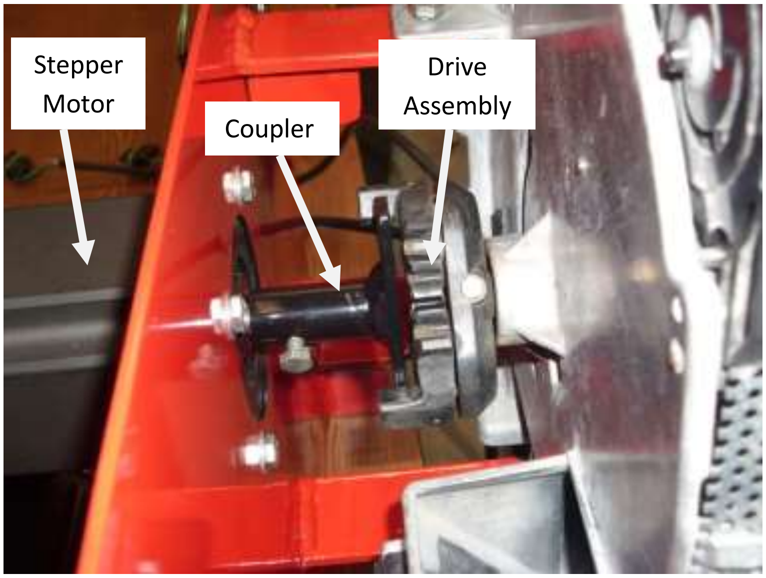


FIGURE 21. COUPLER BETWEEN MOTOR AND PLANTER UNIT

Figures 22 and 23 show the complete stand with the potentiometer and stepper motor installed. The potentiometer is used to regulate the input signal to the stepper motor. By using a potentiometer, the rotational speed of the stepper motor can be easily changed with the turn of a dial. The potentiometer range of speed is set by programming different speed ranges and increments into the microstepping driver via a computer. Once the microstepping driver is programmed, the unit can be disconnected from the computer and can run autonomously.

When building the stand, care was taken to make sure that there were no high voltage wires/cables exposed to eliminate the possibility of electrical shock. A cover for the power supply was constructed for safety as well (see figure 23). Rubber grommets were installed where wires came into contact with metal edges to comply with OSHA standard 1910.305(b) (1).

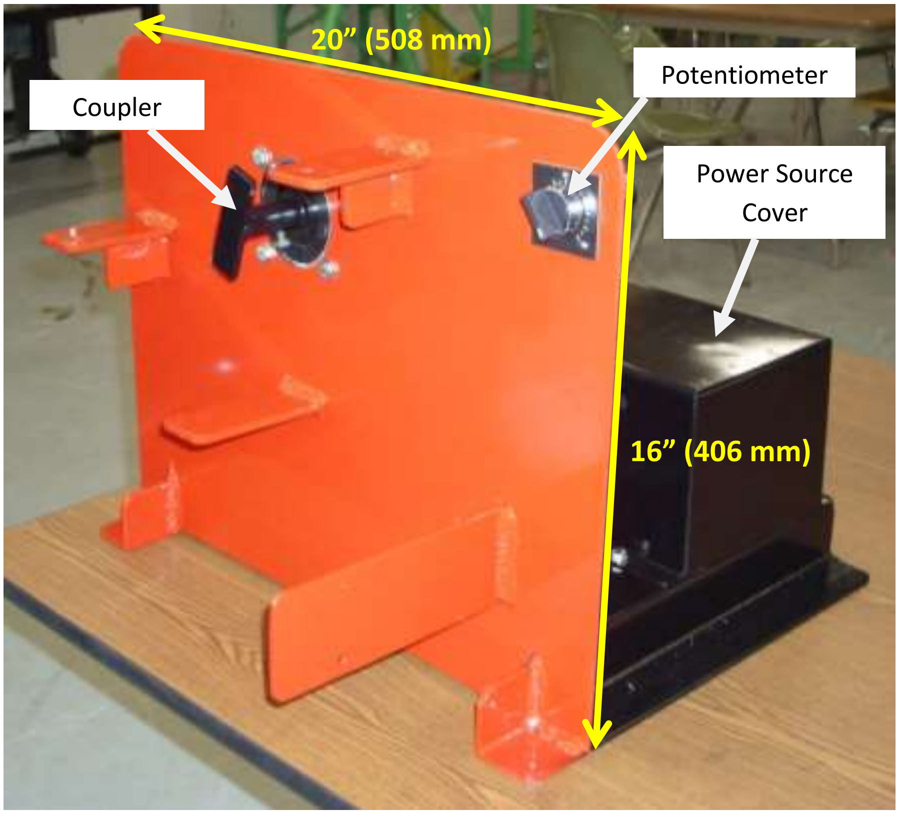


FIGURE 22. COMPONENTS ON FRONT OF TEST STAND

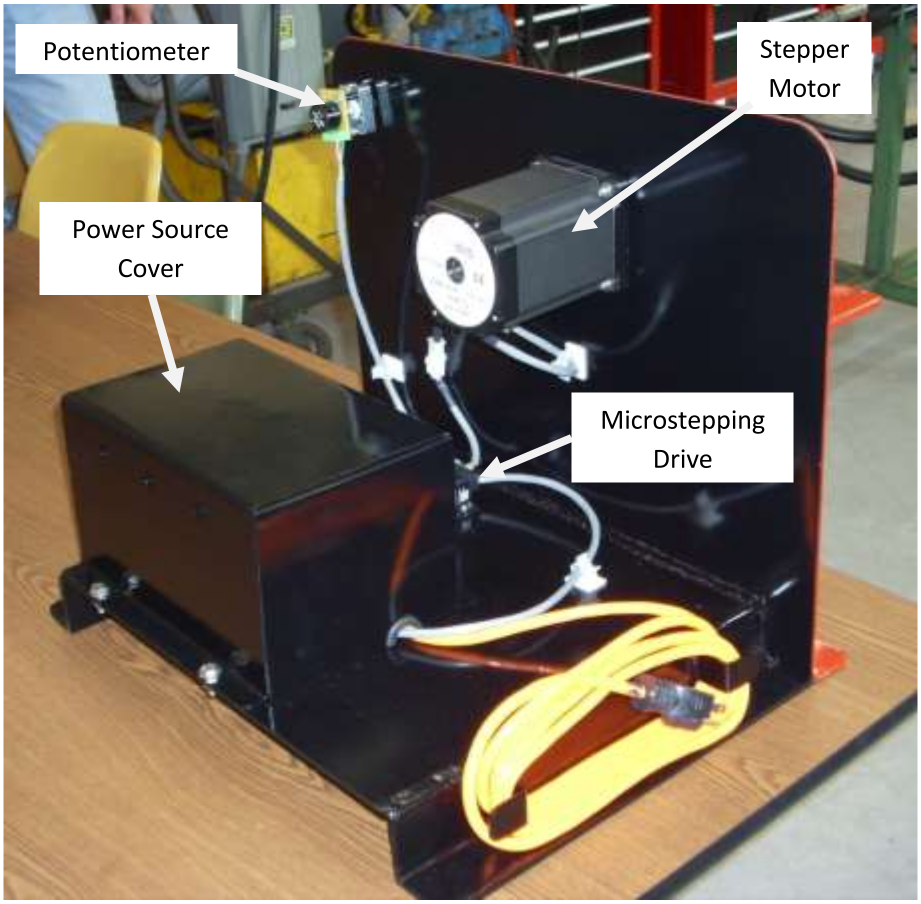


Figure 23. Components on Back of Test Stand

The Case 1200 row unit can easily be attached to and removed from the stand (figure 24). The row unit is held vertically and the seed sensor can be mounted quickly. To complete the system, the vacuum source from the Precision Planting stand is utilized.

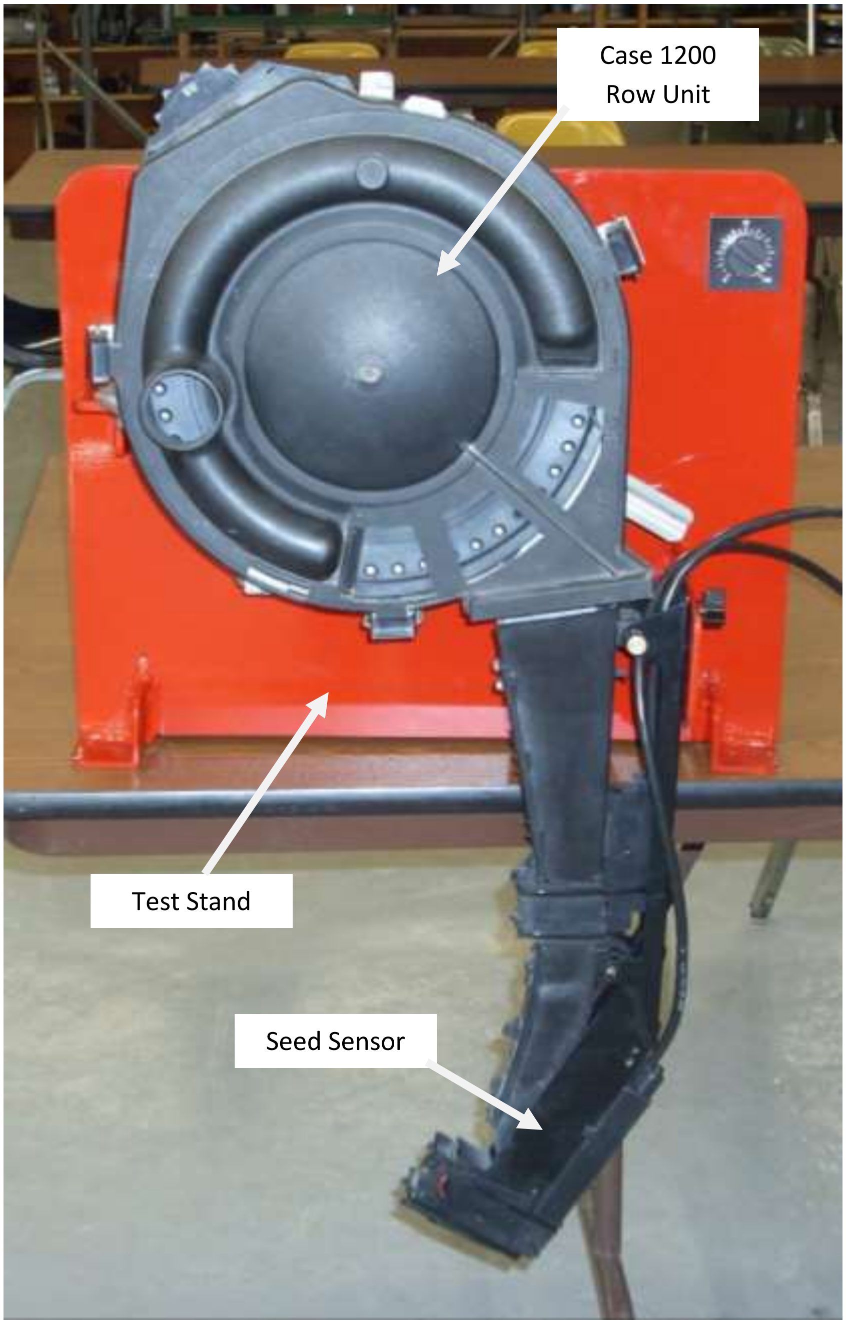


FIGURE 24. TEST STAND WITH CASE 1200 PLANTER UNIT

3.8 Impacts

The concept of driving a planter unit with a stepper motor is economically feasible. The NEMA 34 stepper motor is mass produced and easily available in the market. With low motor costs, using a stepper motor is competitive to alternate planter drives such as hydraulic and DC electric motors. Since the accuracy of planting produces higher yields and lower input costs, the unit should a relatively short payback-period. Since the stepper motor design used in this project is currently manufactured, there would not be issues with the manufacturability. Eliminating the steps of producing a process to create the proposed stepper motor design would greatly reduce the cost for the producer and customer alike.

The stepper motor is claimed to be safe by the manufacturer. All components are neatly contained to remove the chance of hazardous shock. Fewer moving parts also make the stepper motor design a favorable choice when considering safety.

The electronic stepper motor should be a sustainable product. The stepper motor used in this project has the potential to last up to 25000 hours, which would long outlast the life of the planter. Since a stepper motor runs off of magnets rather than a mechanical shaft, there is no friction to wear the motor out. The sustainability of a stepper motor would make marketing the product much easier and would be a benefit to customers.

The stepper motor design will have an effect on the environment as well. By eliminating contacting surfaces and hydraulic systems, greases and oils will not be required for the metering system. By removing some of the oils and resins from the planting process, there will be less likelihood for spills and contamination of water streams. The reduction in oils and resins is a good nice benefit, but a full Life Cycle Analysis (LCA) or Cradle to Grave Analysis would have to be performed to see if the environment benefits gained from using a stepper motor are greater than the "Electronic waste" produced when making electronic systems.

The success of the electronic stepper motor could be affected by political impacts, depending on the acceptance of additional electronics to current planting systems. Many farmers are reluctant to convert from a mechanical system to an electronic system, no matter the situation. A stepper motor design would have to be marketed well with a lot of data to “back up” the validity of the system. A recent trend toward electronics could however create an better acceptance among customers.

Another important impact of the stepper motor system is the effect it will have on precision agriculture. With virtually infinite speed variation, the stepper motor system allows for rapid changes of seeding rates to compensate for the varying fertility of the soil. With this stepper motor system, farming can become more precise than ever by eliminating waste of seed almost completely and by maximizing yields through accurate placement of seeds.

4. Results

4.1 Power Requirements

The test stand was fully assembled, then the Case 1200 row unit was loaded with seed and the vacuum was supplied by the Precision Planting stand. After setting the system to the standard conditions of 20 in H_20 (5 kPa) of vacuum at equilibrium, the stepper motor was engaged. The voltage and current were measured at different disk speeds (Figure 24) with a multi-meter and an ammeter respectively. The test was performed four times to produce statistically significant data. Figure 25 shows the average values of 3 of the tests. The fourth test's results were discarded due to errors in acquiring the data. The data was determined to be statistically significant (see Appendix 8.3).

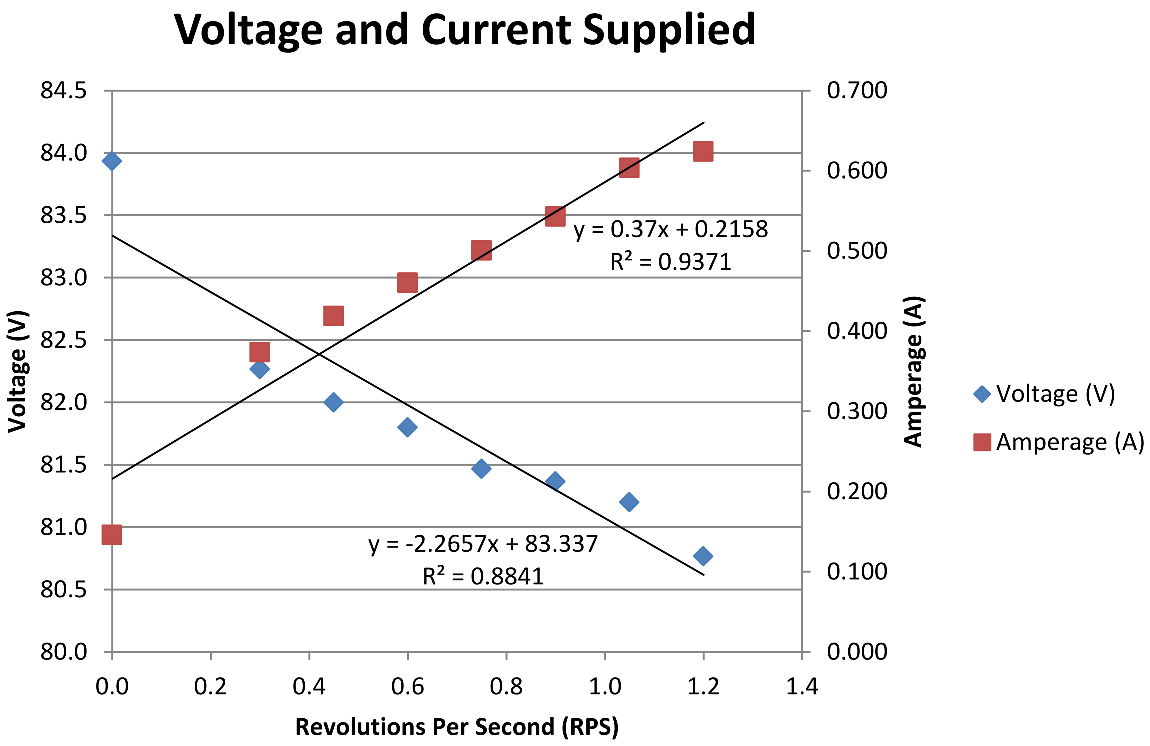


FIGURE 25. VOLTAGE AND CURRENT CURVES VS. RPS

It was necessary to measure the voltage and current in order to determine the amount of power required to drive the stepper motor system. The power required by the system is an important piece of information because if too much power is required, an additional power source will have to be added to the system. The power and amperage tests were conducted due to the hypothesis that an external power source would be necessary to run the stepper motor system. By applying Equation 5, the amount of power was calculated. In the equation, W is the power (Watts), V is the voltage (Volts), and I is the current (Amps). Figure 26 shows the findings of the calculations.

Equation 5 $$W = V * I$$

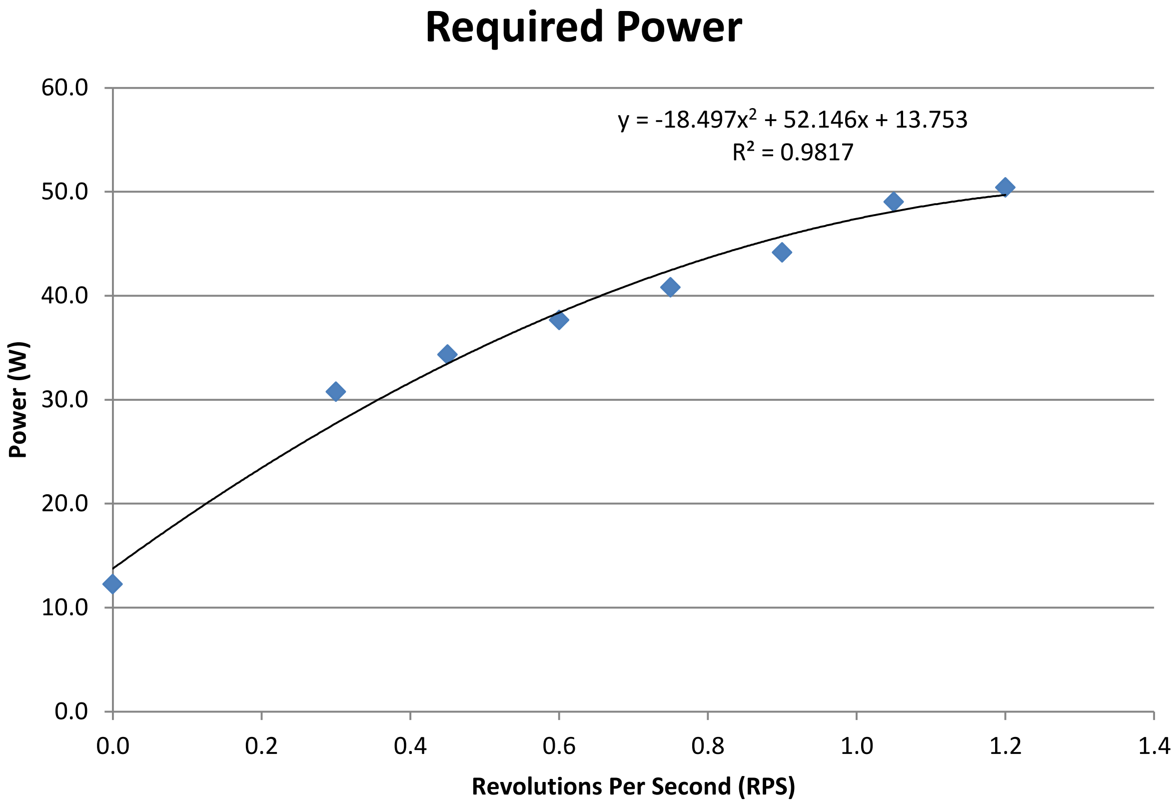


FIGURE 26. REQUIRED POWER VS. RPS

It was found that at a speed of 1.2 RPS the metering unit could no longer effectively meter seeds. The vacuum became erratic and singulation rates plummeted. Thus the highest use of power was recorded to be 50.4 Watts at 1.2 RPS.

4.2 Benchmarking

The effectiveness of the stepper motor was evaluated by running tests while using both the Precision Planting test stand and the stepper motor test stand to drive the meter. All parameters on both stands were set equal and the tests were run back to back to ensure accurate data was produced. The seed singulation percentage (number of doubles/skips vs. total seeds) was measured on both test stands at various speeds. Average values for the trial runs were calculated by using the data obtained from the testing (Appendix 7.3). Figure 27 shows the test results obtained. It is apparent that there is not a significant difference in singulation rates between the two test stands.

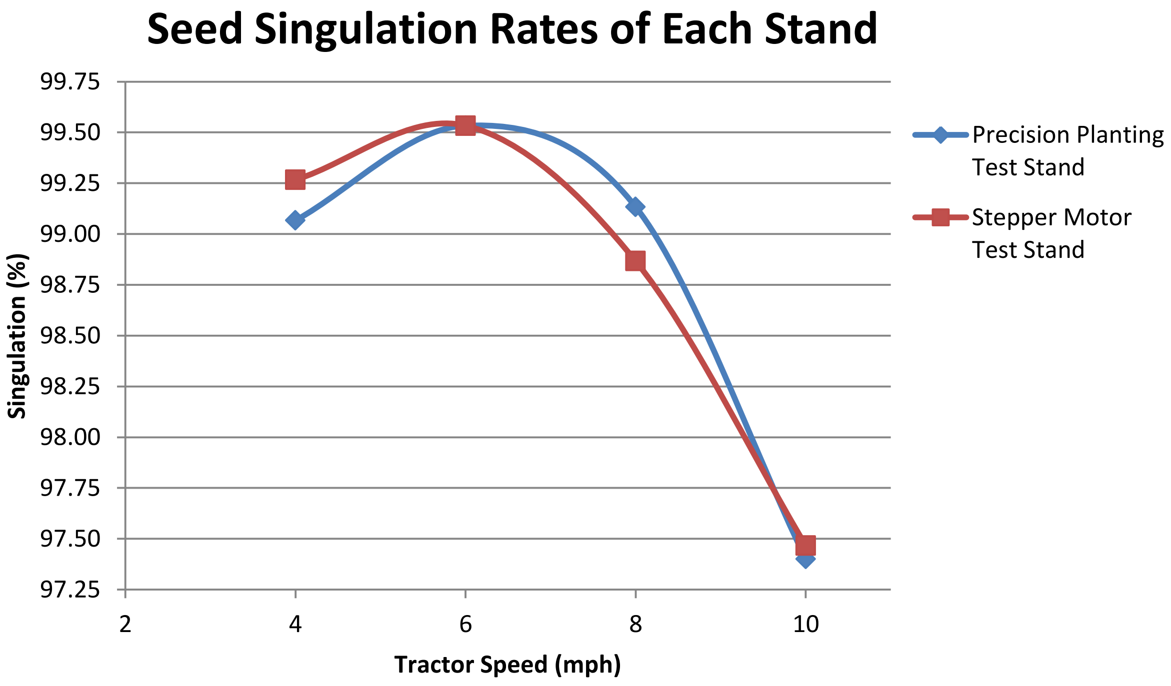


FIGURE 27. SINGULATION COMPARISON BETWEEN TEST STANDS

The results indicate similar peak performances but at different tractor speeds. The Precision stand had a maximum singulation rate of 99.5% at approximately 7 mph and the stepper motor had a maximum singulation rate of 99.5% at 6 mph.

5. Discussion

5.1 Power Requirements

The results from the electrical testing indicate that there will be a need for a higher output power source. The electrical system on a modern tractor is capable of outputting roughly 200 amps in a 12 volt charging system. To power the drive for the stepper motor, there is a requirement of 50.4 watts at 80.8 volts and 0.624 amps. If the voltage requirement is brought down to a 12 volt charging system, then 4.2 amps would be required to drive each stepper motor. If the stepper motor drive system is set up on a 36 row planter there would be a requirement of over 150 amps to drive the motors. This does not leave a lot of extra current available to run other systems on the tractor, such as the engine controller, lights, guidance system, etc. The charging system on the tractor would either have to be upgraded or a power take off (P.T.O) driven generator would have to be incorporated into the design. By using a stand-alone system like the P.T.O. generator, it would be possible to use almost any tractor to operate this system. A transformer would have to be used to bring the set the voltage to the desired level. Based off of the power requirements, the generator would need to be able to output around 2000 watts (2.5 Hp) to supply enough power for a 36 row planter.

5.2 Project Outcomes of Initial Goals

5.2.1 Reduce the length of the seed tube:

The stepper motor system would effectively allow for the elimination of a lengthy seed tube. By eliminating the shafts required to run the current system and using a compact design, the metering unit can be placed at a lower location on the planter. By placing the meter at a lower location, the seed tube would be reduced and scatter due to seeds bouncing while in the tube would be eliminated.

5.2.2 Reduce the size of the metering system:

The size of the metering system was not reduced due to the design selection. Parts were added to the current design; however other items were removed (shafts, gears, etc.) which essentially caused a very small net weight change. Although minimizing the overall weight of the planter is important, the main reason for reducing the size of the metering system was to help satisfy the first goal of reducing the length of the seed tube. So, while this goal was not necessarily satisfied, the overall goal was.

5.2.3 Establish relative communication between individual row units:

In the stepper motor system, each stepper motor is to be driven separately but a CAN bus wiring system could easily be implemented to allow for the motors' microstepping drive to communicate with another motor. Through CAN bus technology and the use of seed sensors, the alternating pattern first introduced in figure 5 of this paper could certainly be achieved. The amount of control that the user has with this system is superior to any mechanical or hydraulic planting system.

5.2.4 Eliminate the need for row clutches and other mechanical components:

Since each motor is controlled separately, there is no more need for row clutches. Each motor can turn on and off individually and can accelerate and decelerate individually. The stepper motor system provides a large improvement to precision agriculture and would essentially eliminate the need for row clutches, since they can only control whether the meter is on or off. Along with removing the row clutches, the gears, shafts and bearings required to run the clutches would be eliminated.

5.2.5 Provide accurate metering at increased ground speeds:

The metering system itself was not changed at this time, so the accuracy at increased speeds was unchanged, but by allowing rates to be changed more quickly some change should be noticed. To change the metering system and implement the stepper drive motor would have increased the project scope ten-fold. This goal should be revisited at a later time as there is still some areas of the meter that could use improvements.

5.2.6 Produce equal or better metering of seed rates compared to current systems:

The benchmarking tests provided the necessary information the show that although a stepper motor is used there is no real difference in the accuracy of seed placement. The seed singulation rates were almost identical and the slight variation could have been due to other factors during the testing. There should not have been much difference as the drive method is the only parameter that was changed.

6. Conclusions

Upon completing the necessary work to verify the operation of a stepper motor as the driving force for a seed meter; it has been concluded that this method is viable. It is important to remember that this project was not intended to prove that an overall electronic system would outperform a hydraulic or mechanical system, but to show that an electronic stepper motor was a viable alternative. The stepper motor meets all the needs of a drive system implemented on current planting devices and has the potential to out-perform current drive methods, but further development would be needed to create an entire system (testing on a real planter). The major conclusions of this project are:

- A properly sized stepper motor can be used to replace hydraulic or mechanical planter drives while maintaining equivalent singulation efficiencies.
- A stepper motor drive system enables communication between row units via digital pulses to provide more accurate and efficient planting.
- The drive tractor's charging system output would need to be increased, or a stand-alone generator would need to be used to meet the power requirements of a stepper motor system.
- Through the use of a stepper motor it is possible to accelerate and decelerate the metering speeds of row units individually.
- A stepper motor eliminates many mechanical components of a drive system and would cut down on maintenance to the implement due to the extended life cycle of the stepper motor.

Upon completion of this project, it is clear that further efforts should be invested in this technology due to the benefits outlined in this project.

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8. Appendix

8.1 Sample Calculations

Equation 1: 16.16 seeds/sec = 32,000 seeds/A * 6 mph * 20ft ÷ (29700 * 8 rows)

Equation 2: 48in-lb = 4 lb * 12 in

Equation 3: .337 rps = 16.16 seeds/sec ÷ 48

Equation 4: 1220 in-lb = 718 in-lb * 1.7

Equation 5: 17 watts = 85 volts * 0.2 amps

8.2 Power Data

Motor power calculations cannot be used because the current that flows into the motor acts like alternating current due to the pulses required to drive the motor. The spike in power can be attributed to the effect of reactive power. The real power is assumed to be identical to the power coming off of the supply.

Supply				Motor			
Avg. Voltage (V)	Avg. Amps (A)	Avg. Power (W)	Power Std. Dev	Avg. Voltage (V)	Avg. Amps (A)	Avg. Power (W)	Power Std. Dev
83.9	0.146	12.2	0.2				
82.3	0.374	30.7	0.2	5.7	4.5	25.9	0.4
82.0	0.419	34.3	0.5	7.9	4.6	35.9	1.0
81.8	0.460	37.7	0.1	9.7	4.6	44.2	0.4
81.5	0.501	40.8	0.9	11.9	4.6	54.8	0.6
81.4	0.543	44.2	0.7	14.4	4.6	66.4	1.0
81.2	0.604	49.0	1.1	16.5	4.6	76.6	1.6
80.8	0.624	50.4	1.1	19.4	4.7	90.6	1.3

8.3 Regression Analysis of Supply Voltage

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.965446374
R Square	0.932086702
Adjusted R Square	0.920767819
Standard Error	3.445118344
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	977.3745549	977.3746	82.3479398	0.000100484
Residual	6	71.21304241	11.86884		
Total	7	1048.587597			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95*
Intercept	18.04669864	2.457342637	7.34399	0.000326061	12.03379781	24.05959946	12.03379781	24.05959
X Variable 1	29.51194282	3.252156463	9.074577	0.000100484	21.55420263	37.46968301	21.55420263	37.46968

RESIDUAL OUTPUT

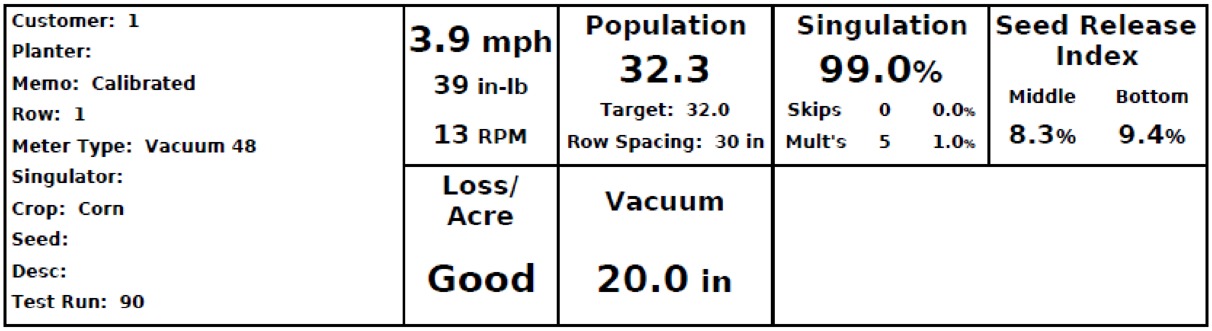
Observation	*Predicted Y*	*Residuals*
1	18.04669864	-5.820409747
2	26.90028148	3.84002963
3	31.3270729	3.003593762
4	35.75386433	1.901402339
5	40.18065575	0.606988694
6	44.60744717	-0.452469396
7	49.0342386	-0.016505263
8	53.46103002	-

3.062630019

8.4 Benchmarking

Seed Used: Dekalb
Hybrid Corn Seed DKC 30-23
Brand: RR2
Kind: Field Corn
Variety: A1010172
Relative Maturity: 80 average

4 mph ground speed (Precision Stand)



Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 90

3.9 mph
39 in-lb
13 RPM

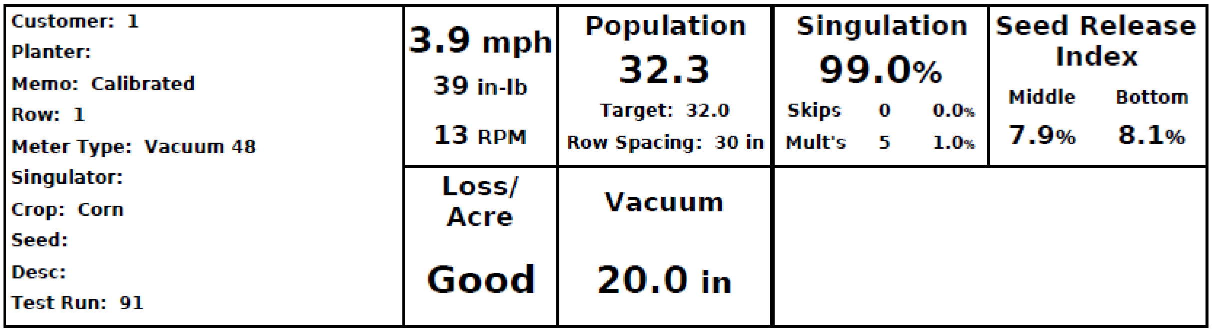
Population
32.3
Target: 32.0
Row Spacing: 30 in

Singulation
99.0%
Skips 0 0.0%
Mult's 5 1.0%

Seed Release Index
Middle 8.3%
Bottom 9.4%

Loss/Acre
Good

Vacuum
20.0 in



Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 91

3.9 mph
39 in-lb
13 RPM

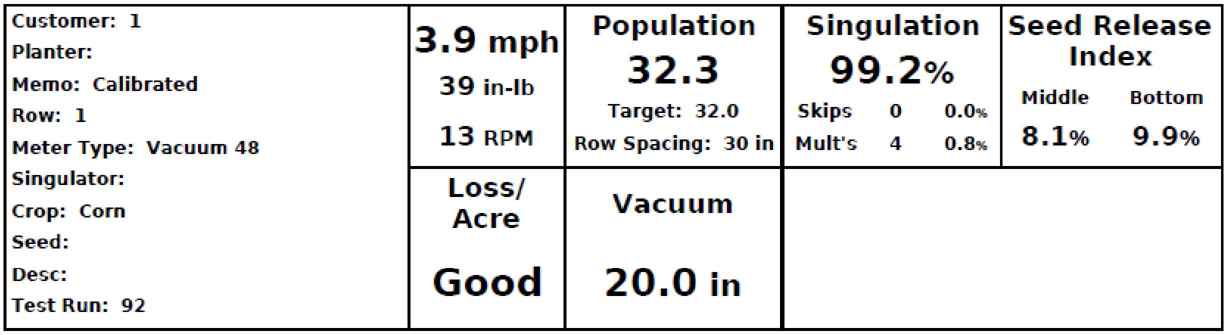
Population
32.3
Target: 32.0
Row Spacing: 30 in

Singulation
99.0%
Skips 0 0.0%
Mult's 5 1.0%

Seed Release Index
Middle 7.9%
Bottom 8.1%

Loss/Acre
Good

Vacuum
20.0 in



Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 92

3.9 mph
39 in-lb
13 RPM

Population
32.3
Target: 32.0
Row Spacing: 30 in

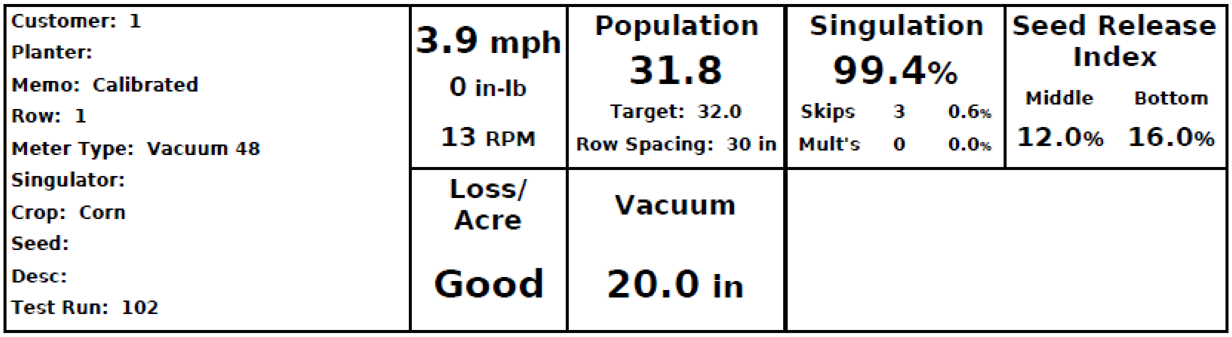
Singulation
99.2%
Skips 0 0.0%
Mult's 4 0.8%

Seed Release Index
Middle 8.1%
Bottom 9.9%

Loss/Acre
Good

Vacuum
20.0 in

4 mph ground speed (Test Stand)


Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 102

3.9 mph
0 in-lb
13 RPM

Population
31.8
Target: 32.0
Row Spacing: 30 in

Singulation
99.4%

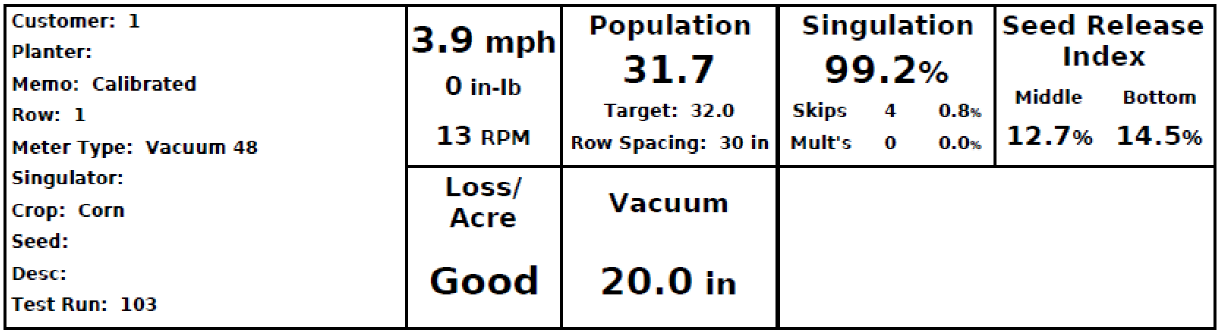
Skips	3	0.6%
Mult's	0	0.0%

Seed Release Index

Middle	Bottom
12.0%	16.0%

Loss/ Acre
Good

Vacuum
20.0 in


Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 103

3.9 mph
0 in-lb
13 RPM

Population
31.7
Target: 32.0
Row Spacing: 30 in

Singulation
99.2%

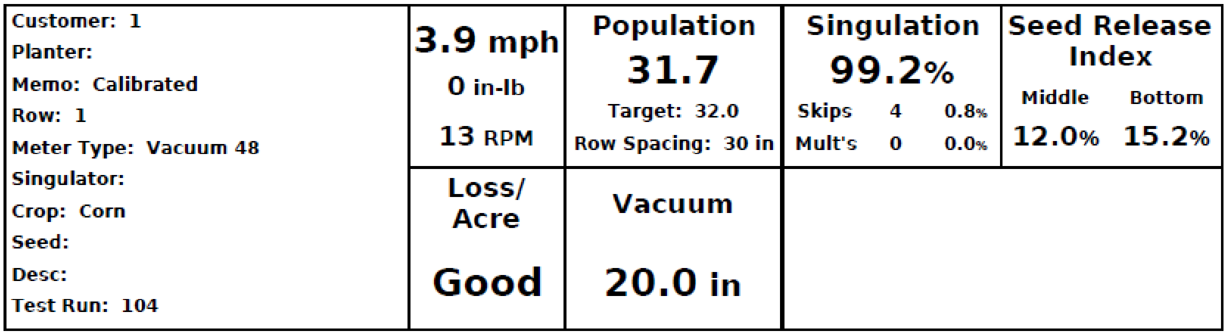
Skips	4	0.8%
Mult's	0	0.0%

Seed Release Index

Middle	Bottom
12.7%	14.5%

Loss/ Acre
Good

Vacuum
20.0 in


Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 104

3.9 mph
0 in-lb
13 RPM

Population
31.7
Target: 32.0
Row Spacing: 30 in

Singulation
99.2%

Skips	4	0.8%
Mult's	0	0.0%

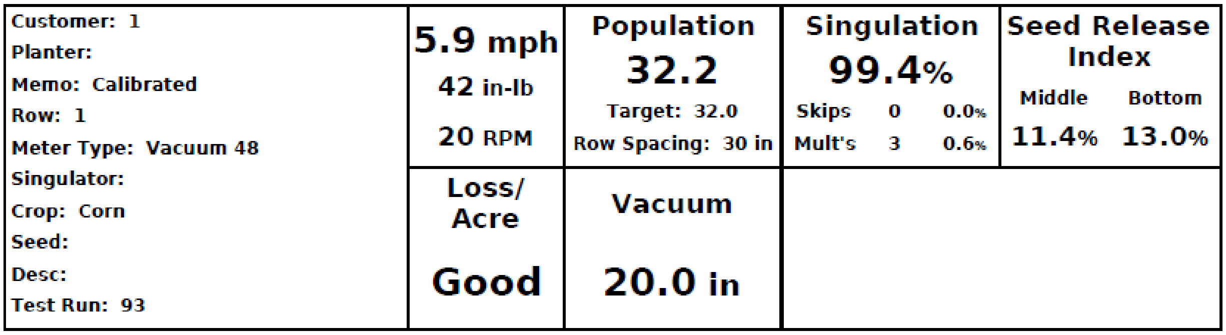
Seed Release Index

Middle	Bottom
12.0%	15.2%

Loss/ Acre
Good

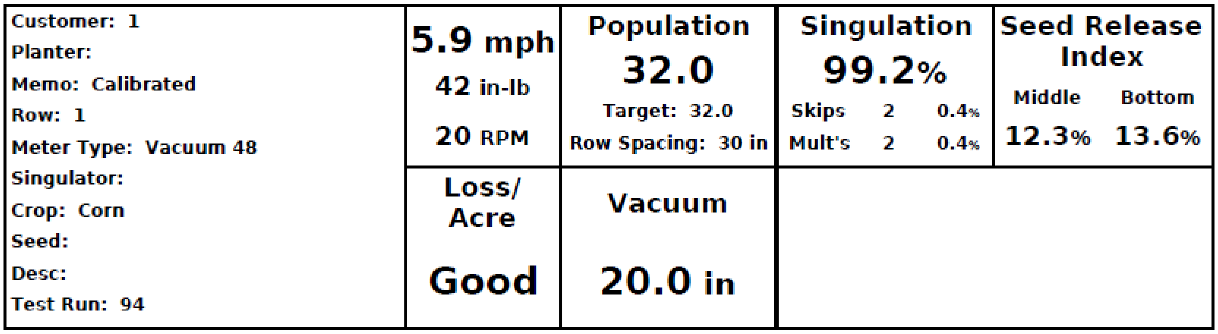
Vacuum
20.0 in

6 mph ground speed (Precision Stand)



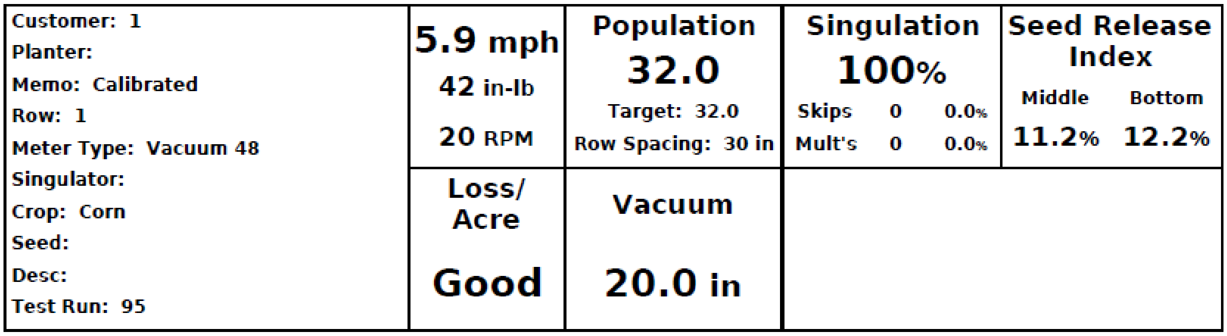
Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 93

5.9 mph 42 in-lb 20 RPM	Population 32.2 Target: 32.0 Row Spacing: 30 in	Singulation 99.4% Skips 0 0.0% Mult's 3 0.6%	Seed Release Index Middle 11.4% Bottom 13.0%
Loss/ Acre Good	Vacuum 20.0 in		



Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 94

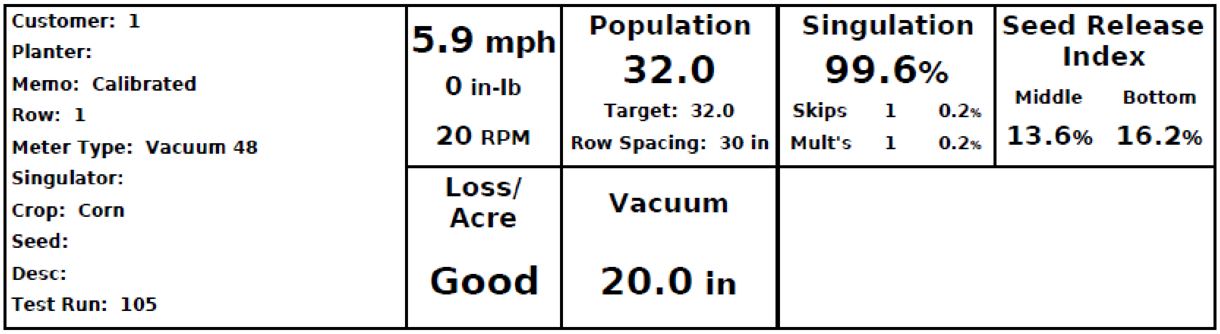
5.9 mph 42 in-lb 20 RPM	Population 32.0 Target: 32.0 Row Spacing: 30 in	Singulation 99.2% Skips 2 0.4% Mult's 2 0.4%	Seed Release Index Middle 12.3% Bottom 13.6%
Loss/ Acre Good	Vacuum 20.0 in		



Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 95

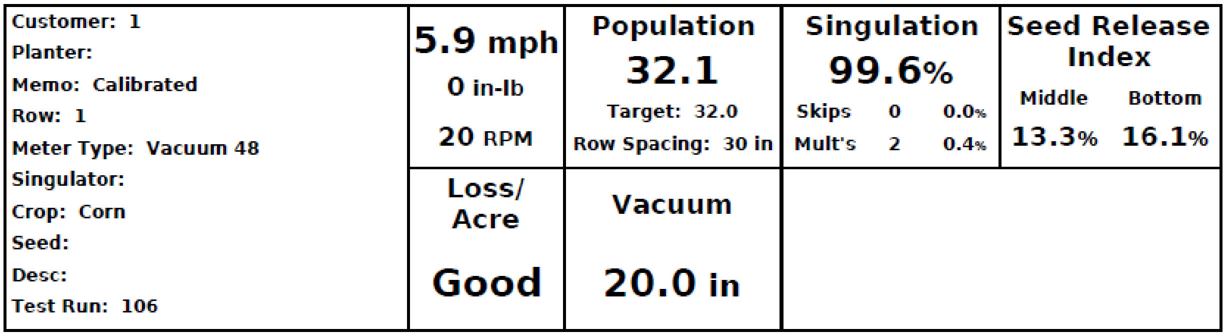
5.9 mph 42 in-lb 20 RPM	Population 32.0 Target: 32.0 Row Spacing: 30 in	Singulation 100% Skips 0 0.0% Mult's 0 0.0%	Seed Release Index Middle 11.2% Bottom 12.2%
Loss/ Acre Good	Vacuum 20.0 in		

6 mph ground speed (Test Stand)

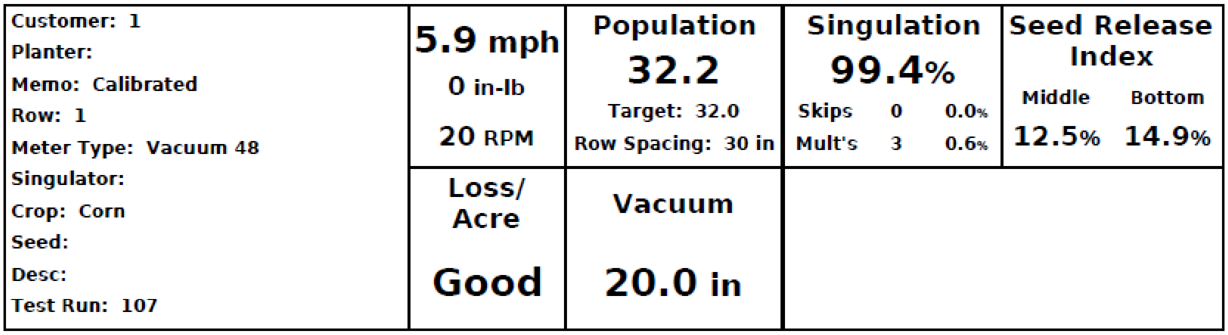


Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 105

5.9 mph 0 in-lb 20 RPM	Population 32.0 Target: 32.0 Row Spacing: 30 in	Singulation 99.6% Skips 1 0.2% Mult's 1 0.2%	Seed Release Index Middle 13.6% Bottom 16.2%
Loss/ Acre Good	Vacuum 20.0 in		

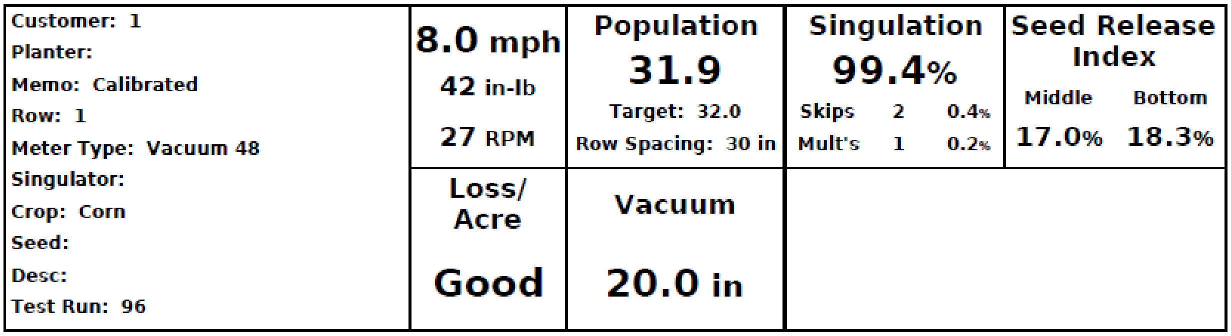


Customer: 1 Planter: Memo: Calibrated Row: 1 Meter Type: Vacuum 48 Singulator: Crop: Corn Seed: Desc: Test Run: 106	5.9 mph 0 in-lb 20 RPM	Population 32.1 Target: 32.0 Row Spacing: 30 in	Singulation 99.6% Skips 0 0.0% Mult's 2 0.4%	Seed Release Index Middle Bottom 13.3% 16.1%
	Loss/ Acre Good	Vacuum 20.0 in		

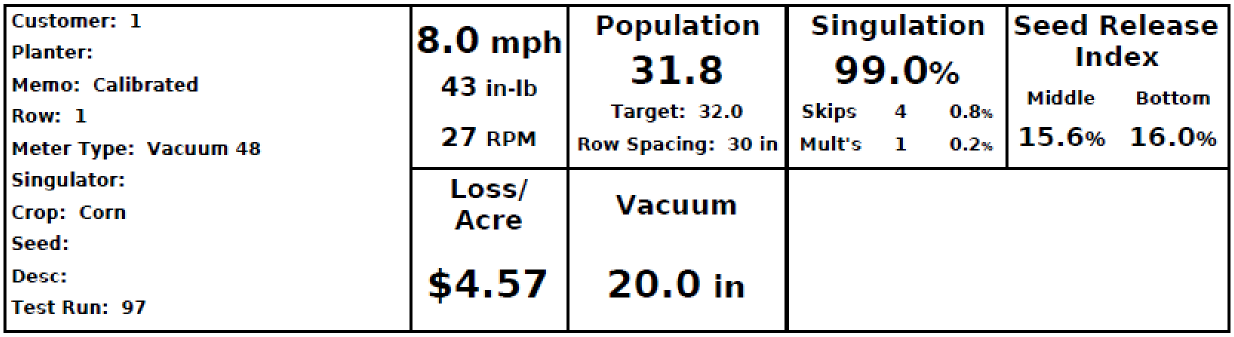


Customer: 1 Planter: Memo: Calibrated Row: 1 Meter Type: Vacuum 48 Singulator: Crop: Corn Seed: Desc: Test Run: 107	5.9 mph 0 in-lb 20 RPM	Population 32.2 Target: 32.0 Row Spacing: 30 in	Singulation 99.4% Skips 0 0.0% Mult's 3 0.6%	Seed Release Index Middle Bottom 12.5% 14.9%
	Loss/ Acre Good	Vacuum 20.0 in		

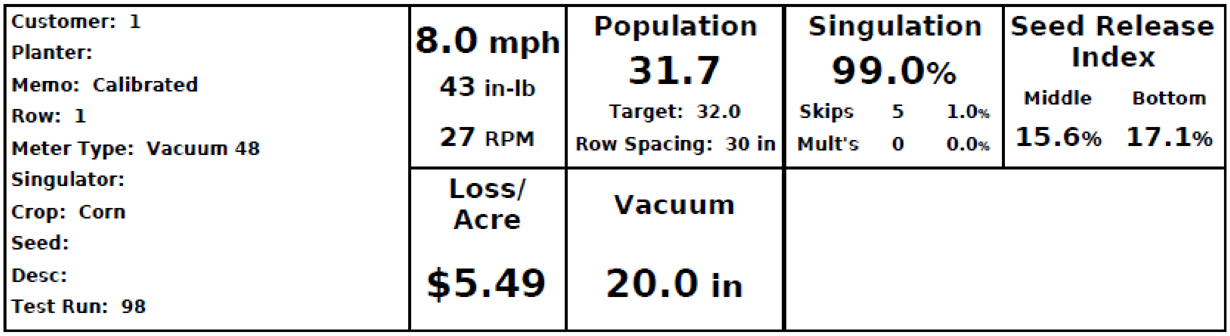
8 mph ground speed (Precision Stand)



Customer: 1 Planter: Memo: Calibrated Row: 1 Meter Type: Vacuum 48 Singulator: Crop: Corn Seed: Desc: Test Run: 96	8.0 mph 42 in-lb 27 RPM	Population 31.9 Target: 32.0 Row Spacing: 30 in	Singulation 99.4% Skips 2 0.4% Mult's 1 0.2%	Seed Release Index Middle Bottom 17.0% 18.3%
	Loss/ Acre Good	Vacuum 20.0 in		

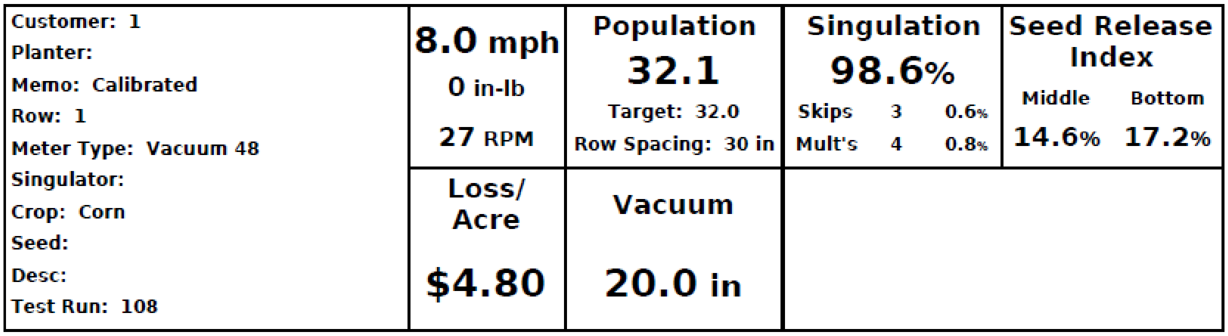


Customer: 1 Planter: Memo: Calibrated Row: 1 Meter Type: Vacuum 48 Singulator: Crop: Corn Seed: Desc: Test Run: 97	8.0 mph 43 in-lb 27 RPM	Population 31.8 Target: 32.0 Row Spacing: 30 in	Singulation 99.0% Skips 4 0.8% Mult's 1 0.2%	Seed Release Index Middle Bottom 15.6% 16.0%
	Loss/ Acre $4.57	Vacuum 20.0 in		

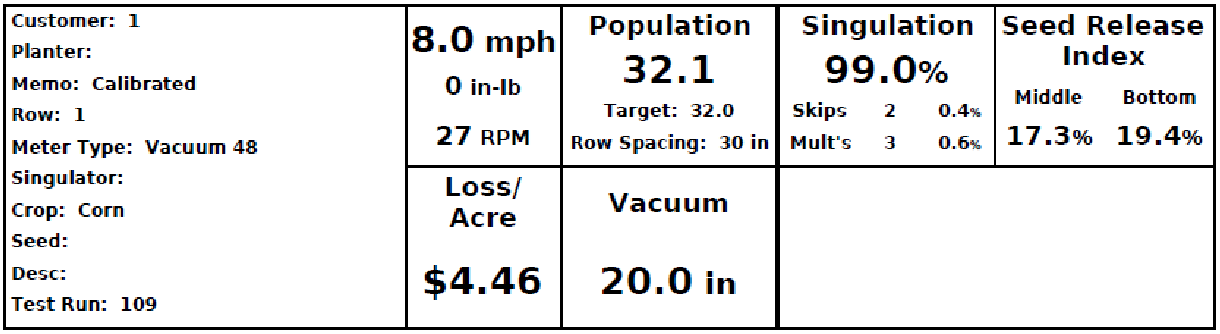


Customer: 1 Planter: Memo: Calibrated Row: 1 Meter Type: Vacuum 48 Singulator: Crop: Corn Seed: Desc: Test Run: 98	8.0 mph 43 in-lb 27 RPM	Population 31.7 Target: 32.0 Row Spacing: 30 in	Singulation 99.0% Skips 5 1.0% Mult's 0 0.0%	Seed Release Index Middle Bottom 15.6% 17.1%
	Loss/ Acre $5.49	Vacuum 20.0 in		

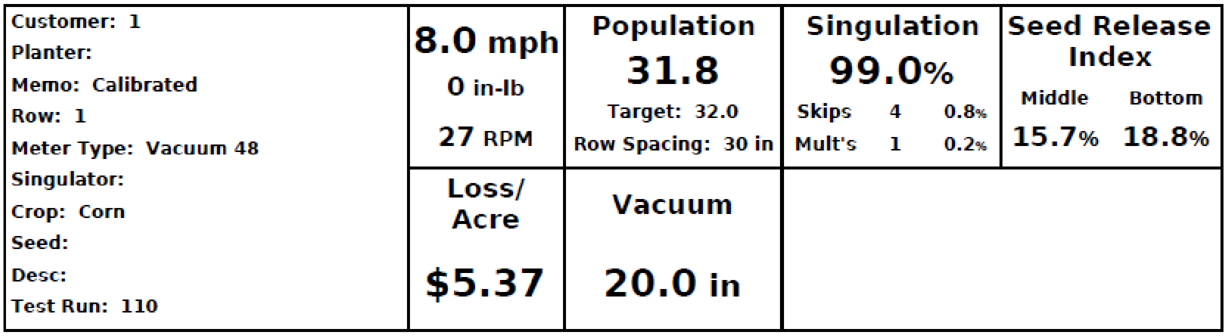
8 mph ground speed (Test Stand)



Customer: 1 Planter: Memo: Calibrated Row: 1 Meter Type: Vacuum 48 Singulator: Crop: Corn Seed: Desc: Test Run: 108	8.0 mph 0 in-lb 27 RPM	Population 32.1 Target: 32.0 Row Spacing: 30 in	Singulation 98.6% Skips 3 0.6% Mult's 4 0.8%	Seed Release Index Middle Bottom 14.6% 17.2%
	Loss/ Acre $4.80	Vacuum 20.0 in		

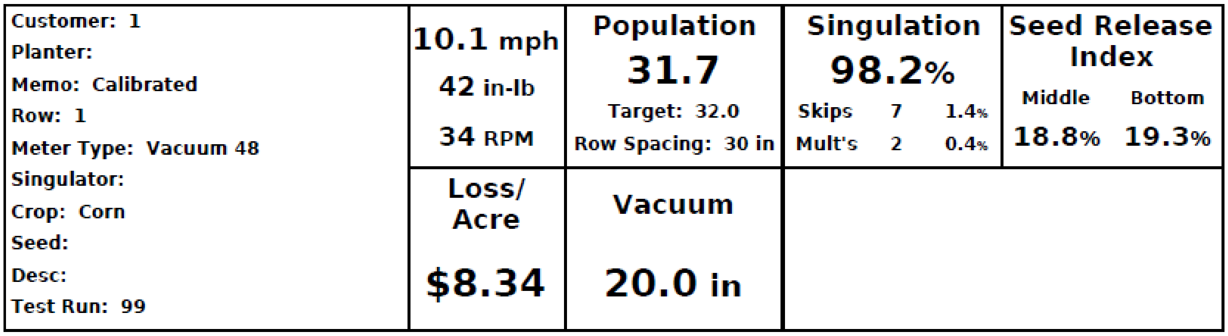


Customer: 1 Planter: Memo: Calibrated Row: 1 Meter Type: Vacuum 48 Singulator: Crop: Corn Seed: Desc: Test Run: 109	8.0 mph 0 in-lb 27 RPM	Population 32.1 Target: 32.0 Row Spacing: 30 in	Singulation 99.0% Skips 2 0.4% Mult's 3 0.6%	Seed Release Index Middle Bottom 17.3% 19.4%
	Loss/ Acre $4.46	Vacuum 20.0 in		

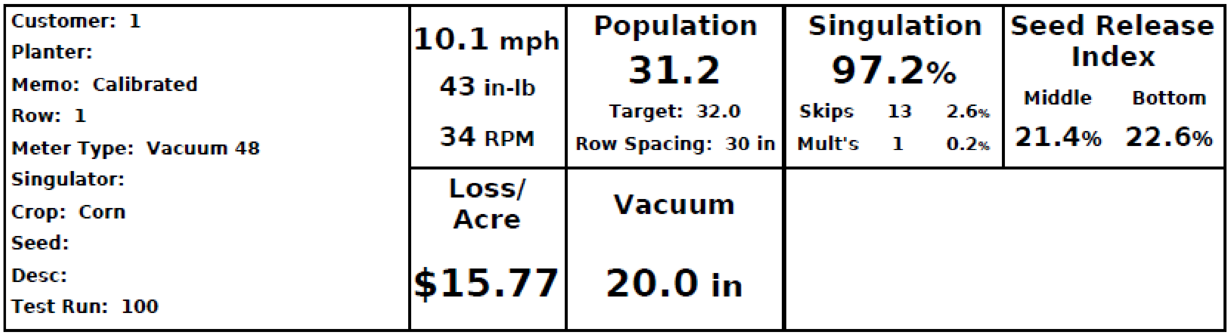


Customer: 1 Planter: Memo: Calibrated Row: 1 Meter Type: Vacuum 48 Singulator: Crop: Corn Seed: Desc: Test Run: 110	8.0 mph 0 in-lb 27 RPM	Population 31.8 Target: 32.0 Row Spacing: 30 in	Singulation 99.0% Skips 4 0.8% Mult's 1 0.2%	Seed Release Index Middle Bottom 15.7% 18.8%
	Loss/ Acre $5.37	Vacuum 20.0 in		

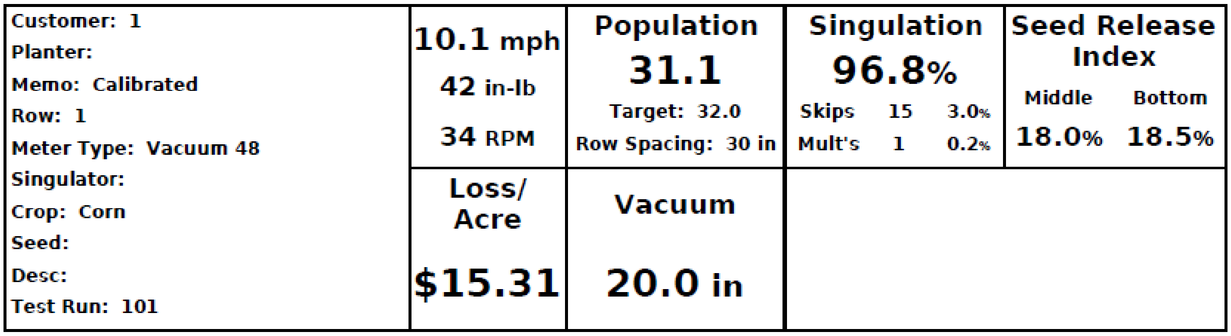
10 mph ground speed (Precision Stand)


Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 99

10.1 mph 42 in-lb 34 RPM	Population 31.7 Target: 32.0 Row Spacing: 30 in	Singulation 98.2% Skips 7 1.4% Mult's 2 0.4%	Seed Release Index Middle 18.8% Bottom 19.3%
Loss/ Acre $8.34	Vacuum 20.0 in		

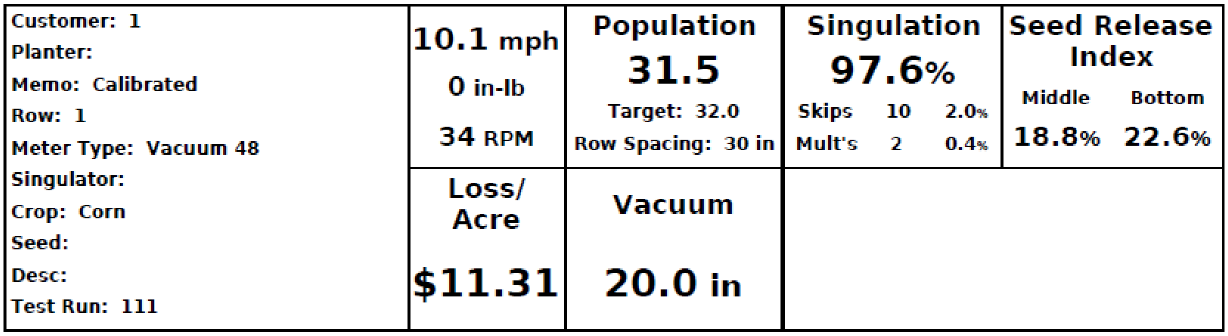

Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 100

10.1 mph 43 in-lb 34 RPM	Population 31.2 Target: 32.0 Row Spacing: 30 in	Singulation 97.2% Skips 13 2.6% Mult's 1 0.2%	Seed Release Index Middle 21.4% Bottom 22.6%
Loss/ Acre $15.77	Vacuum 20.0 in		

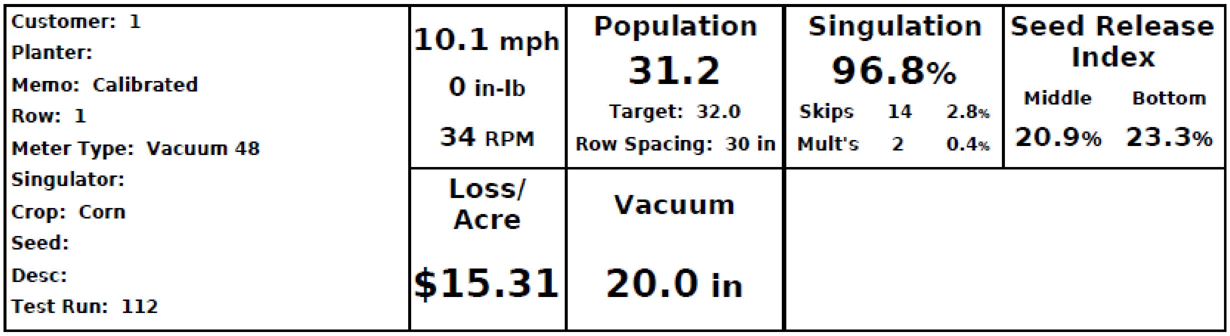

Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 101

10.1 mph 42 in-lb 34 RPM	Population 31.1 Target: 32.0 Row Spacing: 30 in	Singulation 96.8% Skips 15 3.0% Mult's 1 0.2%	Seed Release Index Middle 18.0% Bottom 18.5%
Loss/ Acre $15.31	Vacuum 20.0 in		

10 mph ground speed (Test Stand)


Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 111

10.1 mph 0 in-lb 34 RPM	Population 31.5 Target: 32.0 Row Spacing: 30 in	Singulation 97.6% Skips 10 2.0% Mult's 2 0.4%	Seed Release Index Middle 18.8% Bottom 22.6%
Loss/ Acre $11.31	Vacuum 20.0 in		



Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 112

10.1 mph
0 in-lb
34 RPM

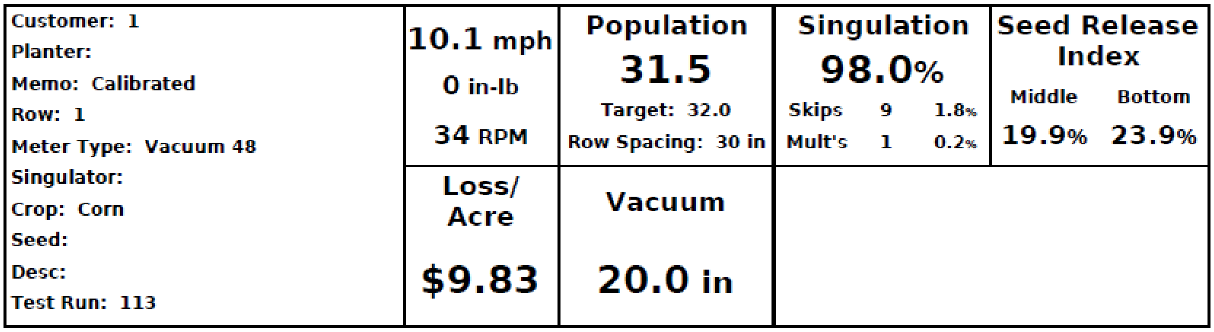
Population
31.2
Target: 32.0
Row Spacing: 30 in

Singulation
96.8%
Skips 14 2.8%
Mult's 2 0.4%

Seed Release Index
Middle Bottom
20.9% 23.3%

Loss/ Acre
$15.31

Vacuum
20.0 in



Customer: 1
Planter:
Memo: Calibrated
Row: 1
Meter Type: Vacuum 48
Singulator:
Crop: Corn
Seed:
Desc:
Test Run: 113

10.1 mph
0 in-lb
34 RPM

Population
31.5
Target: 32.0
Row Spacing: 30 in

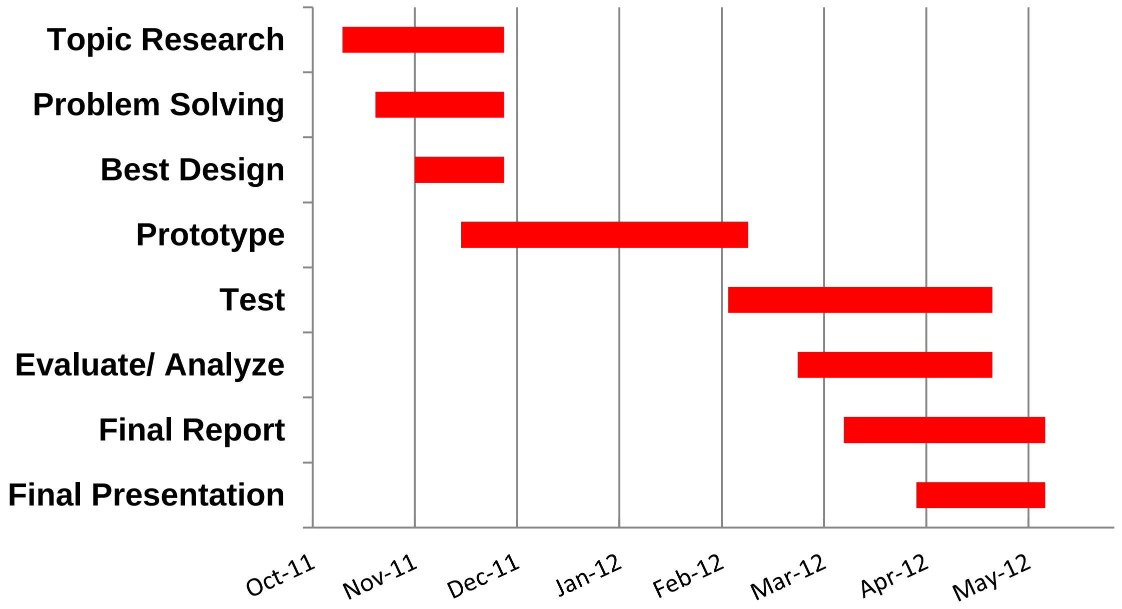
Singulation
98.0%
Skips 9 1.8%
Mult's 1 0.2%

Seed Release Index
Middle Bottom
19.9% 23.9%

Loss/ Acre
$9.83

Vacuum
20.0 in

8.5 Gantt Chart



8.6 Work Division Table

Tasks	**Time Spent (hours)**			
	Jesse Jangula	Jason Pecka	Ethan Dick	Total
Report Writing	31	23	15	69
Testing/Data Acquisition	14	16	17	47
Data Analysis	6	2	2	10
Building of Test Stand	10	10	10	30
Engineering Drawings	10	2	0	12
Work on Powerpoint Slides	6	11	6	23
Meeting with Instructor	4	3	3	10
Meeting with Center for Writers	0.5	1	1	2.5
Meeting with Collaborator	7	7	7	21
Calculations	1	0	5	6
Research	15	24	22	61
Total	104.5	99	88	291.5