HIGH SPEED PRECISION CENTRIFUGAL SEED PLANTING

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THESIS.

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ABSTRACT

HIGH SPEED PRECISION CENTRIFUGAL SEED PLANTING

by Amir U. Khan

Horizontal plate planters are widely used for mechanical seed planting. The capacity of such planters to accurately plant at high speeds is limited. The Farm Machinery Industry is keenly interested in new concepts to solve the high speed seed planting problem.

This research was conducted to study the feasibility of a new centrifugal concept which was proposed by the author for high speed precision planting. The main principles utilized in the new concept were:

1. The time of seed-cell exposure could be controlled by rotating the seeds with the cells at a known differential speed.
2. The force to move the seeds into the cells could be increased by using centrifugal force.
3. The delivery and placement of seeds could be achieved by high speed ejection of seeds to permit embedding in the furrow.

An experimental laboratory machine was developed to meter corn seeds. Tests were conducted to establish seed metering accuracy and the amount of seed damage at metering speeds of 400 to 1100 seeds per minute.

Results indicated that the centrifugal concept was not only practical up to speeds of 1100 cells per minute, but offered potential for further increase in metering speeds. The metering accuracy of this machine increased with high speeds, a performance completely opposite to that of conventional planters.

Seed damage in the machine was comparable to conventional planters for each metering speed. Impact of ejected seeds on steel plate at ejection velocities of up to 2,750 feet per minute did not exhibit any significant effect on germination. The study proved that a machine utilizing the centrifugal concept was feasible for high speed precision seed planting.

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HIGH SPEED PRECISION CENTRIFUGAL
SEED PLANTING

By

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Amir U. Khan

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I. INTRODUCTION

During the past two decades, considerable progress has been made in agricultural machines. Increased farm size and labor costs have dictated larger agricultural equipment to operate at higher speeds. Improvement in high speed planters has followed this general trend but with limited success. In addition to higher planting travel speeds, precise seed metering and seed placement have been desired. The term "Precision Planting" has been widely used and means the accurate, even spaced in-row placement of seeds at uniform depths. In corn, however, some authorities (15) feel that the control of per acre plant population is more important than the precise placement of seeds.

The need of precision planting arose in the interest of larger yields, high speed tractor operations and reduced labor requirements. To a corn grower, precision planting meant higher yields and faster planting operations. To a vegetable and beet grower, precision planting meant lower seed costs and the elimination of labor for thinning operations.

The accurate placement of seeds at high plant population and high planting speeds has been a difficult problem. Barmington (5) wrote:

> Since we are dealing with a seed that is not uniform in size, shape or density, it is difficult to imagine a mechanical device flexible enough to plant non-uniform particles in a strictly uniform pattern.

The common machines used for planting are the cell plate planters. The plates may be mounted horizontal, vertical or inclined at some angle. By far the most popular is the horizontal plate planter. The basic elements of a horizontal plate planter were conceived and developed during the nineteenth century (7). The first patent on corn planter was granted in 1799 to Eliakim Spooner in Vermont(6). Two row horse-drawn planter patents were issued in 1839.

The principle of operation of the cell planters is basically the same. Seed cells in a plate or a belt move into or by the seed hopper for a certain period of time. Seeds fill the cells by gravity and pass under a cut-off mechanism. This mechanism restricts all other seeds, except the one in the cell, from passing under. The seed is then discharged by gravity or mechanically into a seed tube placed under the cut-off for delivery to the furrow.

Records indicate that research efforts in the past have been mostly directed towards the improvement and modification of existing planters. Less attention has been paid toward development of new methods and concepts. Substantial work has been done in matching the geometry of the seed and the metering elements of a planter and in adapting it for different seeds. Attention in recent years

has been focused on incorporating devices for ancillary planting operations such as fertilizer and herbicide applicators and developing devices such as rotary valves for zero relative velocity seed placement. The basic seed metering mechanism, however, has remained unchanged.

A few new concepts for planters have been tried in recent years but were not able to achieve an appreciable degree of success. Notable among these are, the belt planters (24, 26), the vacuum planters (8, 10, 13, 18, 21, 27, 28), the tape planters (16, 19) and the vibratory planters (9).

Basis of the Problem

It has been evident for some years that the conventional horizontal plate planters have failed to meet the operational characteristics in terms of planting speeds, seed metering and placement performance. Higher plant population, made possible due to recent advances in fertilizer application and other culturel practices, has further aggravated the problem. Plant population in corn has increased three to four times during the last ten years (17). Research workers are already speaking of future corn population of 30 to 40,000 plants per acre. It is generally considered that 15 to 20% of seeds are lost due to poor germination. The planter must plant excess seeds to offset this loss.

General Objectives

In view of the past history of the horizontal plate planter and the numerous attempts which have been undertaken to improve its performance, it was felt that this study should only concentrate on radically new approaches to planting. The initial objective was to analyze the seed metering and seed placement operations of the horizontal plate planters and to locate the critical factors which control these operations. Unconventional solutions of the problems associated with these factors were the final objectives of the study. It was felt that conventional solutions could only result in marginal improvement and may not meet the desired operational characteristics.

In order to reduce the number of variables in the study, it was decided to use only one kind and variety of seed. Hybrid corn (Medium Flat Chester KV 35A) was selected as it is one of the most popular variety of corn which is mechanically planted in the major corn growing regions of the United States. Medium flat seeds are considered to be among the difficult seeds for precise metering.

II. REVIEW OF LITERATURE

Literature relating specifically to corn planting is scarce. In recent years very little work has been done by public research institutions on corn planters. Research in industry has been primarily aimed toward specific improvements of the various makes of planters. This research was of a limited interest and did not result in any important publications.

There is, however, enough material relating to planting problems of other crops, which in many ways parallel the corn planting problems. A survey of literature on seed metering indicated the various factors which influence the metering accuracy.

Roth and Potterfield (25) list the following twelve factors:

1. Relative size of seed and cell.
2. Relative shape of seed and cell.
3. Orientation of seed to cell.
4. Relative speed of seed to cell.
5. Distance cell travels when exposed to seed.
6. Time interval during which cell is exposed.
7. Type of cut-off and knockout.
8. Depth of seed above plate.
9. General shape of seed.
10. Variations in seed size and shape.
11. Seed surface characteristics.
12. Density of seed.

Bainer (3) suggested the following additional factor:

13. Cell wall taper.

Autry _et al_. (2) and Johonson (20) added:

14. Peripheral plate speed.
15. Number of cells in the plate.

Seed placement accuracy is dependent not only on the metering accuracy but also on the ejection of the seed from the cell, conveyance of the seed through the tube and the placement in the furrow. Some of the factors which influence the placement accuracy are:

1. Metering accuracy.
2. Knockout pawl operation and its location with respect to the seed tube opening.
3. Cell wall taper.
4. Seed tube section size and shape.
5. Length of seed tube.
6. Furrow opener shape.
7. Design of covering devices.
8. Speed of planting.

Seed Metering

A detailed study of the literature associated with seed metering indicated that relative seed-cell velocity has a decisive influence on cell fill. It has been established by numerous studies that seed metering performance drops when relative seed-cell velocity is increased.

Bainer (3) in his study with sugar beet seeds indicated that plate speed effects cell fill in both the vertical and the horizontal plate planters. According to his study, a speed increase of 200% results in only a 141% increase in the seeding rate.

Autry and Schroeder (2) stated that slow plate speed (below 30 fpm) results in highest accuracy and a higher

mean cell fill. They also indicated that metering accuracy was affected less by change in number of cells per plate than by speed changes, consequently, rates should be varied whenever possible by plate changes rather than by plate speed changes.

Johonson and Teal (20) indicated that both the inclined and the horizontal plate planters exhibit a detrimental effect on cell fill efficiency when speed is increased. However, there was no significant difference between the inclined and horizontal plate performance.

Futral and Allen (12) in their study on peanut planters found that plates in inclined plate planters were rotating so fast that seeds were frequently carried past the drop-out opening and thus affected the metering accuracy.

Barmington (4) in his study with sugar beet planters indicated that the per cent of cell fill reduced with increased cell speed and most planters exhibited minimum seed damage at a speed which gave 100% or slightly less than 100% cell fill.

Roth and Potterfield (25) stated that beyond a certain speed, an increase in plate speed was accompanied by a decrease in cell fill. They found that for a given time of cell-seed exposure, better cell fill resulted with a short exposure distance and slow cell speed.

Andrews (1) concluded that speed of planting and kernel size are the two main factors effecting the metering accuracy of corn planters.

In 1960 Gill (14) studied planting rates of corn at different planting travel speeds. His results are given below:

Planter Setting Plants / Acre	Per Cent Metering Accuracy at Planting Travel Speed		
	3 mph.	5 mph.	7 mph.
12000	106	102	96
16000	103	98	76
20000	101	90	69

He also studied the per cent seed dropped at different plate speeds and found the following results:

Plate RPM	% Seed Dropped
15.5	106
20.0	103
25.4	101
34.6	98
42.3	90
48.6	76
60.6	69

These results indicate that high plant population and high planting speeds, conditions generally encountered in current agricultural practices, have an inverse effect on metering accuracy.

Many research studies have established that 33 revolutions per minute of standard 16 cell plate results in optimum cell fill. This is equivalent to 528 cells per minute or about 62 feet per minute of plate peripheral

velocity. Brandt (6) however, places this limit at 45 rpm (720 cells per minute) or about 90 feet per minute of plate peripheral velocity. This discrepancy and a few other opposing claims in research publications raised doubts about the correct cell velocity for optimum cell fill. It was therefore decided to conduct laboratory tests on a few popular makes of horizontal plate planters with 16, 20 and 24 cell plates and to establish the effect of plate speed and number of cells on metering accuracy.

Seed Delivery and Placement

Morton and Buchele (23) concluded that bouncing and walking action of the seed during fall was responsible for non-uniform seed placement. They found that when the seed hits the ground it scattered in an area of ±4 inches due to bounce. Decreasing the length of the seed drop increased the accuracy of seed spacing. Larsen (22) also mentioned bounce in long seed tube as a factor influencing placement accuracy.

Evers (11) in his studies with sugar beet planters indicated that increased planting travel speed has an adverse effect on seed placement. Speed effects seed placement both before and after delivery in the furrow. He stated:

> This number of seed displacement before delivery shows that with an advance of 0.75 m/s and a drop of 40 mm and in spite of a regular cell sequence, 37% of all seeds have already before delivery suffered a disturbance of their sequence and do not reach the ground at the theoretical interval.

> When the speed is doubled, this figure rises to 50%, so at this speed half the seeds are not hitting the ground at the correct interval.

His study with rolling and shoe coulters exhibited a severe rolling and bouncing movement of the seed in the furrow after the delivery of the seed. A wedge coulter exhibited reduced seed roll and bounce. He found the following results on his studies associated with the rolling of seed in different type of furrows.

	Per Cent of Seeds Affected by Rolling at Forward Speed			
Coulter Type	0.75m/s	1.00m/s	1.25m/s	1.50m/s
Roller	60.9	62.5	67.1	67.3
Shoe	45.7	48.8	57.6	58.1
Wedge	13.5	20.1	21.1	23.2

Thus the speed of travel and the type of furrow openers effect the placement accuracy even after the delivery of the seed to the furrow.

Autry and Schroeder (2) studied the dispersion of seed and found that it was a function of longitudinal cell dimension (or cell shape), plate speed, location of knock-out pawl and ground speed of planter. They also found that the seed tube caused considerable seed scatter and demonstrated with experiments that a tube confirming to the parabolic path of a falling seed showed less dispersion.

They concluded that height of fall has little or no effect on seed dispersion unless there is interference in the seed tube.

III. ANALYSIS OF PLANTING OPERATION

The planting operation consists of two steps, seed metering and seed placement.

Seed Metering

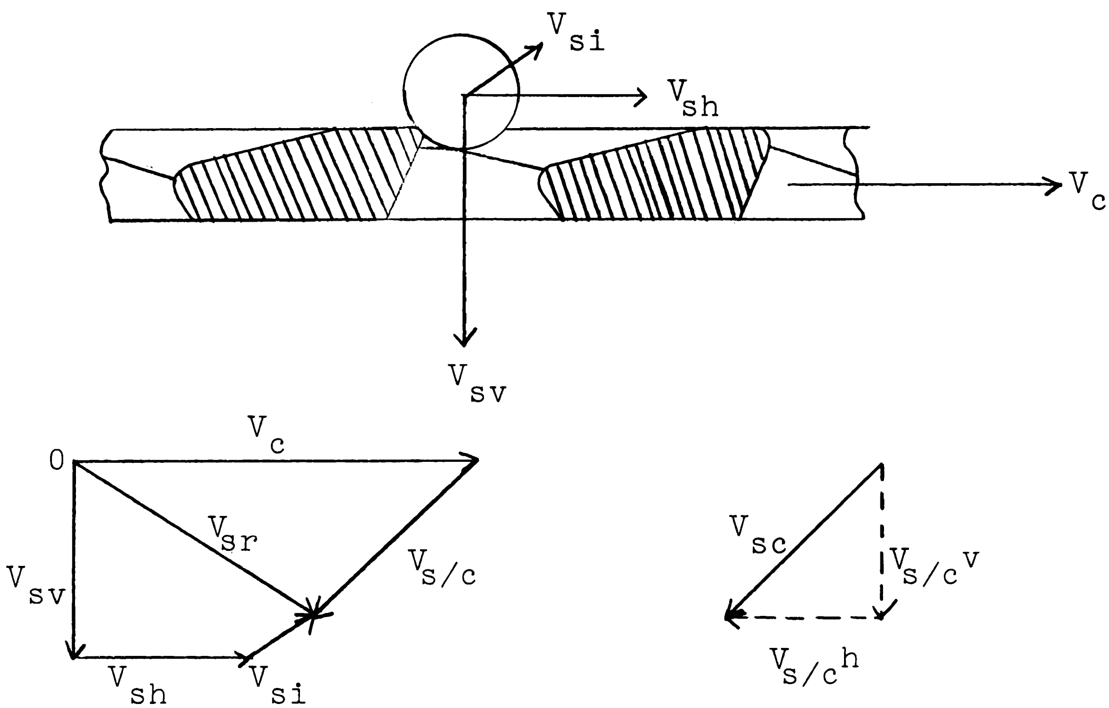
Seed metering is the process of singling of seeds from a bulk supply. The filling of a seed in a cell and the ejection comprises the process of metering in a planter utilizing the cell concept.

A velocity and force analysis of a seed as it starts to enter the cell is essential to understand the cell fill operation. Figure 1 shows a seed as it starts to move into the cell and the velocity vector diagram in a horizontal plate planter.

The resultant seed velocity V_{sr} is due to the velocities caused by the acceleration of gravity (V_{sv}), friction between seed and seed plate (V_{sh}) and by the impact of the seed on the edge or walls of the cells V_{si}.

$$V_{sr} = V_{sv} \mathbin{+\!\!\to} V_{sh} \mathbin{+\!\!\to} V_{si} \qquad - - - - - (1)$$

The relative seed-cell velocity ($V_{s/c}$) is the vector sum of the resultant seed velocity (V_{sr}) and the cell velocity (V_c)



V_{sv} = Vertical Seed Velocity

V_{sh} = Horizontal Seed Velocity

V_{si} = Seed Velocity imparted due to impact with edge of cell

V_{sr} = Resultant Seed Velocity

V_c = Cell Velocity (horizontal only)

$V_{s/c}$ = Relative Seed Cell Velocity

$V_{s/c}v$ = Vertical Component of $V_{s/c}$

$V_{s/c}h$ = Horizontal Component of $V_{s/c}$

Figure 1.--Velocity diagram of seed during cell fill.

$$V_{s/c} = V_{sr} \nrightarrow V_c \qquad - - - - - - - - (2)$$

The relative seed-cell velocity is composed of the vertical ($V_{s/c}v$) and horizontal ($V_{s/c}h$) components.

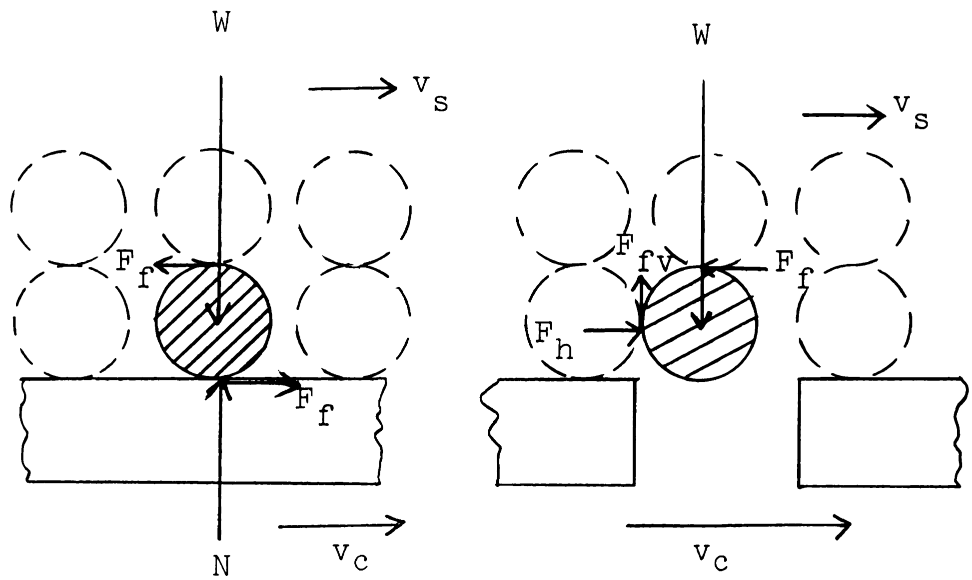
$$V_{sc} = V_{s/c}h \nrightarrow V_{s/c}v \qquad - - - - - - - (3)$$

Ideal cell fill would occur when the vertical component of the relative seed-cell velocity ($V_{s/c}v$) is maximum in magnitude, since it is the velocity along the direction of possible seed movement, with respect to the cell. This condition can be achieved when the horizontal component of the relative seed-cell velocity ($V_{s/c}h$) is zero. In practice, however, a cell must be exposed to a fresh seed after each seed delivery to avoid cell starvation. It is therefore necessary to maintain some horizontal relative seed cell velocity ($V_{s/c}h$) for satisfactory seed metering.

It seems obvious that to achieve high cell fill, it is essential to maximize the vertical component of the relative seed-cell velocity ($V_{s/c}v$). It is also necessary to control the horizontal component of the seed-cell relative velocity ($V_{s/c}h$) close to a value which is sufficient to maintain constant fresh seed exposure but not too large to unduly reduce seed-cell exposure time. These two objectives have been the fundamental basis for the improvement of seed metering accuracy in this study.

Figure 2 shows a force diagram of an ideal round seed in contact with the horizontal seed plate in between the cells and exactly on top of a cell, in a vertical tangential plane.

(a) Between cells (b) On top of cell



W = Weight forces due to the seed and the column of seeds on top

F_{fv} = Resultant vertical friction retarding force

F_h = Resultant horizontal force

F_f = Frictional force between seed and seed plate and between seeds

Figure 2.--Forces on an ideal seed in contact with seed plate.

The resultant vertical force F, which helps to propel a seed into the cell, is the sum of the vertical forces on the seed.

$$F = W - F_{fv} \qquad \text{- - - - - - - - - -} \qquad (4)$$

Very little is known about the resultant vertical retarding force F_{fv} except that it is affected by the coefficient of friction between seeds, coefficient of friction between seed and internal surfaces of the hopper and by the amount of seed in the hopper.

Newton's law of motion states

$$F = \frac{Wa}{g} \qquad \text{- - - - - - - - - -} \qquad (5)$$

in which F is the accelerating force in pounds, W is the weight of the mass being accelerated in pounds, a is the acceleration of the mass in feet per second squared and g is the gravitational constant. Substituting equation 5 in 4 we get

$$a_v = g - \frac{F_{fv}}{m} \qquad \text{- - - - - - - - - -} \qquad (6)$$

in which a_v is the acceleration of the seed in the vertical direction and m is the mass of the seed.

Even if it is assumed that F_{fv} is very small, the resultant maximum vertical acceleration a_v available to the seed in a conventional planter will always be less than the gravitational acceleration.

The seed must fall through a distance of approximately half its diameter before it can be securely lodged in a cell. The seed cell exposure time required for a seed to drop this distance into a cell, is dependent on the resultant vertical acceleration (a_v) which in a conventional planter is always less than 32 ft/sec^2. Therefore in a gravity dependent cell type seed metering machine, there is always a minimum theoretical time of seed-cell exposure below which no cell fill can occur.

Significant improvement in cell fill can be achieved if the seed could be subjected to higher than gravitational acceleration along the direction of the seed movement into the cell. Compressed air, impact and centrifugal force are some of the possible means to achieve high acceleration. A careful study indicates that the use of centrifugal force would be most practical. Centrifugal force increases in proportion to the square of the angular velocity and can provide increasing force at the higher planting speeds. The mechanism used in this study utilized centrifugal force for cell fill.

Very little is known about the horizontal relative seed-cell velocity ($V_{s/c}h$) which also plays a significant part in the cell-fill operation. Experimental studies indicate that a 62 fpm cell velocity results in an optimum cell fill in horizontal plate planters. The horizontal seed velocity (V_{sh}) of seeds in contact with or in the immediate vicinity of the plate, is not well known. High

planting speeds result in high cell speed (Vc) and reduced seed-cell exposure time. This is one of the major causes for the poor seed metering performance associated with conventional planters at high planting travel speeds.

It seems logical that the seed-cell exposure time could be successfully controlled by rotating both the seed in the hopper and the cell plate in the same direction at a desired speed differential. While such a control is not possible with existing planter designs, it is conceivable that conventional planters could be redesigned to incorporate this feature. The speed differential can maintain the relative seed-cell velocity at a level which would provide sufficient seed-cell exposure time for optimum cell fill at any seed metering speeds.

Rotating the hopper is one possibility but it would consume considerable power. It may also create problems due to the presence of a stationary cut-off inside a rotating hopper full of seeds. The mechanism used in this study achieved a controlled relative seed-cell velocity by rotating only a small quantity of seeds with the cells without rotating the hopper.

Seed Delivery and Placement

The operation of cell emptying, in a conventional horizontal plate planter, has been photographed and studied in slow motion. It is observed that, when the knock out pawl is properly located in relation to the

seed delivery tube, the seeds fall by gravity and do not require assistance from the knock out pawl. Only seeds with an interferance fit in the cells are ejected with the help of an impact from the knock out pawl. If the force available for seed ejection is high, the knock out pawl can be eliminated. High ejection force can be developed by subjecting the seed in the cell to an acceleration greater than that of gravity. The experimental machine utilizes this means for seed ejection. Due to the varying contact surfaces between the knock out pawl and each seed, the direction of ejection is not uniform in a conventional planter. It is presumed that the seed ejected with the help of the knock out pawl strikes the inside walls of the seed delivery tube and descends the tube with a motion involving richochet and whirring. The seeds which fall on their own, by gravity, are also thrown against the seed tube walls because of the horizontal seed and cell velocity. The interference from the tube, results in a non-uniform transfer of seed to the ground and causes uneven in-row spacing. It is not possible to develop a seed tube which would conform to free fall trajectories of all the different kinds of seeds at different planting speeds. One approach to eliminate the tube interference problem is to eject seeds from the cell at high initial velocity to almost instantaneously transfer the seed to the ground along a straight path.

Disregarding air resistance, the time required for a seed to fall from a cell to the ground under free fall conditions can be calculated by the equation:

$$S = 1/2\ gt^2 + V_o t \quad \text{- - - - - - - - - - -} \quad (7)$$

S = distance of vertical seed fall
t = time in seconds
g = gravitational acceleration
V_o = initial vertical seed velocity

In a horizontal plate planter, the initial vertical seed velocity is zero. If the seed is ejected with high initial velocity, the time required for seed delivery can be substantially reduced. The high velocity seed delivery would eliminate the need for a seed tube and the problems associated with it. It would also permit the embedding of a seed in the furrow and eliminate the seed bounce and roll problems encountered with conventional planters.

Centrifugal Planting Concept

From the analysis presented earlier in this chapter, it seems evident that a centrifugally dependent seed metering and placement mechanism would solve most of the problems encountered with conventional planters. Such a mechanism would utilize the following three principles:

1. Control of the seed-cell exposure time can be achieved by rotating both the seed and cell at a desired velocity differential.

2. Improved cell fill at high planting speeds can be achieved by subjecting the seeds to higher than gravitational acceleration along the direction of seed movement into the cell.
3. Almost instantaneous seed delivery and placement in the furrow by high velocity ejection can improve seed placement accuracy.

Based on the above three principles, the author was able to develop a laboratory seed metering machine (Figures 3 and 4). It takes in, an unmetered flow of seeds from a hopper, spins, meters and ejects the seeds in the desired direction with the help of centrifugal force.

It consists of a circular seed chamber rotating in a vertical plane with a cell-ring and metering-ring around its periphery. Unmetered seeds enter the rotating chamber through an axial opening and start to rotate with the chamber. Centrifugal force distributes the seeds in the chamber and aids the seeds to fill the cells in the cell-ring which forms the peripheral wall of the seed chamber. The cell-ring can be set to rotate at any desired velocity differential with the seed-chamber. The metering-ring has a single metering slot and rotates concentric to the cell-ring. The metering-ring and cell-ring drive ratio permits the alignment of the metering slot with a subsequent cell on each revolution of the metering-ring. The seed in the cell transfers to the metering slot during alignment. A stationary shield holds the seed in the metering slot until

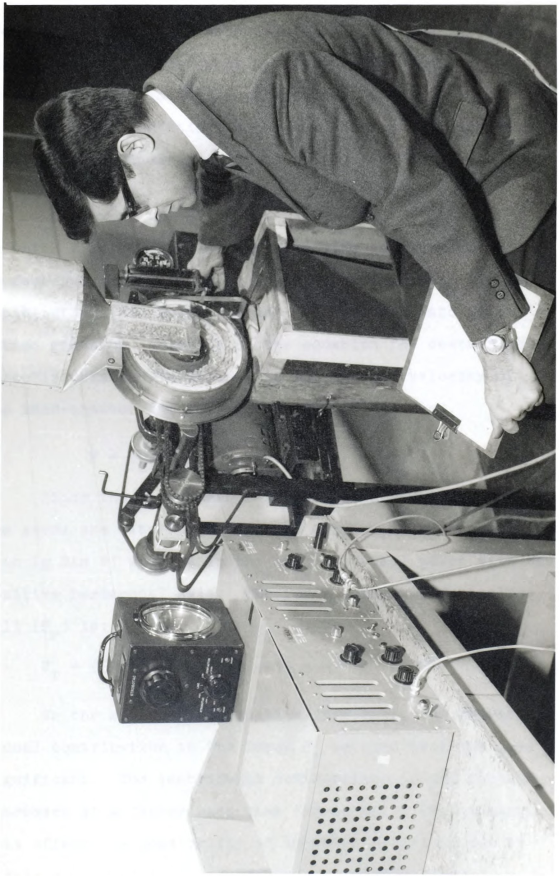


Figure 3.--Centrifugal seed metering maching set up for seed metering test.

the ejection point is reached. The seed is thus ejected in the desired direction at a velocity which is equal to the peripheral velocity of the metering slot.

The seeds rotating in the seed-chamber are subjected to a non-rectilinear acceleration (a) which is:

$$a = \frac{V_2}{r} \quad \text{- - - - - - - - - - - - -} \quad (8)$$

in which V is the absolute speed of the accelerated mass in feet per second and r is the radius of rotation in feet. Substituting this value for the acceleration into Newton's Motion equation, equation 5, the equation for centrifugal force is obtained in which w is the angular velocity of the seed-chamber and W is the weight of the seed.

$$F = \left(\frac{W}{g}\right) rw^2 \quad \text{- - - - - - - - - -} \quad (9)$$

Since the seed-chamber rotates in a vertical plane the seeds are also subjected to a gravitational acceleration ($g \sin \theta$) where θ is the angle the cell makes with the positive horizontal axis. The force available for cell fill (F_r) is:

$$F_r = \left(\frac{W}{g}\right) rw^2 - W \sin \theta \quad \text{- - - - - - -} \quad (10)$$

As the speed of the machine increases, the gravitational contribution to the force F_r becomes less and less significant. The centrifugal contribution to the force F_r increases at a faster pace than the speed of the machine. This offers the possibility of improved cell fill due to higher cell fill force at increased planting speeds.

Since the seed is ejected at the peripheral velocity of the metering slot, the kinetic energy (KE) of the ejected seed is:

$$KE = 1/2\ mV^2 = \frac{W(rw)^2}{2g} \quad \text{- - - - - - - - - -} \quad (11)$$

This is an expression for the kinetic energy which must be dissipated before the seed becomes static. When the seed strikes an object or the ground, the energy of rebound (T) becomes:

$$T = \frac{W}{2g}\ (E_g{}^2)\ V^2 \quad \text{- - - - - - - - - - - - - -} \quad (12)$$

in which E_g is the coefficient of restitution of the seed and the work (Q) by the seed becomes:

$$Q = \frac{WV^2}{2g}\ (1-E_g{}^2) \quad \text{- - - - - - - - - - - - - -} \quad (13)$$

Ideally, it would be desirable to have the ground or the impacted surface such that would make E_g zero and absorb all the seeds' kinetic energy. This would be ideal from the standpoint of seed damage. It is, however, possible that the seed may strike a stone or any other hard object which may damage the seed. It was, therefore, necessary to study seed damage by impacting the seeds on a steel surface at different ejection velocities.

IV. SPECIFIC RESEARCH OBJECTIVES

The specific objectives of the research were:

1. To establish seed metering performance of conventional 16, 20, 26 cell edge drop horizontal plate planters as a yardstick to compare with experimental planter performance.

2. To design and develop a laboratory seed metering and placement mechanism utilizing the centrifugal concept and incorporating the three principles stated in Chapter III.

3. To conduct seed metering accuracy tests at metering speeds of 400 to 1100 cells per minute. The 1100 c.p.m. metering speed provides a planting travel speed of 7 mph when planting in 40 inch rows for a population of 22,400 seeds per acre.

4. To conduct germination tests on seeds ejected from the experimental machine at velocities of up to 3500 feet per minute and collected in cloth chutes to avoid any impact. These tests were to provide information on the extent of seed damage within the machine.

5. To conduct germination tests on seeds ejected from the experimental machine at velocities of up to 3500 feet per minute and impacted on a steel surface placed at a distance of 18 inches from the point of seed ejection.

These tests were to provide information on the extent of maximum possible seed damage that could occur during seed placement in the furrow.

6. To evaluate comparative performance of the experimental machine with conventional planters.

7. To suggest guide lines for further research and for the adaptation of the centrifugal concept to a field machine.

V. RESEARCH EQUIPMENT AND TECHNIQUES

Only one kind of corn, medium flat (Chester KV 35A) was used in the entire study to reduce the number of variables. Performance tests on conventional planters were conducted on test stands at the Engineering Laboratories of The Ford Tractor Division, Birmingham, Michigan, during the author's employment with the Company.

The first part of the study at Michigan State University was concerned with the design and development of an experimental machine utilizing the centrifugal concept (Figures 3 and 4). Considerable time was spent on this phase because of the numerous problems encountered before satisfactory operation was achieved.

Transparent plexiglass materials were widely used in making the metering unit of the experimental machine to permit photographing of seeds inside the mechanism during operation. Strobe lights and high speed movies, photographed at 5,000 frames per second, were used to study the machine operation. These techniques were useful in studying the cut-off performance, the distribution and movement of seed in the chamber, the transfer of seed from the cell to the metering slot and the ejection path of the seed. This information was instrumental in improving the performance of the machine.

Figure 4.--Centrifugal seed metering machine set up for seed damage test.

Tests with the experimental machine were primarily conducted to establish the metering accuracy and seed damage at various seed metering speeds and impact conditions.

Experimental Mechanism

Figure 5 shows the schematic arrangement of the experimental seed metering machine. The seed metering head with the drive arrangement is illustrated in Figures 6, 7, 8, and 9. There were three separate driven members in the seed metering head, seed chamber, cell-ring and metering-ring. The drive to the three members was taken from a stub shaft which was driven by a 1/4 HP electric motor through an infinitely variable hydraulic transmission. The speed of the metering unit could be varied between 0 to 1600 revolutions per minute. The seed-chamber was driven from a stub shaft through a variable speed V belt drive which permitted differential drive between the cell-ring and the seed-chamber.

Figure 10 shows a close up of the seed metering unit in operation with the seed hopper and seed passage removed. Figures 11 and 12 are the end and side view assembly drawings of the seed metering head. The construction and operational details of the seed metering head are described as follows with reference to the assembly drawings (Figures 11 and 12).

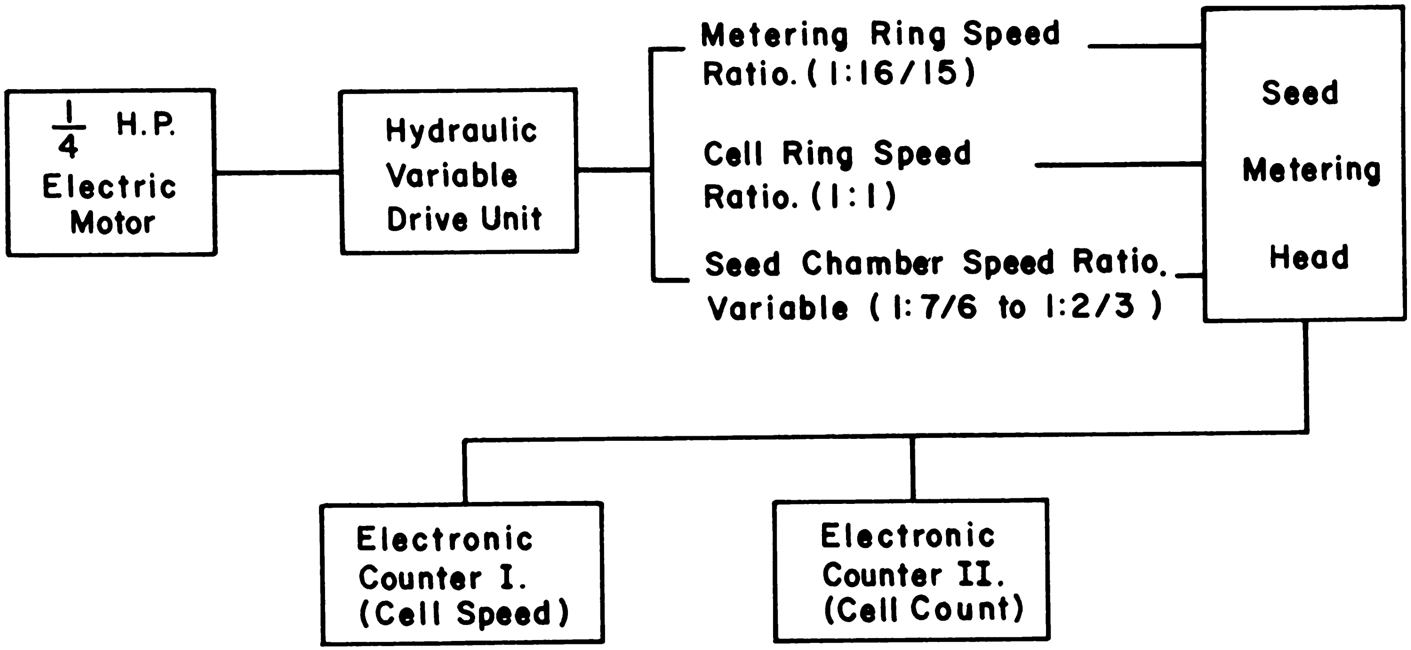


Figure 5.--
Schematic Laboratory Arrangement Of The Experimental Seed Metering Unit.

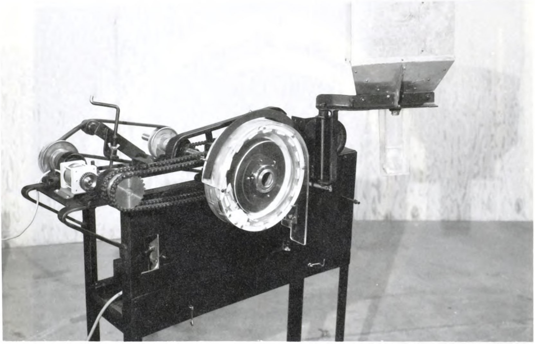


Figure 6.--Centrifugal seed metering machine showing the metering head.

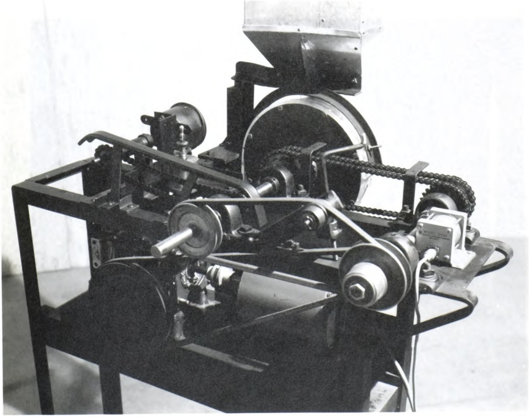


Figure 7.--Centrifugal seed metering machine showing drive arrangement.

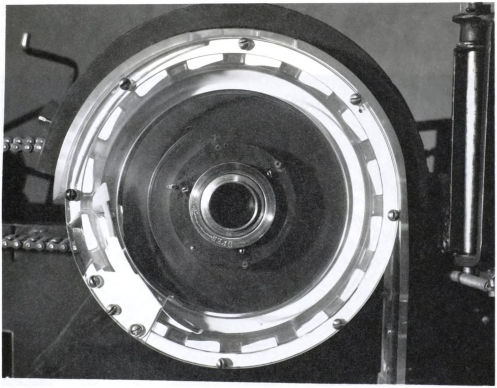


Figure 8.--Seed metering head at impending metering slot and cell alignment.

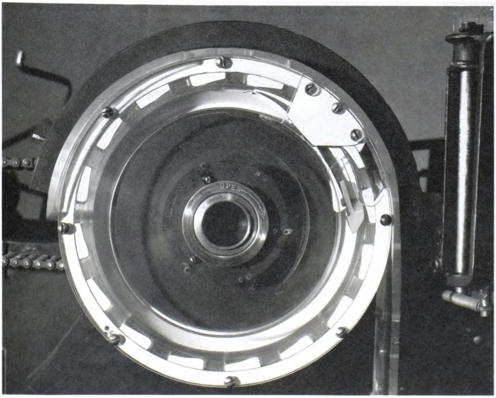


Figure 9.--Seed metering head at complete metering slot and cell alignment.

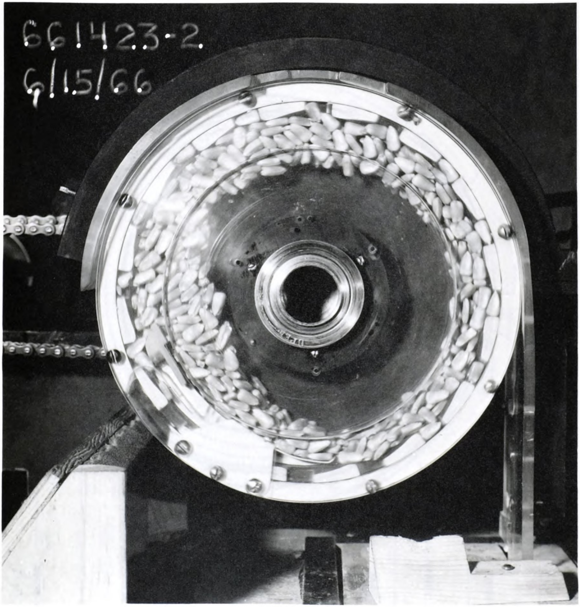


Figure 10.--Seed metering head during operation.

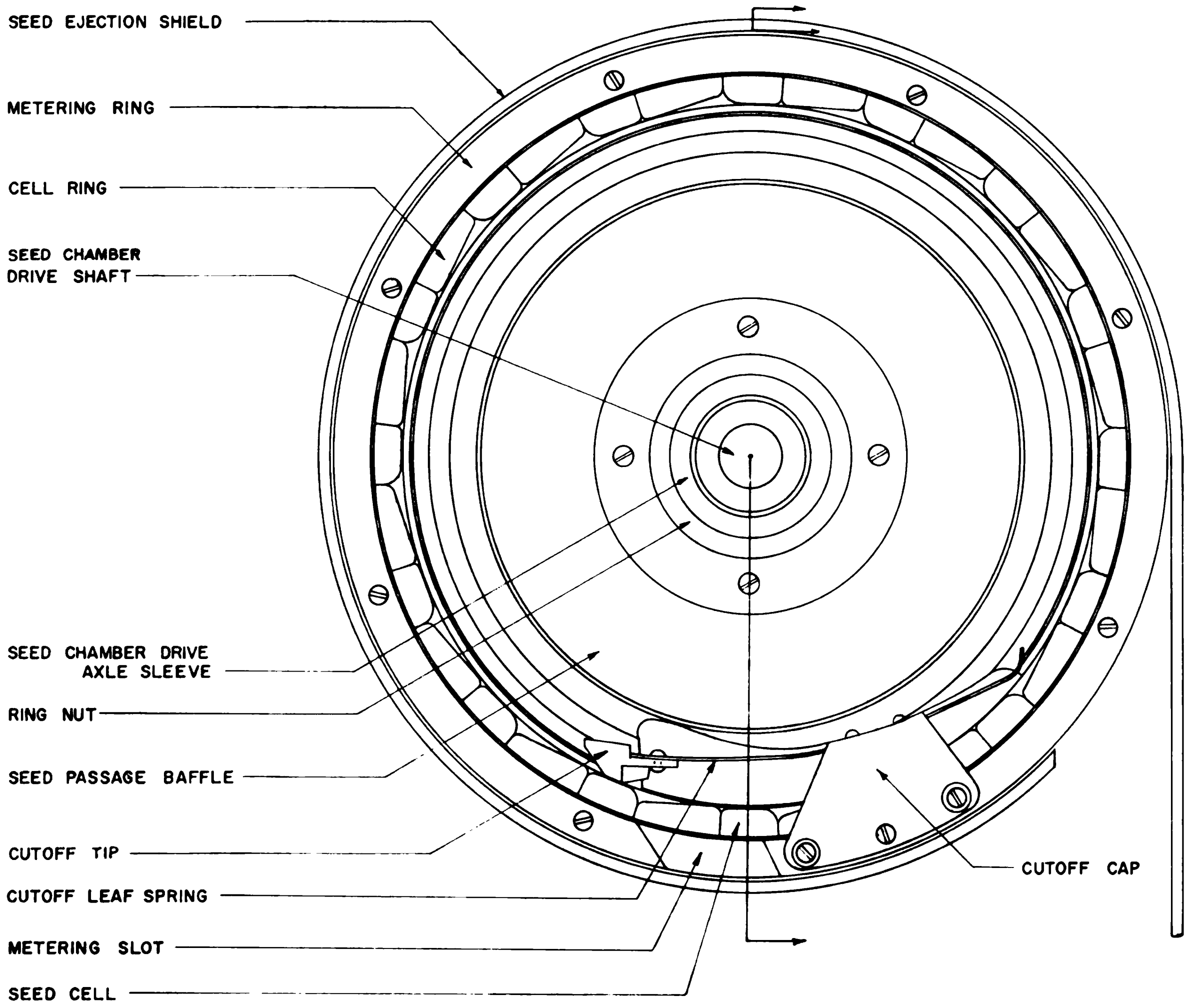


Figure 11.-- **METERING HEAD ASSEMBLY** (Drawing end view)

(SEED HOPPER REMOVED)

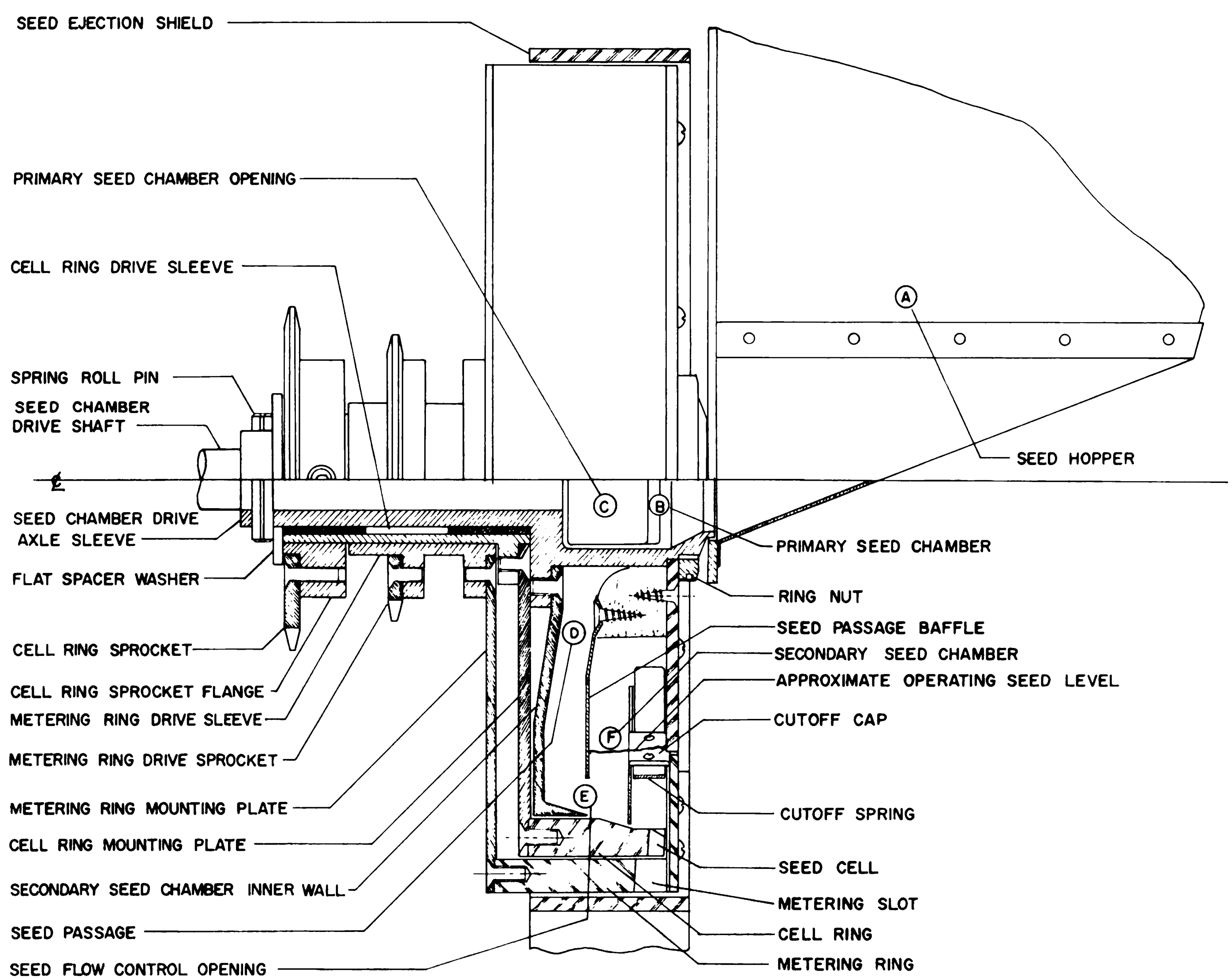


Figure 12.-- **METERING HEAD ASSEMBLY** (Drawing side section view)

Construction Details

Seed Hopper

It was a sheet metal box with three sloping and one vertical wall. The bottom of the hopper was slightly furrowed, with the furrow ending into a passage tube which conveyed the seeds to the seed metering mechanism. The hopper served as a storage for the seeds and was mounted on a hinge for easy access to the seed metering unit. Seeds flowed into the metering head at an unmetered rate by gravity.

Seed-Chamber Drive Axle Sleeve

It consisted of a hollow member which was rigidly fixed at one end to the drive shaft. The other end had a bell shaped housing which formed the primary seed-chamber (B). The bell shaped primary seed-chamber had three peripheral openings (C) and a 1 5/16 inch diameter axial opening. The seeds entered the axial opening of the primary chamber (B) through the seed passage from the hopper. The seeds left the primary chamber through the three peripheral openings (C). A circular plate which formed the inner wall of the secondary seed-chamber (F) was mounted to a flange on the seed-chamber drive axle sleeve. This circular plate was shaped at its periphery to guide the seeds towards the cells.

Feed Control Baffle

This baffle (Figures 12 and 13) was mounted on the bell end of the Seed-Chamber Drive Axle Sleeve and formed a passage (D) to the secondary seed-chamber (F). The seeds entered the secondary seed-chamber (F) at its periphery. The Feed Control Baffle rotated with the Seed-Chamber Drive Axle Sleeve, and controlled the amount of seed in the secondary seed-chamber during the machines operation.

Cell-Ring

It was a 8 1/2 inch circular (outer diameter) ring machined from a 1/2 inch thick wall plastic tube to a shape as shown in the section view. Sixteen edge drop cells were machined on one side of the cell-ring. Sixteen cells were selected for better performance evaluation since the same number of cells are popularly used in conventional corn planters. The cell dimensions for the Chesters KV 35A medium flat hybird corn were, length 40/64 inch, width 14/64 inch, and depth 20/64 inch. These dimensions were very similar to the ones used during the tests on conventional planters (Table 1). A slope on the inside surface of the cell-ring was machined to guide the seeds into the cells. The shape of the cells were similar to those used during the tests on conventional planters. The cell-ring was fitted to the Cell-Ring Drive Sleeve with a flat circular plate. The relative drive between the cell-ring and the seed-chamber was variable.

Figure 13.--Feed control baffle assembly.

Figure 14.--Seed pressure relieving baffles.

TABLE 1.--Plate, cell and seed dimensions.

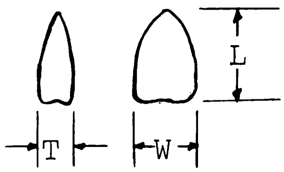


	Plate Diameter	L	W	T
Conventional Planter (A) 16 cell plate	7.00"	43/64"	19/64"	14/64"
Conventional Planter (B) 20 cell plate	7.30"	42/64"	20/64"	19/64"
Conventional Planter (C) 24 cell plate	7.00"	43/64"	19/64"	14/64"
Experimental Centrifugal Planter 16 cell-ring		40/64"	20/64"	14/64"
Dimensions from 200 Measured Seeds				
Minimum Seed Dimensions		31/64"	19/64"	11/64"
Maximum Seed Dimensions		42/64"	23/64"	14/64"

Seed Company graded this corn through 22/64" round hole screen and over 19/64" round hole screen for width, through 13-1/2 / 64" slot and over 12-1/2 / 64" slot for thickness. Length sizing was by separation of shorter kernels by means of a 26/64" indent cylinder.

Metering-Ring

It was a 9-1/2 inch outer diameter circular ring machined from a 1/2 inch thick wall plastic tube and mounted to the drive sleeve with a circular plate. The inside diameter of the metering-ring was slightly larger than the outside diameter of the cell-ring. This permitted

concentric relative rotation between the two. The metering-ring had a single seed metering slot, placed axially in the same position as the cells in the cell-ring. Rotating the metering-ring with respect to the cell-ring permitted the alignment of the metering slot with any desired cell. The two rings were driven at a positive ratio, such that the metering slot aligned with a subsequent cell on every revolution of the metering-ring. Further, the drive was so timed that the alignment occurred at a position which permitted complete transfer of the seeds from the cell to the metering slot before reaching the ejection point.

Cut-Off

This consisted of a sheet metal housing with a leaf spring and a cut-off pawl tip. The cut-off pawl was formed by mounting a cut-off pawl tip to the leaf spring (Figure 15). The cut-off was mounted to the metering-ring at a position coincident with the metering slot. The cut-off tip rode on the inside of the cell (Figure 16) and wiped excess seeds from entering the cut-off housing area during the operation. This arrangement permitted the transfer of the seed within the cell to the metering slot and blocked additional seed from transferring. No knock out pawl was used with the cut-off pawl.

Seed Ejection Shield

It consisted of a shield, formed from a flat plastic material, around the metering-ring. It was similar in

Figure 15.--A few of the cut-offs used in the study.

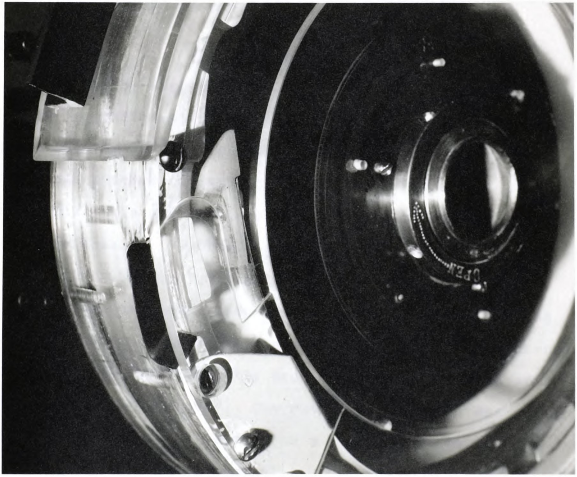


Figure 16.--Cut-off area.

shape to a centrifugal blower housing. The shield retained the seeds in the metering slot until the ejection point was reached. This permitted the ejection of the seeds in a uniform specific direction.

Operational Details

The seeds stored in the seed hopper (A) were transferred by gravity through a seed passage connected to the axial opening in the rotating primary seed-chamber (B). The seeds entered the primary seed-chamber at almost its rotational axis and were subjected to minimum impact and low acceleration. During the operation of the machine, a zone, just outside of the primary seed-chamber axial opening, was observed which contained seeds in the process of acceleration. Non-rotating seeds from the hopper entered this zone and were gradually accelerated to the speed of the primary seed-chamber. The radius of rotation was small and the transition of seeds from a relatively static to a rotating condition was gradual.

Once the seeds had acquired the angular velocity of the primary seed-chamber, centrifugal force distributed the seeds around the periphery inside the primary seed-chamber. The inside surface of the primary seed-chamber was inclined toward the three peripheral openings (C). Centrifugal force pushed the seeds on the sloping surface and moved the seeds to the three openings (C). The seeds were then transferred into the seed passage (D).

As the seeds moved outward from the axis of rotation, they were subjected to an increased radial acceleration. The seeds entered the secondary seed-chamber (F) around its periphery through the restricted passage (E).

This method of feeding seeds into the secondary seed-chamber was used to regulate the quantity of seeds in the chamber during operation. Centrifugal force acted on the seeds in the passage and in the secondary seed-chamber. The pressures in the two areas were balanced through the connecting passage (E). When some seeds were metered out of the secondary seed-chamber, pressure in that area was reduced. This permitted flow of additional seeds through the passage (E) until pressure was again equalized. In practice, since the metering of seed was continuous, flow of seed through passage E was also assumed to be continuous.

This method of controlling seed flow was successful in maintaining a partly empty secondary seed-chamber during the operation. A fully packed secondary seed-chamber resulted in high centrifugally induced pressures and high seed damage. A partially loaded secondary seed-chamber permitted a free movement of seeds within the chamber and this facilitated cell fill. The seeds in the chamber (F) were distributed around the periphery and filled the cells in the cell-ring.

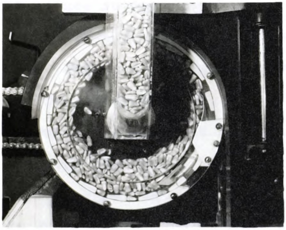
The metering-ring with its single metering slot and cut-off, rotated with a drive ratio of 16/15: 1 with the 16 cell cell-ring. The metering slot aligned with the

leading cell on each revolution of the metering-ring. The seed from the cell was transferred to the metering slot during the alignment. The cut-off restricted the seeds in the secondary chamber from transferring through during the cell-slot alignment.

The seed ejection shield retained the seed in the metering slot. The seed was carried around in the metering slot until the ejection point was reached where it was ejected out of the machine in a specific direction. Thus for every revolution of the metering-ring, a new seed was transferred from the subsequent leading cell and was guided around for ejection along a specific path.

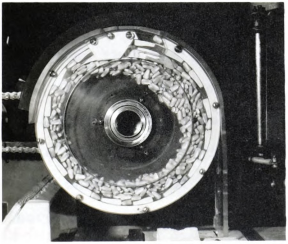
The number of cells in the cell-ring controlled the drive ratio between the cell-ring and the metering-ring. On each revolution the metering-ring advanced with respect to the cell-ring to accept a fresh seed from the leading cell. The alignment of the metering slot and the cell occurred sufficiently in advance of the ejection point, and permitted enough time for complete transfer of seeds from the cell to the slot. Such a timing resulted in a uni-directional ejection from the machine.

The seed metering sequence is shown in Figure 17 with the help of four sequence photographs. The direction of rotation of the seed-chamber, cell-ring and metering-ring is clockwise. In Figure 17a, the cut-off is shown in the 5 o'clock position. It is shown in the process of restricting the excess seed from passing under the cut-off housing.

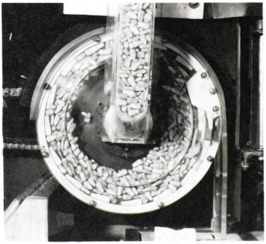


A

B



C



D

Figure 17.--Seed metering sequence.

Figure 17b shows the cut-off at about the 8 o'clock position. The seed lodged within the cell is completely under the knock out pawl. The trailing edge of the cell is almost in line with the leading edge of the metering slot. This is the position of impending alignment.

Figure 17c shows the complete alignment of the cell and the metering slot. The seed has just transferred to the metering slot and is being guided around by the ejection shield.

Figure 17d shows the seed in the metering slot ready to eject out of the mechanism. The metering slot is proceeding ahead of the cell to start the cycle again with the next leading cell.

High speed movies and observation with strobe lights indicated that the actual transfer of seeds between the cell and metering slot did not occur at one specific spot but occurred over a small region. This was due to the variations in kernel size. Larger kernels transferred later than the smaller kernels due to the gradually increasing transfer opening during the cell-slot alignment.

A major problem encountered in achieving satisfactory performance was the design of the cut-off. An accumulation of seeds in the vicinity of the cut-off pawl was encountered which created high centrifugal forces and high seed damage. To avoid this problem a variety of cut-offs were tried. It was suspected that the presence of a cut-off cap inside the narrow seed-chamber further restricted its width. This

interfered with a free movement of seeds past the cut-off cap and resulted in the seed accumulation near the pawl.

A cut-off cap with the spring and its mountings, located completely outside the seed-chamber, was tried but it did not prove satisfactory. Different types of seed pressure relieving baffles (Figure 14) were mounted near the cut-off pawl but did not improve the performance.

A variety of other cut-offs were tried, four of which are illustrated in Figure 15. Cut-off (A) had a narrow pawl with a stationery tapering nylon piece mounted next to the pawl. Cut-off (B) had a curved extension on the cap which was used to divert the excess seeds side ways in an attempt to reduce seed pressures on the cut-off pawl. Type (C) cut-off had a completely shielded pawl. This was designed to keep the top of the pawl free from the pressures due to the seed in the chamber and to achieve an unrestricted up and down movement of the pawl during the operation. None of these cut-offs proved satisfacotry and most of them resulted in additional accumulation of seeds and excess seed damage.

Another problem encountered with the cut-off was the spring force in the cut-off pawl. If a weak spring was used, it tended to lift up and in some cases completely fold back at high metering speeds. If a strong spring was used, it increased seed damage. A combination spring and weight loaded unshielded pawl (Figure 15D) proved to be most

satisfactory. At low speeds, the spring provided the major portion of the cut-off pawl force. As the speed increased, centrifugal force due to the weighted pawl, contributed the additional force required for high speed operation. This cut-off had an open top pawl which resulted in minimum restriction in the chamber and reduced the seed accumulation problem.

During the early stages of the work with the seed accumulation problem, the metering-ring with its cut-off was set to operate at the same speed as the seed-chamber. This was logical since it was analogous with the situation encountered in conventional planters where the cut-off cap and the hopper walls have the same zero velocity. After considerable work and time had been spent on the seed accumulation problem, it was found that rotating the seed-chamber at a slower velocity than the cut-off cap assisted the movement of seeds past the sides of the cut-off and reduced the accumulation of seeds. Later tests proved that the seed-chamber could be rotated with the cell-ring to achieve uniform seed distribution in the chamber. The cut-off housing in the seed-chamber provided enough drag to develop a relative seed-cell velocity and provide fresh seed-cell exposure after each delivery.

Observation of the machine under strobe lights indicated that the cells were generally filled almost as soon as they emerged from under the cut-off cap. This observation offered the possibility of using two cut-offs

to double the seed metering rate without an increase in the machine speed. Alternately it offers the possibility of using a smaller diameter cell-ring with maybe only 6 or 8 cells. This will reduce the rotating mass in the machine.

Seed Metering Performance Tests

Initially a photocell activated electronic counter was used to count the ejected seeds. The cells were counted by a second electronic counter coupled to a tachometer generator. The photocell counting did not prove satisfactory, due to a single count when seeds were ejected closely in doubles. Manual checks of the photocell counts exhibited negative errors. The photocell method was therefore abandoned and a counting board was used for manual counting of the seeds. A dual chamber seed collection box, with a flipping partition was used in the metering tests. Figure 3 shows the test set-up for metering accuracy tests. The two electronic counters were activated by the same tachometer driven at the metering-ring speed. One counter was used to indicate the metering speed in cells per minute and the second counter was used for accumulative counting of the total number of cells during a test.

A test was conducted by accelerating the machine to the desired test speed. After the speed stabilized, the second counter was activated simultaneously with the

flipping of the partition in the seed collection box. After a desired sample was collected, the accumulative count was stopped and the partition flipped simultaneously to stop the test.

The collected sample was placed in a sieve to separate the small broken kernel pieces. The larger broken kernels were removed by hand. The total broken seeds were weighed and the per cent seed damage calculated. The remaining seeds in the samples were hand counted and the per cent seed metering accuracy calculated as follows:

$$\%\ \text{Seed Metering Accuracy} = \frac{\#\ \text{undamaged seeds in samples}}{\#\ \text{of cells registered}} \times 100$$

Seed Damage Tests

Two kinds of seed damage were tested. The first was the seed damage which occurred within the metering machine without any external impact on the seed during delivery. The second was the seed damage found after the seed had been subjected to an external impact on a slightly convex steel surface at a distance of 18 inches from the ejection point. The convex surface deflected the impacted seeds away from the ejection path to avoid seed to seed impact. A loose cloth shroud was used around the steel surface to keep the seeds from scattering during tests.

The samples collected from the tests were hand picked for visibly damaged seeds. The rest of the seeds were subjected to germination tests by rolling in wet newspapers and placing for seven days in germination chambers at 70° F. Control seed samples were placed in the germination chambers along with the impacted seeds to determine original seed viability. Seeds exhibiting weak seedlings were considered as damaged.

A few tests were also conducted by weighing the broken kernels and calculating only the visible seed damage. Tests No. 7 and 8 were conducted in this manner.

VI. RESULTS AND DISCUSSIONS

Metering Accuracy

Tests were conducted during the development stages of the machine to establish the effect of relative rotation of seed-chamber, metering-ring and cell-ring. Table 2 indicates that seed damage is lower when the seed-chamber is rotated slower than the metering-ring. The seed-chamber can be rotated with the cell-ring which rotates slower than the metering-ring. Such an arrangement can simplify the machine because only two independent drives are required.

Some tests were conducted to establish the effect of different types of baffles (Figure 14) which were mounted to support part of the weight of the seeds above the cut-off pawl. The result of one 1/2 inch wide baffle is given in Table 3. The result indicates that the baffle contributed towards additional seed damage. After the mechanism had been improved to function properly, tests were conducted to establish seed metering accuracy and seed damage limits between 400-1100 seed/min. metering speed.

Figure 18 consists of four seed metering curves, results of tests conducted on three conventional planters using 16, 20, and 24 cell plates and the experimental 16 cell machine. The tests for the conventional planters (Tables 4, 5, 6) were conducted using the same corn and the

best performing standard plates offered by the manufacturers for the specific variety of corn used. The cell dimensions (Table 1) were very similar for the four tests. The seed metering test results of the experimental machine are given in Table 7 (Test No. 9).

The performance curves of the conventional planters using 16, 20 and 24 cells plates indicated that an increase in the number of cells increased cell fill at each speed. The three conventional planters exhibited the same metering accuracy (96%) at about 33 rpm of the cell plates.

It is interesting to note that the required metering speed of the 16 and 24 cell plate planters to maintain 96% metering performance is in direct relation to the increase of the number of cells in the plates only at the 33 rpm of the plates. Below the 33 rpm, the 24 cell plate exceeds the performance that could normally be attributed to the increase in the number of cells from 16 to 24. Above 33 rpm, the performance of the 24 cell plate is poorer than that which could be expected due to increase in the number of cells from 16 to 24. Thus the metering speed required to maintain any desired metering accuracy level is only in direct relation to the increase in the number of cells at the 33 plate rpm or about 62'/min. plate peripheral speed. The 33 plate rpm seems to be a datum speed and should be used for comparative evaluation of the performance of plates with different number of cells. The performance at 33 plate rpm could also be used as a basis for

TABLE 2.--Effect of relative speed of seed-chamber, cell-ring and metering-ring on visible seed damage.

Test No. 2

Corn: Chester Hybrid KV 35A (Medium Flat).

Cut-off: Open top metal pawl tip (Weight 28.8 gms).

Speed cells/min	Seed chamber	Weight of sample, gms	Weight of damaged seeds, gms	Percent seed damages
(a) Seed-chamber rotating with metering-ring and cut-off				
1250	1250	264	22.5	8.52
1400	1400	259	41.0	15.83
(b) Seed-chamber rotating faster than metering-ring and cut-off				
1250	1400	272	35.0	12.86
1400	1565	362	48.0	13.26
(c) Seed-chamber rotating slower than metering-ring and cut-off				
1250	1170	219	7.0	3.18
1370	1280	176	12.5	7.10

Remarks: Test indicates lowest seed damage when seed-chamber rotates slower than metering-ring. The seed-chamber can be rotated at the speed of the cell-ring, which rotates slower than the metering-ring.

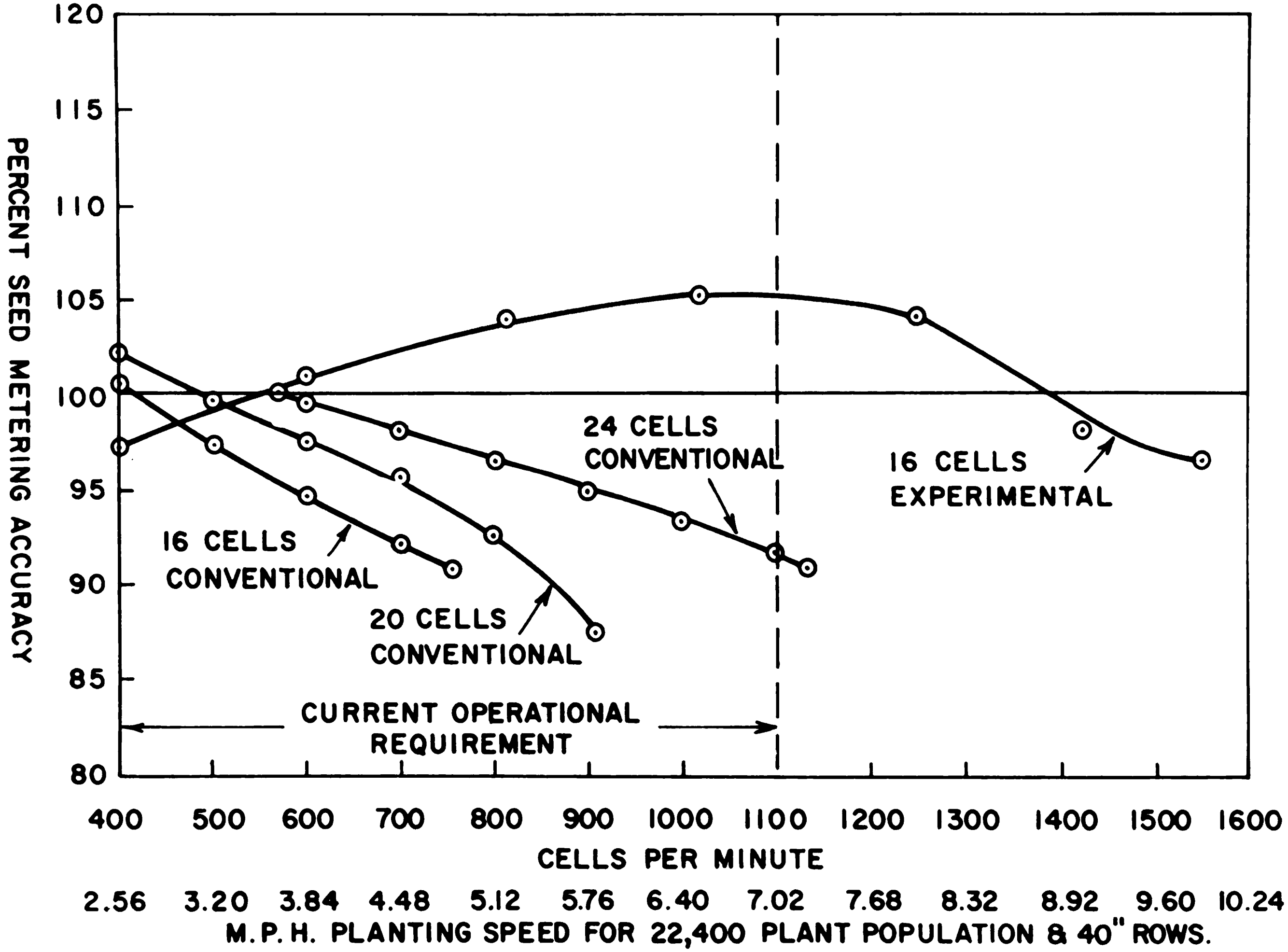


Figure 18.-- COMPARATIVE METERING ACCURACY. CONVENTIONAL vs. EXPERIMENTAL MACHINES.

TABLE 3.--Effect of a ½" wide baffle on seed damage.

Test No. 1

Corn: Chesters Hybrid KV 35A (Medium Flat).

Seed-Chamber Rotation: 1:1 with metering-ring and cut-off.

Speed in cells/min.	Weight of sample, gms	Weight of damaged seed gms	Per cent damaged seed
(a) with baffle 1260	215	40	18.6
(b) without baffle 1250	256	21	8.2

Remarks: The ½ inch sheet metal baffle was mounted just above and slightly ahead of the cut-off pawl tip to relieve the excessive centrifugally induced seed pressures from the cut-off pawl. The results indicate an increased seed damage with the baffle. It seems that the baffle restricts the seed-chamber causing additional seed accumulation near the cut-off pawl. Observations under strobe lights confirm this.

calculating the number of cells required in a horizontal plate to maintain the same accuracy at other seed metering speeds.

Comparative tests between conventional and experimental machines indicates that the conventional machines exhibit a decreased seed metering accuracy with increased metering speeds. The experimental machine, however, exhibits an increased metering accuracy with increased metering speeds within the desired seed metering speeds of 400 to 1100 cells per minute. The experimental machine

TABLE 4.--Seed metering accuracy and seed damage of conventional planter A.

Test No. 14:
Corn Used: Chester Hybrid KV 35A Medium Flat
Number of Cells in Plate: 16
Cell Dimensions: 43/64" - 15/64" - 19/64"
Floor Plate Groove Depth and Position: .051" or > 3/64" facing towards cell
Amount of Corn in Hopper: 3 lbs.

No.	Time in Seconds	Number of Seeds Dropped	Seed Rate/ Min.	Damaged Seeds	% Average Cell Fill	% Average Seed Damaged
I Speed Setting (Cell Rate 377.5 Cells/Minute)						
1	60	381	381	1		
2	60	373	373	5		
3	60	395	395	6		
4	60	391	391	6		
5	60	386	386	3	100.00	0.99
6	60	382	382	1		
7	60	386	386	2		
8	60	373	373	5		
9	60	383	383	4		
10	60	378	378	5		
	600	3828	3828	38		
II Speed Setting (Cell Rate 563 Cells/Minute)						
1	45	393	524	5		
2	45	398	531	2		
3	45	414	552	2		
4	45	396	528	7		
5	45	413	550	4	95.60	1.04
6	45	414	552	4		
7	45	409	546	2		
8	45	398	531	5		
9	45	394	526	4		
10	45	410	547	7		
	450	4039	5387	42		
III Speed Setting (Cell Rate 752 Cells/Minute)						
1	30	334	668	5		
2	30	338	676	3		
3	30	328	656	4		
4	30	337	676	4		
5	30	350	700	5	90.60	1.20
6	30	353	706	3		
7	30	344	688	5		
8	30	343	686	4		
9	30	336	672	5		
10	30	345	690	3		
	300	3408	6816	41		

TABLE 5.--Seed metering accuracy and seed damage of conventional planter B.

Test No. 15:
Corn Used: Chester Hybrid KV 35A Medium Flat
Number of Cells in Plate: 20
Cell Dimensions: 39/64' - 16/64" - 21/64"
Floor Plate Groove Depth and Direction: .0735" or <5/64" away from cells
Amount of Corn in Hopper: 3 lbs.

No.	Time (Sec.)	Plate Rev.	Seed Dropped	Seed Damaged	Avg. cells/ min.	%Avg. cell fill	% Avg. Seed Damage
I (Speed Setting (2" Pully)							
1	60.00	15	309	-			
2	60.30	15	305	-			
3	60.00	15	321	-			
4	60.20	15	312	-			
5	60.00	15	308	-	300	103.50	0.00
6	60.10	15	307	-			
7	60.10	15	313	-			
8	60.30	15	313	-			
9	60.30	15	310	-			
10	60.00	15	308	-			
	601.30	150	3106	-			
II Speed Setting (3" Pully)							
1	54.40	20	400	-			
2	54.30	20	406	1			
3	54.40	20	406	-			
4	54.10	20	399	-			
5	40.70	15	301	-	422	101.20	0.09
6	40.70	15	309	1			
7	40.70	15	303	-			
8	40.80	15	309	-			
9	40.70	15	302	1			
10	40.80	15	310	-			
	461.60	170	3445	3			

TABLE 5.--(Continued)

No.	Time Secs.	Plate Rev.	Seed Dropped	Seed Damaged	Avg. cells/ min.	%Avg. Cell Fill	% Avg. Seed Damage
III Speed Setting (4" Pully)							
1	30.60	15	300	-			
2	30.60	15	296	-			
3	30.50	15	290	1			
4	30.60	15	296	-			
5	30.60	15	296	-	589	97.90	0.102
6	30 50	15	295	1			
7	30.50	15	290	1			
8	30.50	15	289	-			
9	30.60	15	294	-			
10	30.60	15	291	-			
	305.60	150	2937	3			
IV Speed Setting (4½" Pully)							
1	26.20	15	283	1			
2	26.40	15	285	-			
3	26.30	15	282	-			
4	26.35	15	298	-			
5	26.15	15	285	-	684	96.10	0.141
6	26.30	15	283	1			
7	26.40	15	288	1			
8	26.35	15	298	-			
9	26.35	15	291	-			
10	26.40	15	290	1			
	263.20	150	2883	4			
V Speed Setting (6" Pully)							
1	19.90	15	273	-			
2	19.90	15	277	-			
3	19.90	15	266	2			
4	18.65	14	234	1			
5	19.80	15	272	-	905	87.40	0.20
6	26.70	20	358	-			
7	26.40	20	332	-			
8	26.40	20	347	1			
9	26.50	20	350	1			
10	26.60	20	333	1			
	230.75	174	3042	6			

TABLE 6.--Seed metering accuracy and seed damage of conventional planter C.

Test No. 16:
Corn Used: Chester Hybrid KV 35A Medium Flat
Number of Cells in Plate: 24
Cell Dimensions: 43/64" - 14/64" - 19/64"
Floor Plate Groove Depth and Direction: .059" or < 4/64" groove toward cells.
Amount of Corn in Hopper: 3 lbs.

No.	Plate Rev.	Time Secs.	Seeds Dropped	Seeds Damaged	Avg. cells/ min.	% Avg. Cell Fill	% Avg. Seed Damage
I Speed Setting							
1	24	60.80	572	4			
2	14	35.60	341	-			
3	14	35.40	325	2			
4	14	35.50	331	2			
5	14	35.60	341	3	568	100.00	.50
6	14	35.40	346	1			
7	14	35.50	334	2			
8	20	50.70	474	3			
9	14	35.50	335	1			
10	14	35.50	347	1			
	156	395.50	3746	19			
II Speed Setting							
1	16	27.10	370	2			
2	16	27.30	382	2			
3	16	27.10	372	4			
4	16	27.10	369	4			
5	16	27.10	363	4	850	95.60	.80
6	16	27.10	365	6			
7	16	27.10	362	2			
8	16	27.10	359	1			
9	16	27.00	363	1			
10	16	27.10	363	3			
	160	271.10	3668	29			
III Speed Setting							
1	16	20.30	354	2			
2	16	20.20	336	3			
3	16	20.20	338	2			
4	16	20.20	351	2			
5	16	20.40	342	2	1136	91.00	.84
6	16	20.30	341	4			
7	16	20.20	337	3			
8	16	20.40	397	4			
9	16	20.30	361	4			
10	16	20.30	335	3			
	160	202.80	3492	29			

TABLE 7.--Effect of cut-off pawl tip weight on metering accuracy and visible seed damage.

Corn: Chester Hybrid KV 35A Med. Flat 9.26% (W.B.) Moisture Level. Freshly Received from Seed Company
Cut-off: Open top single leaf spring
Seed-Chamber Rotation: 1:1 with cell-ring.

No.	Speed cells/ min.	Total no. cells passed	Test Sample Total wt., gms.	Test Sample Broken wt., gms.	Damaged %	Good Seed Metered no.	Good Seed Metered %
Test No. 9.	Cut-off Pawl Tip Weight 28.8 gms.						
1	400	1104	364.00	0.30	-	1072	97.1
2	609	1831	646.00	1.30	0.20	1843	101.1
3	810	537	201.70	1.50	0.75	561	104.2
4	1020	526	202.70	7.20	3.55	554	105.2
5	1250	893	334.50	11.00	3.28	927	103.7
6	1425	1278	471.20	30.50	6.46	1250	98.0
7	1550	727	272.50	22.30	8.18	700	96.5
Test No. 10.	Cut-off Pawl Tip Weight 16.2 gms.						
1	400	602	221.50	0.30	0.15	628	104.3
2	600	603	219.00	0.30	0.16	621	103.0
3	805	603	225.00	0.60	0.28	637	105.6
4	1010	605	229.50	3.25	1.41	650	107.0
5	1200	1212	473.50	11.50	2.33	1347	111.0
6	1420	612	230.00	11.00	4.75	659	107.5
7	1570	615	219.00	12.30	5.60	630	102.5
Test No. 11.	Cut-off Pawl Tip Weight 6.8 gms.*						
1	416	496	173.00	1.0	0.58	496	100.0
2	610	517	204.50	0.5	0.25	589	114.0
3	860	583	248.70	0.7	0.28	715	123.0
4	1040	525	222.30	1.3	0.59	634	121.0
5	1260	525	216.90	1.9	0.88	629	120.0
6	1335	567	270.30	5.3	2.00	759	134.0

*Note: The cut-off spring folded and machine stopped functioning at 1400 cells per minute.

continued to meter seeds at speeds up to 1550 cells per minute. This unconventional behavior is of considerable importance, since the detrimental effect of speed on metering accuracy has been a major problem with conventional planters. The controlled seed-cell exposure and the increased centrifugal force at higher speeds are responsible for increased accuracy at higher speeds.

The seed damage increased at higher speeds in both the conventional and experimental machines (Tables 4, 5, 6 and 7) but compared favorably for the experimental machine. Higher seed damage in conventional planters moved the metering curves further below the 100 per cent metering level whereas in the experimental machines additional damage tended to bring the curve closer to the 100 per cent level.

If we consider a 100 ± 5% seed metering accuracy as our only goal, the following maximum seed metering speeds were permissible among the four machines.

Planter	Max. Metering Speed
Make A- 16 Cell Conventional	570 Cells/Min.
Make B- 20 Cell Conventional	720 Cells/Min
Make C- 24 Cell Conventional	930 Cells/Min.
Experimental 16 Cell	1550 Cells/Min.

These tests clearly exhibited the superior performance of the experimental machine over a wider range of metering speeds. The relatively flatter performance curve of the

experimental machine indicated that increased speed had less effect on its performance.

The force exerted by the cut-off pawl tip on the cell seemed to have an important bearing on metering accuracy and seed damage. Observations under strobe lights indicated that a heavier cut-off pawl tip reduced the number of extra seeds passing under the cut-off pawl. Tests were conducted using three different tip weights of 28.8 grams, 16.2 grams, and 6.8 grams, and a constant spring force of 170 grams (Table 7). The three different tip weights induced different centrifugal force on the cell and affected the performance of the machine.

Figure 19 has two sets of curves, one exhibiting seed damage and the other seed metering accuracy, for three different cut-off pawl tip weights. The heavier cut-off tip lowered the metering accuracy and brought the curve closer to the 100 per cent line. It also increased the seed damage. The 6.8 gram tip stopped functioning at 1,250 cells per minute due to the backward folding of the spring.

There seems to be a definite inverse relationship between seed damage and the number of excess seeds moving under the cut-off. Since it is desireable to reduce both the seed damage and the excess seeds, the selection of the cut-off tip weight would depend on a compromise. In a commercial machine, seed damage can be easily noticed by the farmer. The pawl weight would have to be based on

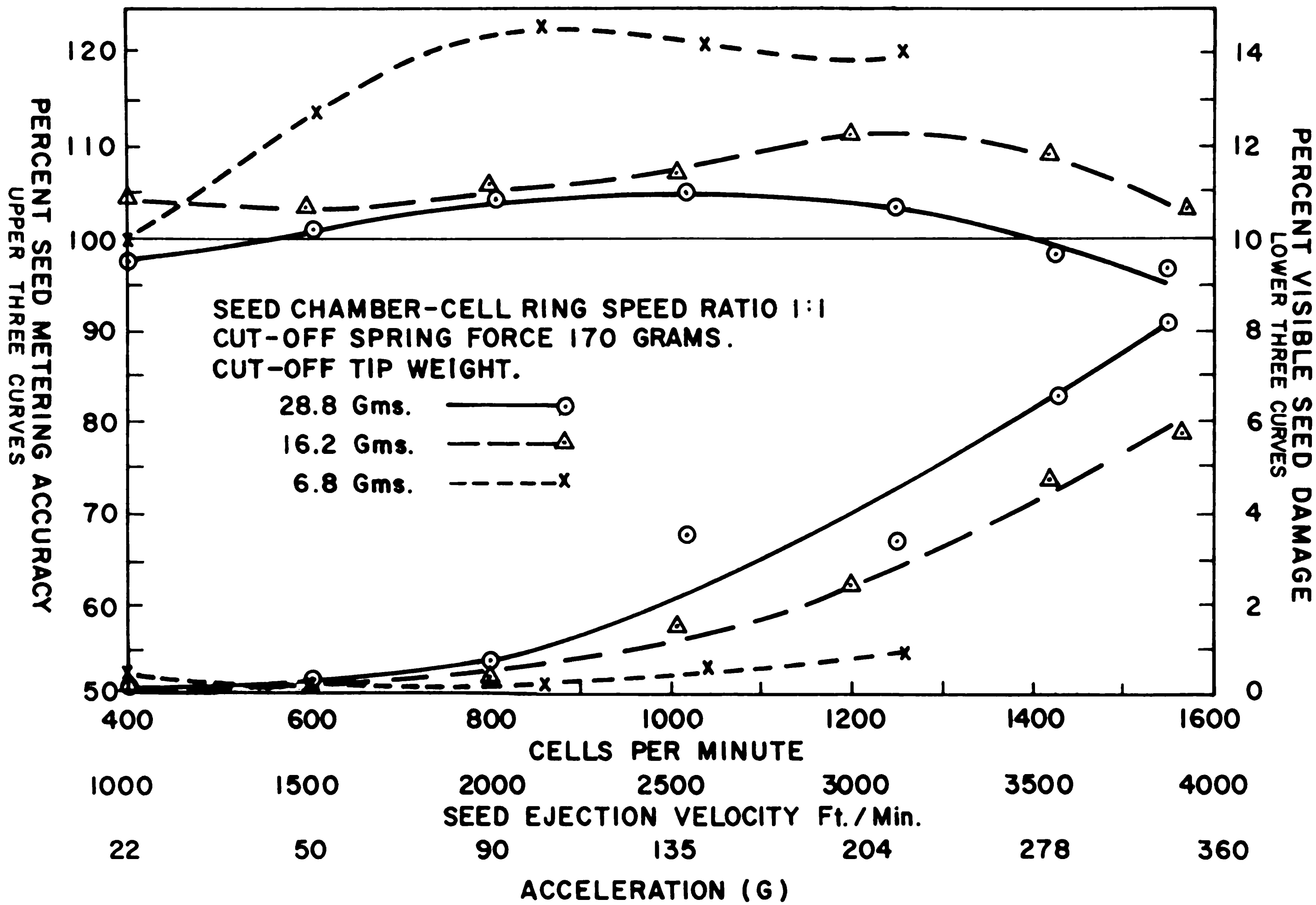


Figure 19.-- **EFFECT OF CUT-OFF WEIGHT ON METERING ACCURACY & SEED DAMAGE CORN MOISTURE. 9.26% TEST NOS. 9, 10 & 11.**

the amount of seed damage that could be safely tolerated without adverse customer response. The movement of a few excess seeds under the cut-off is not so detrimental from the operational point of view in corn planting. Based on the above remarks, perhaps the 16.2 gram cut-off pawl may be desireable.

An additional factor which contributes to the pawl force is the force due to the spring. Performance tests with a 6.8 gram pawl and 270 grams and 1,000 grams spring force were conducted (Table 8). Figure 20 illustrates the test results. Time did not permit the testing of additional spring forces. The weaker spring exhibited a steadily increasing accuracy whereas the stronger spring exhibited a dip in the performance curve at the middle of the speed range. The seed damage was higher with the stronger spring.

It seems that spring force is more effective at slow metering speeds and weight induced force is more effective at higher speeds. This leads to the conclusion that a proper combination of spring force and weight force will maintain close to a 100 per cent metering accuracy over the total range of metering speeds and within desireable seed damage limits.

Seed Damage

Tests were conducted to establish seed damage on corn, prior to an impact and after an impact on a steel

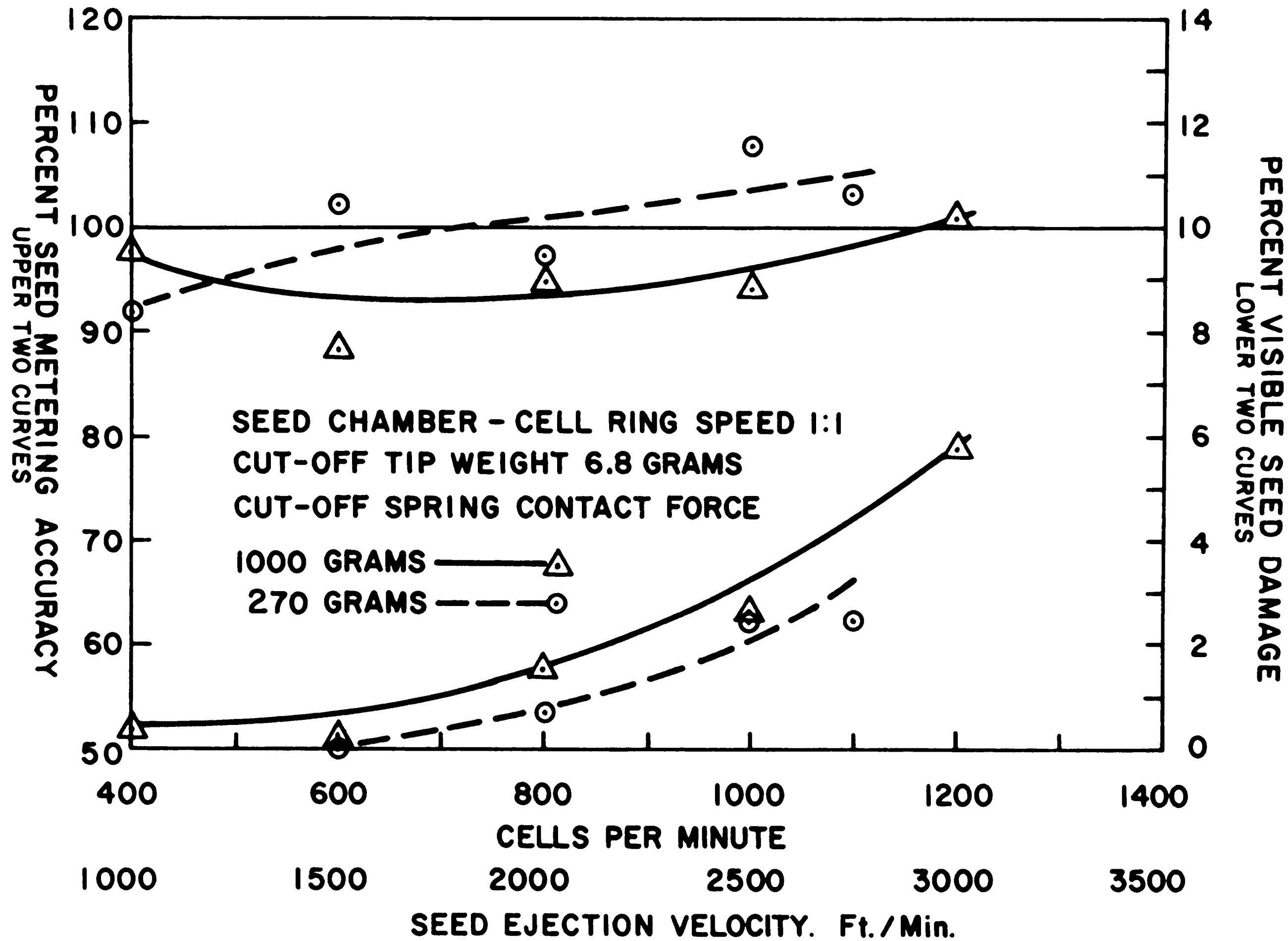


Figure 20.--EFFECT OF CUT-OFF SPRING CONTACT FORCE ON METERING ACCURACY AND SEED DAMAGE. CORN MOISTURE 8%. TEST NOS. 12 & 13.

TABLE 8.--Effect of cut-off pawl tip spring force on metering accuracy and seed damage.

Corn: Chester Hybrid KV 35A Medium Flat. 8.00% (W.B.) Moisture Level.
Impact Surface: Cloth Chute (No Impact)
Cut-off: Open Top Type. Pawl Tip Weight 6.8 gms.
Seed-Chamber Rotation: 1:1 with cell-ring.

No.	Speed cells/ min.	Total no. cells passed	Test Sample: Total wt. gms.	Test Sample: Broken wt. gms.	Damaged %	Good Seed Metered: no.	Good Seed Metered: %
Test No. 12: New Single Leaf Spring. Cut-off Pawl Contact Force 270 gm.							
1	400	503	160.00	0.00	0.00	461	92.00
2	600	502	178.00	0.00	0.00	503	102.00
3	800	506	169.00	1.20	0.71	486	97.00
4	1000	538	200.00	5.00	2.50	580	108.00
5	1100	505	189.00	4.70	2.50	536	103.00
Test No. 13: Dual Leaf Spring. Cut-off Pawl Contact Force 1000 gms.							
1	400	992	339.00	1.60	0.47	976	98.50
2	610	1019	317.00	1.00	0.31	900	88.50
3	820	989	333.00	6.00	1.80	955	96.60
4	1010	1019	336.00	9.40	2.80	959	94.20
5	1270	1044	373.00	29.00	7.76	1071	102.50

surface, placed 18 inches from the seed ejection point of the machine. Figure 21 illustrates the seed damage test (Table 9) on corn with 10% W.B. moisture before and after the impact on a steel anvil. There is little significant difference between the two curves. This indicates that the impact on a steel surface up to velocities of 2,750 feet per minute (metering speed of 1,100 cells/min.) do not significantly contribute to seed damage. The seed damage within the machine was 1.00% at a metering speed of 1,100 cells/min. The additional damage due to impact on the steel surface at the same metering speed was only about 0.5%. A 2.2 gram nylon cut-off pawl with a 170 gram spring force was used for this test. The seed chamber was set to rotate with the cut-off. Subsequent tests indicated that this drive arrangement resulted in an uneven seed distribution in the chamber and an increased seed damage.

Figure 22 includes two seed damage test curves (Table 10) on corn at 12% W.B. moisture level. The results are similar to the tests in Figure 21 except that the damage levels up to the metering speed of 1,100 seeds per minute are slightly lower. This indicates that at 12% W.B. moisture level, corn is less susceptible to impact damage than at 10%. It also confirms that the impact during seed delivery is not so significant at ejected velocities of up to 2,750 feet per minute (seed metering speeds of 1,100 seeds per minute). Both Figures

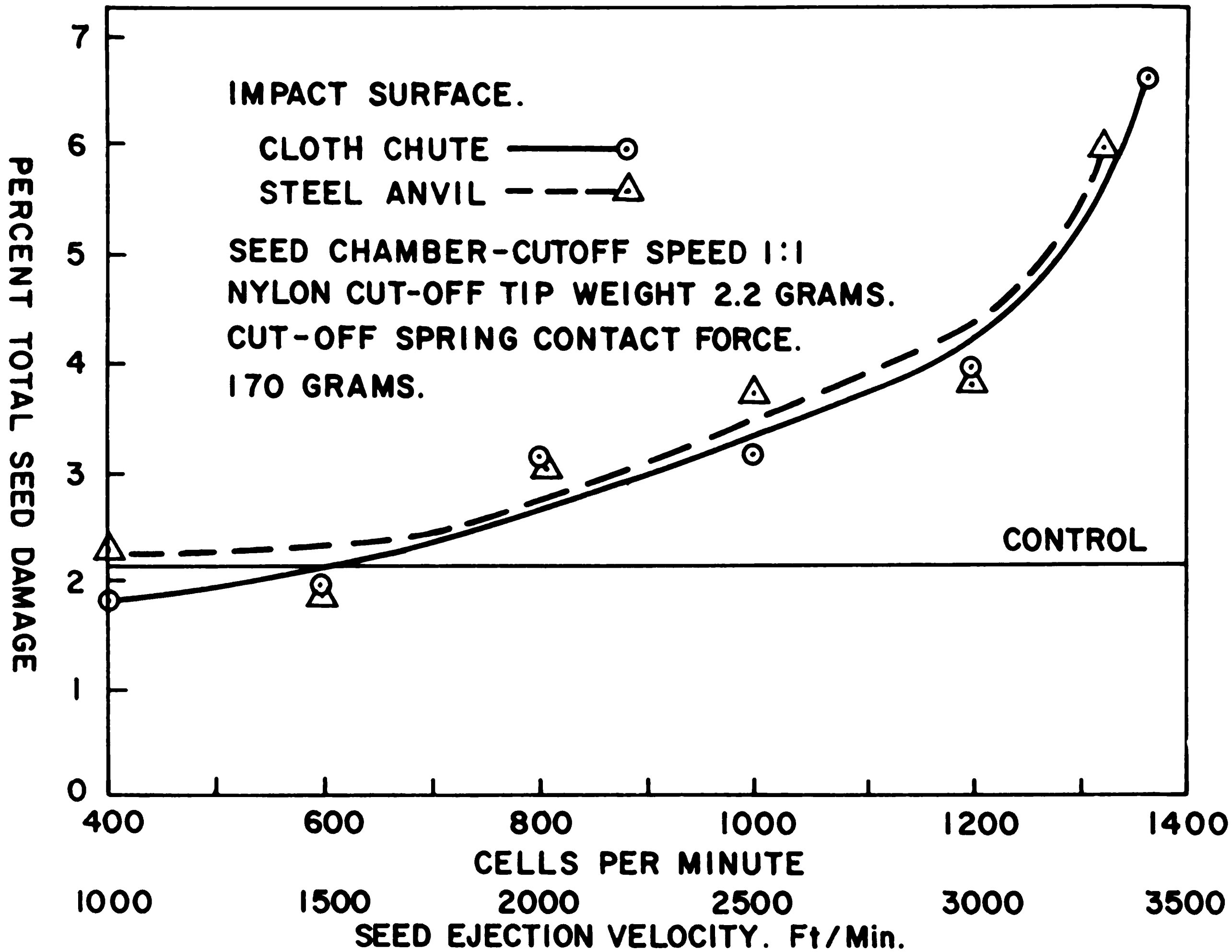


Figure 21.-- EFFECT OF IMPACT ON SEED DAMAGE. GERMINATION TESTS ON CORN AT 10 % MOISTURE. TEST NOS. 3 & 4.

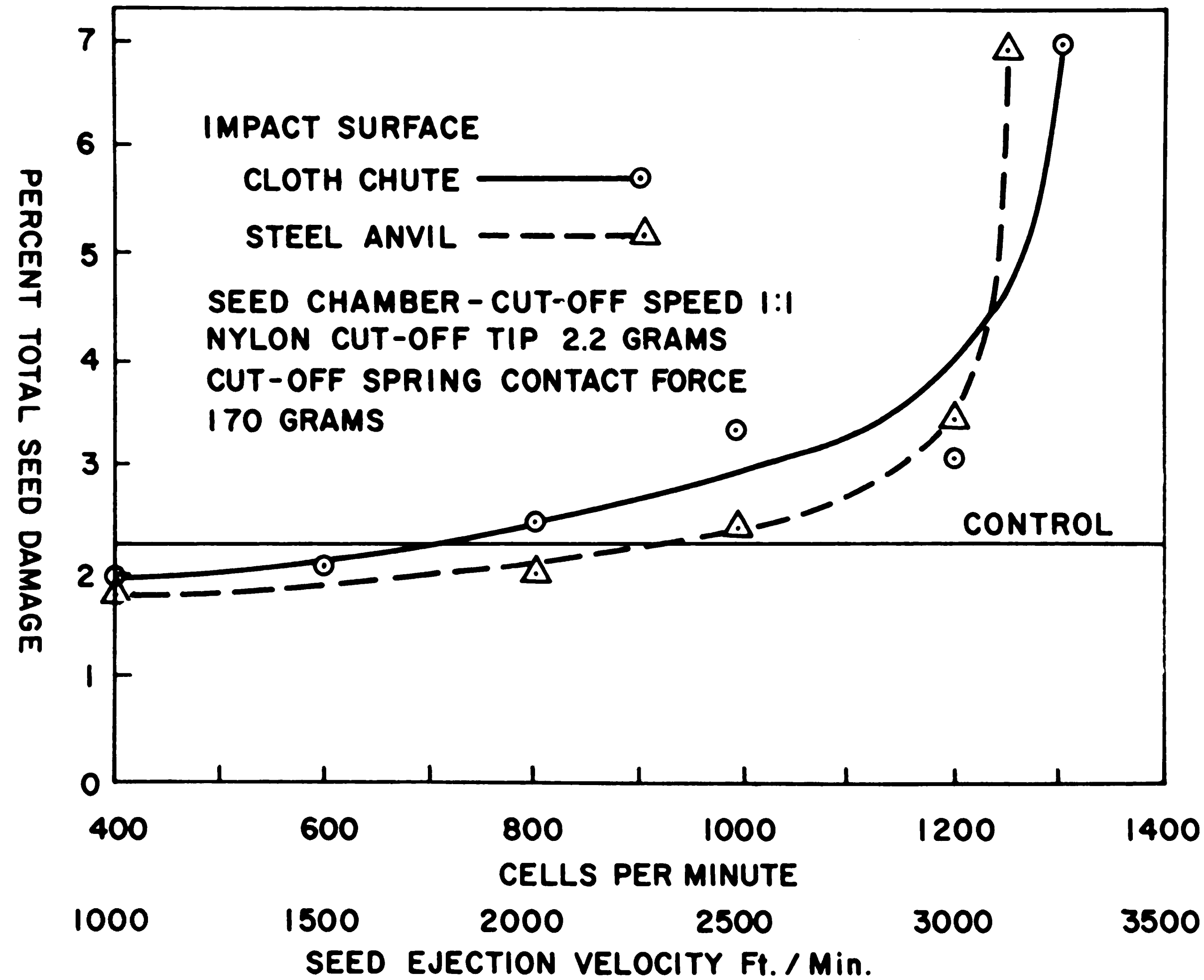


Figure 22.-- EFFECT OF IMPACT ON SEED DAMAGE. GERMINATION TESTS ON CORN AT 12% MOISTURE. TESTS NOS. 5 & 6

TABLE 9.--Effect of impact surface on seed damage (germination test).

Corn: Chester Hybrid KV 35A Medium Flat. 10% Moisture Level (W.B.), Stored for One and a Half Years.
Cut-off: Open Top Single Leaf Spring with Nylon Pawl Tip (2.2 gms weight).
Seed-Chamber Rotation: 1:1 with metering-ring and cut-off.

No.	Cells/ min.	Velocity ft./ min.	Sample Size	Visibly Damaged Seed	Germination Poor	Germination None	Damaged Seed no.	Damaged Seed %
Test No. 3. Impact Surface: Cloth Chute (No Impact).								
1	400	1000	424	-	1	7	8	1.87
2	600	1500	577	-	4	7	11	1.91
3	800	2000	577	2	3	13	18	3.12
4	1000	2500	409	2	6	5	13	3.18
5	1200	3000	480	4	7	8	19	3.95
6	1360	3400	660	7	14	21	42	6.36
7	Control	--	1200	-	6	20	26	2.17
Test No. 4. Impact Surface: Steel Plate 18" from Ejection Center								
1	400	1000	484	-	8	3	11	2.27
2	600	1500	438	-	5	3	8	1.83
3	800	2000	565	2	6	9	17	3.01
4	1000	2500	456	5	7	5	17	3.72
5	1200	3000	367	4	7	3	14	3.81
6	1320	3300	454	5	6	16	27	5.95
7	Control	--	1200	-	6	20	26	2.17

TABLE 10.--Effect of impact surface on seed damage (germination test).

Corn: Chester Hybrid KV 35A Medium Flat. 12% (W.B.) Moisture Level. Stored for One and a Half Years.
Cut-off: Open Top Single Leaf Spring with Nylon Pawl Tip (2.2 gms. weight).
Seed-Chamber Rotation: 1:1 with metering-ring and cut-off.

No.	Cells/ min.	Velocity ft./min.	Sample Size	Visibly Damaged Seeds	Germination Poor	Germination None	Damaged Seed no.	Damaged Seed %
Test No. 5. Impact Surface: Cloth Chute (No Impact).								
1	400	1000	572	1	2	8	11	1.93
2	600	1500	639	1	1	11	13	2.04
3	800	2000	611	4	4	7	15	2.46
4	1000	2500	623	6	4	11	21	3.37
5	1200	3000	522	-	4	12	16	3.07
6	1300	3250	493	3	11	21	35	7.00
7	Control	--	568	4	1	8	13	2.29
Test No. 6. Impact Surface: Steel Plate 18" From Ejection Center								
1	400	1000	521	-	6	3	9	1.76
2	600	1500	586	-	5	7	12	2.05
3	800	2000	520	1	5	4	10	1.93
4	1000	2500	583	4	4	6	14	2.40
5	1200	3000	605	4	5	12	21	3.47
6	1250	3110	451	10	9	12	31	6.90
7	Control	--	568	4	1	8	13	2.29

21 and 22 indicate a rapidly increasing seed damage within the machine at metering speeds of over 1,200 seeds per minute.

Figure 23 illustrates seed damage tests (Table 11) on corn at 10.5% W.B. moisture level. A slightly heavier cut-off pawl (15.5 grams) was used for this test. The corn used for tests in Figures 21 and 22 was stored for about one and a half years. The tests of Figure 23 were carried out with fresh corn received from the seed company. This was done to assure that the results would be comparable to actual planting conditions.

The results exhibited the same general pattern. At 1,100 seeds per minute the seed damage within the machine was 1.4% and the impact on steel surface resulted in an additional damage of 0.9%. There seems to be some error around the 1,000 seed per minute speed. From Tables 7 and 8 we find that at 1,000 seeds per minute the actual seed damage within the machine is only .13%, whereas the impact damage is 3.05%. At 1,200 seeds per minute, both the seed damages are about equal (3.14% and 3.49%), which is contrary to general expectation.

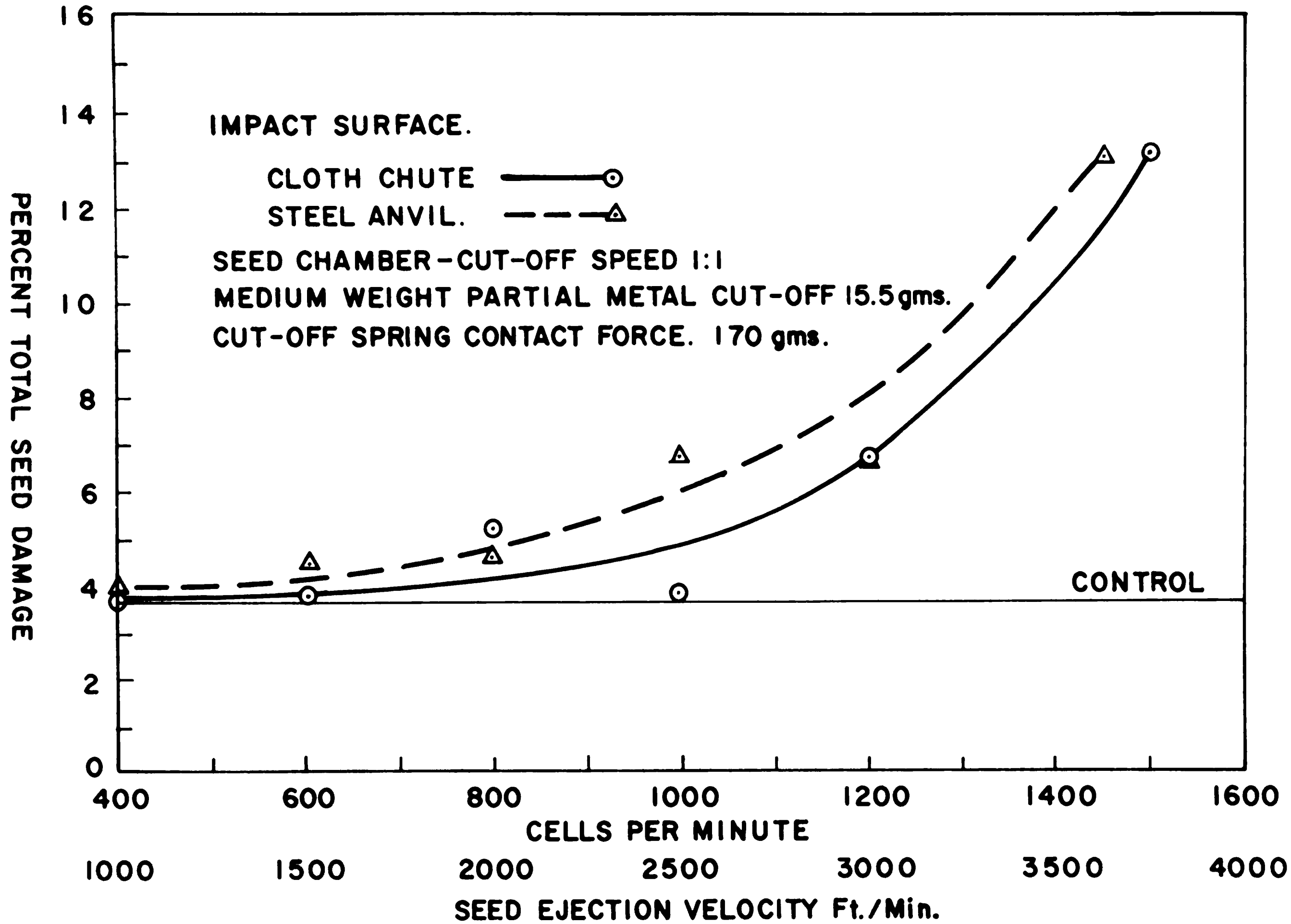


Figure 23.-- **EFFECT OF IMPACT ON SEED DAMAGE. GERMINATION TEST ON CORN AT 10.5 % MOISTURE. TEST NOS. 7 & 8.**

TABLE 11.--Effect of impact on seed damage (germination test).

Corn: Chester Hybrid KV 35A Medium Flat. 10.5% (W.B.) Moisture Level. Freshly Received from Seed Company.
Cut-off: Open Top Single Leaf Spring with Nylon Pawl Tip (2.2 gm. weight).
Seed-Chamber Rotation: 1:1 with metering-ring and cut-off.

No.	Cells/ min.	Velocity ft./min.	Sample Size	Visibly Damaged Seed	Germination Poor	Germination None	Damaged Seed no.	Damaged Seed %
Test No. 7. Impact Surface: Cloth Chute (No Impact).								
1	400	1000	476	-	4	14	18	3.78
2	600	1500	581	1	3	18	22	3.79
3	800	2000	499	1	6	16	23	4.60
4	1000	2500	511	-	4	15	19	3.73
5	1200	3000	579	7	6	26	39	6.74
6	1550	3875	680	13	18	59	90	13.20
7	Control	--	500	-	3	15	18	3.60
Test No. 8. Impact Surface: Steel Plate 18" from Ejection Center.								
1	400	1000	501	-	7	13	20	4.00
2	600	1500	516	-	9	14	23	4.45
3	800	2000	535	4	9	11	24	4.48
4	1020	2550	495	5	10	18	33	6.65
5	1200	3000	602	9	6	24	39	6.49
6	1450	3625	400	19	6	27	52	13.00
7	Control	--	500	-	3	15	18	3.60

VII. APPLICATION OF RESEARCH

This study was conducted to establish the feasibility of the new concept of planting. The experimental machine and the test results have proved that the concept is practical and meets the desired operational planting requirements. The farm machinery industry has been faced with the high speed planter problem for many years and is very receptive to practical solutions. While this study has been financed by a grant from the Ford Tractor Division and the patents originating from this study would be under control by the company, it is hoped that this new concept will generate original thinking among engineers engaged with planter development.

At this stage it is only possible to suggest broad recommendations about a field machine. Additional information will be required about the performance of this machine with other seeds and planting rates before specific recommendations could be made. Information will also be required about the ejection velocities to imbed different seeds in different soil conditions.

Based on the available information, a field seed metering unit with only two rotating members has been proposed in Figure 24. The unit has its own set of gears to provide the speed differential between the cell-ring and

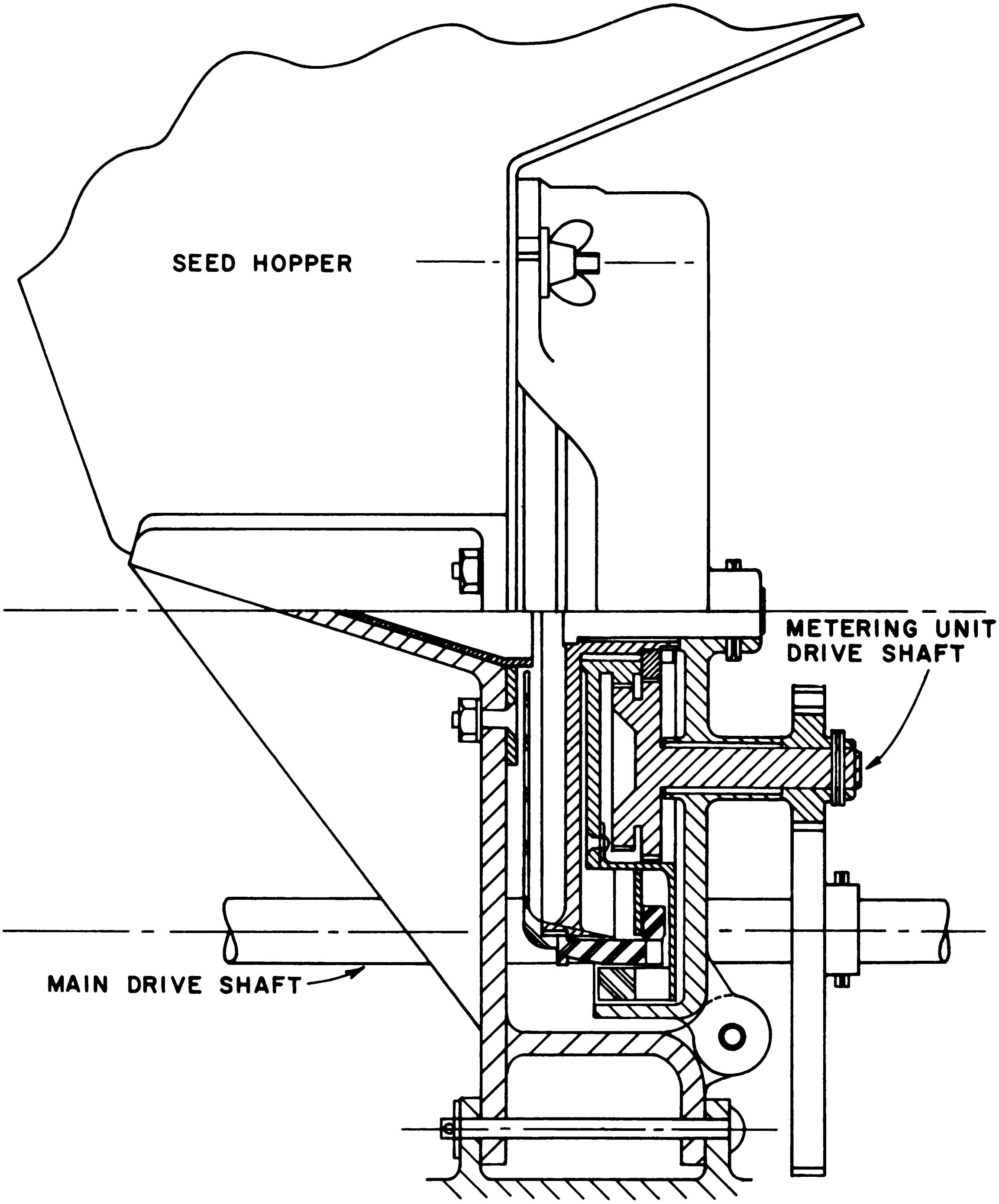


Figure 24.-- **Suggested Seed Metering Unit for a Field Planter.**

metering-ring. It incorporates the baffle type feed-in arrangement to maintain a constant amount of seed in the chamber during operation. It provides means for easy changing of cell-rings for different kinds of seeds, by unscrewing a molded cap. This cap has a feed intake hole in the center and it also serves as a seed passage wall.

The metering unit is driven from a single shaft to simplify power input. The metering unit is mounted on the machine frame by a bracket which permits the tilting of the hopper. The machine could be either ground driven or tractor P.T.O. driven. The metering unit need not be mounted very close to the ground since the distance will hardly effect the placement accuracy. The suggested sketch for a field planter is one of the many possible approaches for a field machine, each offering some advantages. Further work on the experimental machine with other seeds may help to evaluate the different possible designs.

VIII. SUMMARY

The use of centrifugal force for seed metering, ejection, and placement is feasible. The experimental laboratory machine was successfully tested up to a metering speed of 1,100 cells per minute. In terms of planting travel speed, 1,100 cells per minute is equivalent to planting 22,400 plants per acre in 40 inch rows at 7.02 miles per hour. It is considered that a maximum planting travel speed of 7 m.p.h. would be desireable for current farming practices. The study has proved that planting requirements are well within the scope of the new concept and that it offers a potential for further increase in planting speeds.

The effect of high planting speed on metering accuracy in the experimental machine is contrary to that of conventional planters within the speed range of 400 to 1,100 cells per minute. The metering accuracy increases with an increase in metering speed in the centrifugally dependent concept.

Ejected corn seeds with 2,750 feet per minute initial velocity (1,100 seeds per minute metering speed) did not exhibit a significant reduction in germination after impact on a steel plate at a distance of 18 inches from the ejection point. It can be concluded that impact of corn

seeds with stones during planting will not effect germination up to ejected velocities of 2,750 feet per minute.

Seed damage, within the machine, increased with an increase in metering speed. It compared favorably with seed damage in conventional planters at each level of metering speed. Seed damage increased rapidly above the 1,200 cells per minute metering speed. Seed damage at 800 cells per minute averaged about one half per cent and it increased to an average of 1.5% at speeds of 1,200 cells per minute. Seed damage within the machine is affected by the cut-off pawl force. This force can be best provided by a combination of spring and weight induced forces. Seed damage and excess seeds passing under the cut-off pawl have an inverse relationship.

Amount and distribution of seed in the seed chamber have an effect on seed damage. Excess seeds in one corner of the chamber can induce very high centrifugal force and unbalance in the machine. The seeds are subjected to about 175g acceleration at 1,100 cells per minute metering speed. Uniform seed distribution can be achieved in the seed-chamber by rotating the seed-chamber with the cell-plate and not with the metering-ring. Such an arrangement will also result in a simpler mechanism with only two independently rotating members. The amount of seed in the chamber during operation can be successfully controlled by a pressure equalizing baffle as described earlier in Chapter V.

IX. RECOMMENDATIONS FOR FURTHER STUDY

1. The centrifugal concept of seed metering needs to be tried in the laboratory on all the other kinds of seeds which are planted with conventional planters. This concept offers the possibility of planting cotton without delinting the seed and this should be studied.

2. Additional work is necessary to study the combined effect of spring and weight induced cut-off pawl pressures on metering accuracy and seed damage.

3. The required ejection velocities to imbed different kinds of seeds in soils, representative of actual field conditions, has to be established.

4. A field machine is required to study the field performance and to experimentally determine the point of seed impact with respect to the furrow openers.

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