

DESIGN AND DEVELOPMENT OF A
STEP METERING DEVICE

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Rey J. Jimenez
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DESIGN AND DEVELOPMENT OF A
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by

Rey J. Jimenez

AN ABSTRACT

Submitted to the College of Agriculture of
Michigan State University of Agriculture
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ABSTRACT

The design and development of a step metering device is described. As the design was completed a plastic model was constructed in the Agricultural Engineering Laboratories of Michigan State University. This model was tested to some extent.

Because of the limitations of the plastic model a full scale metal model was built. This metal model was tested with different size of seeds, at different velocities and at various dropping distances, fixed on top of a moving belt. Results were tabulated and the precision of the metering device determined by means of the coefficient of variation. Seed size, velocity of travel and dropping height are related in the tabulated results.

A statistical analysis, discussions of results and a critique of the metering device are given. An appendix with a kinematic analysis of the mechanism is also included.

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INTRODUCTION

The production of most food and fiber crops begins with the planting of seeds in or on the ground. This is accomplished either by hand or with a machine. Machines are rapidly replacing hands in the agricultural fields. Although crops are still planted by hand in many countries throughout the world, the use of highly developed precision planters is rapidly increasing.

Recent studies (Morton and Buchele, 1959, and Berrett and Reeve, 1959), concerning the percent stand of seeds have shown that when precise methods of metering seeds are used, higher profits results. Precision planting eliminates hand thinning labor and the profit losing skips in the row.

The objectives of this research is to invent, design, and construct a precision metering device. In order to obtain satisfactory results in this thesis, a solution to a problem crop, with national importance, should be found. This is why sugar beets seeds were chosen as the test seed. It is a challenge to ingenuity, it is a challenge to all who wants to help our farmers, just as it was a challenge to those who had tried in vane and failed leaving their experiences behind for us to use.

Barmington (1956) wrote,

"Precision planting of sugar beet is a goal that research men in this industry have had for a long time. If the seed could be made

large, smooth, and dense, the problem of precision planting would be greatly reduced Since we are dealing with 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."

Before attempting a solution to this problem, existing commercial and experimental planters were studied in detail. The study showed that all of the planters were dependent on the physical characteristic of the seeds for good performance. If a prompt solution is desired it will be easier to produce a good new planter capable of working with any seed, than to breed a new type of seed. Good results had been obtained by breeders in the production of a monogerm seed, and still, the problem exists. Records show that nearly all of the past machinery research effort was directed toward a modification of the existing planters and very little was expended on new ideas or new approaches.

After studying the existing planters, it was decided to expend all our efforts on a new idea, where special attention was paid to separation, spacing and placement of seeds on the ground with interest in the speed and simplicity of the process.

These factors were considered to be the most important of all. Separation of the seeds without harming them and their proper spacing, when placed on the ground, are two of the major economical factors. Morton and Buchele (1959) stated that,

"The emergence of the stand of plants is directly proportional to the uniform operation of the planting unit."

If the emergence is proportional to the uniform operation of the unit, the farmers income will be also proportional to it. Berrett and Reeve (1959) showed that increasing the seed spacing from two to three inches resulted in a thinning cost reduction ranging from \$3.50 to \$4.75 per acre.

It is interesting to note that a small difference of one inch in the seed spacing can effect a cost reduction in spring labor. If thinning was not necessary, due to precision planters, profits will still be higher than that estimated by Berrett and Reeves.

With the above points in mind and a desire to increase the speed of planting a step planter was invented, designed and constructed. The new planter was tested and compared with existing commercial planters. A kinematic approach for analysis was made of all types of planters, according to the classification used, in order to point out some of the actual problems that have not been solved and presumably were neglected by others investigators.

LITERATURE REVIEW

History

The Indians used to say, "When the woman plant maize the stalks will produce two or three ears, because women know how to produce children. They only know how to plant corn to ensure its germinating. Then let them plant it. They know more than we do."*

Thru the ages, clearing the land by hand was men's work while planting, sowing, tending and collecting were women's work. Even today this still holds true in many parts of the world. A more interesting fact is that the same planting principles are used today with little variation from those used 2,000 years B. C. At that time the fore-runners of the grain drills were used in China and Mesopotamia. These drills placed the seeds at a controlled depth and in accurate amounts. Encyclopaedia Britannica (a) describes this machine as consisting of a plow of that era equipped with a seed hopper and a tube to convey the seed to the groove made by the plow point. The method of metering is not known. Thirty six centuries later, in the 16th century, some changes were incorporated to this planter. In the 16th and 17th century, systems to ensure accuracy of rate were used. Almost all of them consisted of a wheel equipped with spoons. The spoons dipped into the hopper and collected a quantity of seed. The seed was transferred to the seed tube

* Payne, History of the New World, ii 7, Encyclopaedia Britannica

which guided it to the furrows made by the plows points or special openers.

This method of metering is still used today (1960) in many European drills.

This brief history shows that few changes were made on planters and that the most important of these changes were made during the twentieth century.

Literature Review

A review of literature published during the past 30 years will provide us with information concerning planting methods and systems, and their development.

Mervine and Mc Berney (1936) stated that the usual practice of growing sugar beets was to drill the seed in a continuous row at a rate of 18 to 20 lb of seed per acre. After the seedlings were up and well established, they were thinned to single plants usually at about 10 or 12 inches intervals. In average stands, the thinning operation reduced the number of seedlings in a hundred inches of row from one and two hundred to about eight or ten. They also suggested hill planting because of a saving in work and seed per acre. Hill planting will reduce the seed from 18 -20 lbs to 7-8 lbs per acre. Referring to hill planters, Mervine and Mc Berney (1936) reported that one-row models were designed and

built using a seed plate in a vertical plane. Seed cells in the circumference of the plate accumulated seed as they passed through a seed hopper, carried the seed downward, and discharged it near the bottom of the opened furrow. The peripheral speed of the seed plate was approximately equal to the forward travel velocity of the planter, and rotated in the same direction as the press wheel. Thus seeds in the cells were practically stationary with respect to the ground and since they dropped less than two inches, there was little seed scattering.

Three years later Mervine and Mc Berney (1939) reported, other investigations with planters, and stated that none seemed to have a uniformity of seed drop which approached what was desired. Other types of seed-metering mechanism were investigated to discover one which would drop single seed balls and which, in addition could be used with any sized commercial seed. The pick-up cup or cell type of mechanism seemed to show the most promise. It utilized an endless chain of small seed cups passing up through a seed hopper where one ball was picked up in each cup. The cups emerged from the surface of the seed and allowed all surplus balls to fall away. They then entered a tube which confined the balls between the cups and passed over the driving sprocket and down to the bottom of the opened furrow where the seed balls, still equally spaced, were dropped. The seed spacing was varied by changing the travel of seed chain relative to the forward travel of the planter.

Mc Berney (1946) after the death of E. M. Mervine, pointed out that the sugar beet seedling stand accepted as desirable in 1933-36 were not well suited to present mechanization. The seedlings were not uniformly distributed in the rows and were too thick so that blocks left by machine thinning contained several seedlings and would not produce a satisfactory crop of marketable size beets without further hand thinning. Careful hand planting convinced them that much of the solution of mechanical thinning laid on improved planting. Success in the development of an improved single-seed planting equipment made it evident that seeding rates could be reduced without causing large gaps and thus produce seedling stands which could be thinned by hand much faster, or machine-thinned without leaving so many multiple beet blocks. Seedling rates of 20 lbs per acre in 1936 were reduced to 3 lb per acre.

By this period Brooks and Baker (1946) had developed a statistical method of evaluating and comparing planters by the use of a dispersion coefficient.

Roy Bainer (1947) published results of five different planters compared to hand planting. This showed that the dispersion coefficient of the planters ranged from 0.95 to 2.87 compared to 0.79 by hand. These results are from field trials. Using the grease board test (see appendix), Bainer (1947), at a board speed of 2 1/2 mph, obtained dispersion coefficient of 0.009 to 0.48 on the same planters.

Guelle (1947) reported that beet planters operating at current trac-

tor speeds distributed seeds at rates averaging about 35 seeds per second. Because seed particles distributed at this tremendous rate varied widely as to shape and as much as 20 percent in size, it was necessary to drill and counter-sink the cells in the seed plates and machine finish these plates and other parts to close tolerances.

Partridge (1947) in discussing some of the problems with planters wrote that no matter how mechanically perfect the metering device of a drill was, a satisfactory distribution of the seed is impossible without seeds of fairly uniform size.

Bjerkan (1947) pointed out that an increase in plate "speed was always accompanied with a decrease in percent of filled cells and consequently the planting rate." If seeds were large in relation to the seed cells, greater variation in the planting rates resulted from changes in speed.

One of the most significant studies conducted in the 1940 decade was that of Barmington (1948). Here he related the seed, cell size, and speed to the performance of the planter. In his studies, Barmington showed that the percent cell fill was dependent upon seed plate. The higher the cell speed the lower the percent fill of the cells. During this decade, interest developed not only in the perfection at the planters, but also in the obtaining of seed with better physical and physiological characteristics. Great interest and effort was shown not only by the gov-

ernment but also by the private enterprise.

Futral and Allen (1951) reported that there were three main reasons for the drop in planting efficiency at higher speed:

1. Angular velocity of plates was so fast that the seed was frequently carried past the drop-out opening.
2. The inertia of the spring loaded kick-out mechanism was too high to function properly and damage resulted to the seed when spring tension was increased.
3. With tractor-mounted hoppers, seed frequently set up a spiralling motion in the round flexible seed spouts thereby delaying the drop and causing bunching.

Barmington (1956) compared the performance of various foreign and domestic planters. He developed a numerical system for comparing the planters. A perfect planter would have a score of 100 and all planters were penalized for planting seeds too close together, or too far apart. The planters that place half of the seeds in the theoretical position would have a zero rating, and would not be considered a precise machine. Negative values would be obtained when less than half of the seeds were placed in the desired position. The results obtained varied from -42 to +54.89. This showed that the more precise mechanism was not exactly what should be called a precise planter. In his test he found

that 13% of the seeds were damaged.

Two years later Barmington (1958) wrote that there was a need for a new planter for the new monogerm seeds, which would not damage the seed but would convey the seed to the bottom of the furrow in a uniform pattern. Describing the metering process he said that the distribution usually begins with some kind of seed cell in either metal plates or rubber belts. It would seem that at that point seed spacing should be accurate except for empty cells or multiple seeds in a single cell. After the seed left the seed cells, everything seemed to go wrong from a distribution standpoint.

Michigan State University had been conducting research in the last three years in an effort to improve the performance of actual planters and their metering device (Morton, Stout and Buchele 1958-59).

This literature review shows that better methods of metering seeds is needed. The thinning problem could in all probability be solved by accurate planting which would in turn decrease the seeding rate and save seed. Thinning of the plants to a stand, seed cost and speed of planting are economics factors that have to be under control in order to obtain higher profits.

Based on these facts, a method of separating seeds at low speeds and depositing them was used as a way of solving those problems in -

stead of conveying the seeds or dropping them as by present means.

IMPORTANCE OF WORK

Our National income is greatly dependent on agricultural products. The farmers income is related to the stand of their crops. Failure to emerge a crop stand is therefore costly to the Nation.

Poor planter performance forces farmers to over-plant and makes hand or machine thinning necessary. Hand labor cost has steadily increased through the years and is becoming scarcer every season. Mechanization is thus a must in all crops, especially in sugar beets.

Less pre-harvesting work is desired, and a good solution is the accurate metering of the seeds when planting.

OBJECTIVES

Three main objectives were chosen for this work:

1. To invent, design, and construct an accurate and dependable seed metering device.
2. To study the performance of existing metering devices and compare them to the experimental seed metering device developed in this thesis.
3. If necessary and possible improve the performance of existing metering devices.

METHOD OF PROCEDURE

The method of procedure was:

1. Conduct a bibliographic study of planter development.
2. Classify and conduct a functional analysis of existing planters.
3. Invent, design and construct an experimental planter.
4. Conduct planter test and compare results with others already tested.

CLASSIFICATION

Planters have been classified according to the metering system and to the type of furrow opener (Bainer, Kepner, Barger -1955). A different classification system was used to divide the planters according to the metering principle.

Two main groups were adopted: seed separation principle, continuous or intermittent ; and seed conveying or depositing principle, continuous or intermittent. Sub-divisions such as mechanical, vertical, horizontal, step, and others were used to provide a means of general description. Examples using this classification system are:

1. John Deere Flexiplanter - Continuous seed separation and conveying horizontal plate planter.
2. Milton Planter - Continuous seed separation and conveying vertical plate planter.

This system not only describes the type of mechanism but also their working principle. A better idea will be given to the reader by describing some important or characteristic feature of the mechanism, such as, belt or chain driven, positive or pneumatic ejecting, fixed or variable seed spacing, etc.

An example is the description of the experimental metering device designed for this work:

Precision Step Plater- Ground driven, continuous seed separation, step seed depositing with horizontal rotating cylinder planter.

The above planter description shows that this classification grouped nearly all planters in a main body.

Commercial planters could be classified in a general group of ground driven continuous seed separation and conveying plate planters. The operational description of any of these planters could be applied to the rest when compared in working principles. The step planter was different from those in the group by not being a continuous conveying planter. Instead, this planter will deposit in steps the seed separated and metered by the mechanism.

A classification list was made of a number of commercial and experimental planters and is as follows:

A- Ground driven, continuous separation and conveying plate planters.

1. Horizontal Plate with positive cut-off and kick out.

- a) John Deer Flexiplanters

- b) International Harvester 185

2. Vertical Plate

- a) Milton Planter (with positive cut.- off and kick out).

- b) Taxigraine Planter

- c) Ventura Planter

3. Inclined Plate

- a) Case Planter

- B. Ground driven, continuous separation and conveying belt planters..

1. Horizontal Belt with rotating cut-off

- a) Stanhey Planter

2. Inclined Belt

- a) Semora Planter

- b) Experimental Planter (Futral and Allen)

- C. Ground driven, continuous separation, step depositing planter.

1. Horizontal rotating cylinder

- a) Experimental Step Planter

PLANTER ANALYSIS

A functional analysis of the metering units will illustrate some of the principal factors affecting their performance.

Three following basic principles were established:

1. To prevent damage to the seed and secure better separation, low separating speeds must be used, even at high tractor speeds.
2. Fixed cut offs cannot be used for removing the excess seeds from the seed cells.
3. The seeds must be ejected as close as possible to the ground surface and with a zero relative velocity with respect to the ground.

These basic principles must be carefully studied and a solution to each must be found if good performance is expected from any planter unit. According to our classification, continuous separation and conveying with horizontal or vertical plates are the most common of all systems.

Two commercial planters, John Deere Flexi-Planter 70 and the Milton Precision Planter will be analyzed. Another very interesting system, but not so common, is the experimental belt type, high speed planter (Futral and Allen, 1951) classified as continuous separation and conveying inclined belt planter. A variation of this system is the inclined

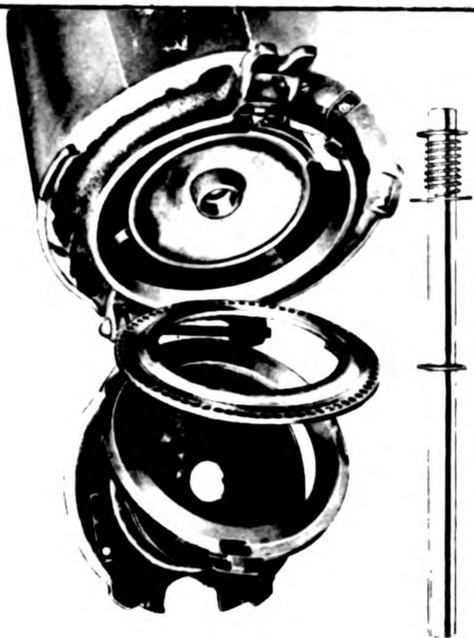


Fig. 1a - Exploded view of the John Deer Flexiplanter showing seed plate (John Deer Co.)

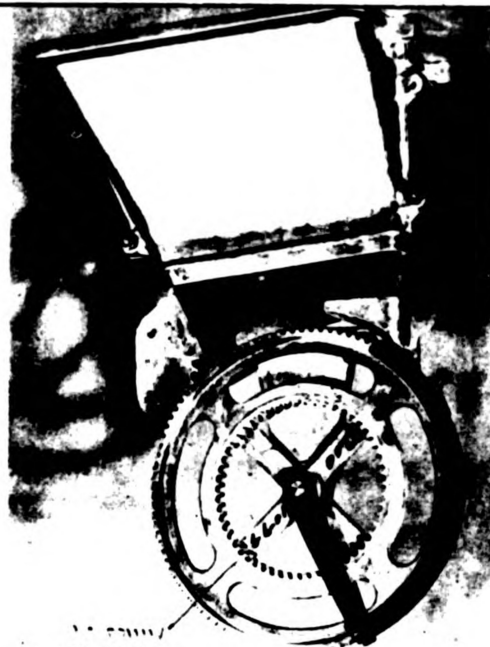


Fig. 1b - Complete hopper assembly with seed wheel in place on the Milton planter (Harbison Paine, Inc.)



Fig. 1c - Inclined plate seed metering unit. (J. I. Case Co)

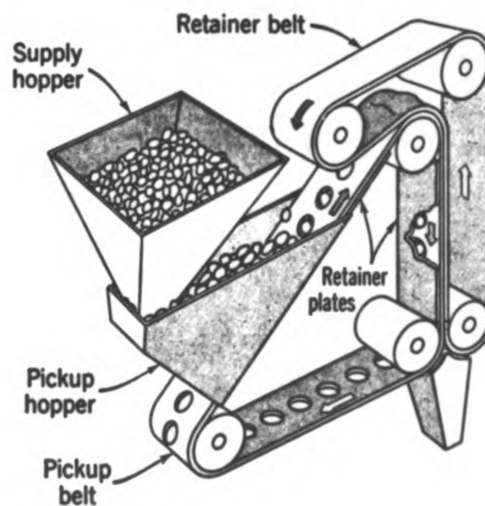


Fig. 1d - Experimental belt type planter developed for high speed drilling (J. G. Futral and R. L. Allen, Agr. Eng. April 1951.)

plate planter (Figs. 1a, 1b, 1c and 1d.)

All these planters, although they have differences in construction, have the same operating principles. Mainly they consist of a seed cell in or on a plate or belt that moves into or by the seed hopper for a certain period of time. Seeds fill the cells and pass through a restricted passage where a cut-off eliminates the excess seeds from the cell, discharging the seed or seeds by gravity or mechanically into a tube that conveys the seed or seeds close to the bottom of the furrow.

These seeds separating systems are dependent on two factors, peripheral velocity of the seed plate and the resultant velocity of the seeds. A vector analysis of the seed movement is shown in Fig.2. The resultant velocity (V_{sr}) is due to velocity caused by the acceleration of gravity (V_{sv}), friction of seed to plate (V_{sh}) and by the impact of the seed on the edge or walls of the cell (V_{sp}). Vector analysis (Fig. 2a) shows that the percent fill of cell will be affected by the vertical velocity and the impact velocity, but mainly by the plate velocity (V_p).

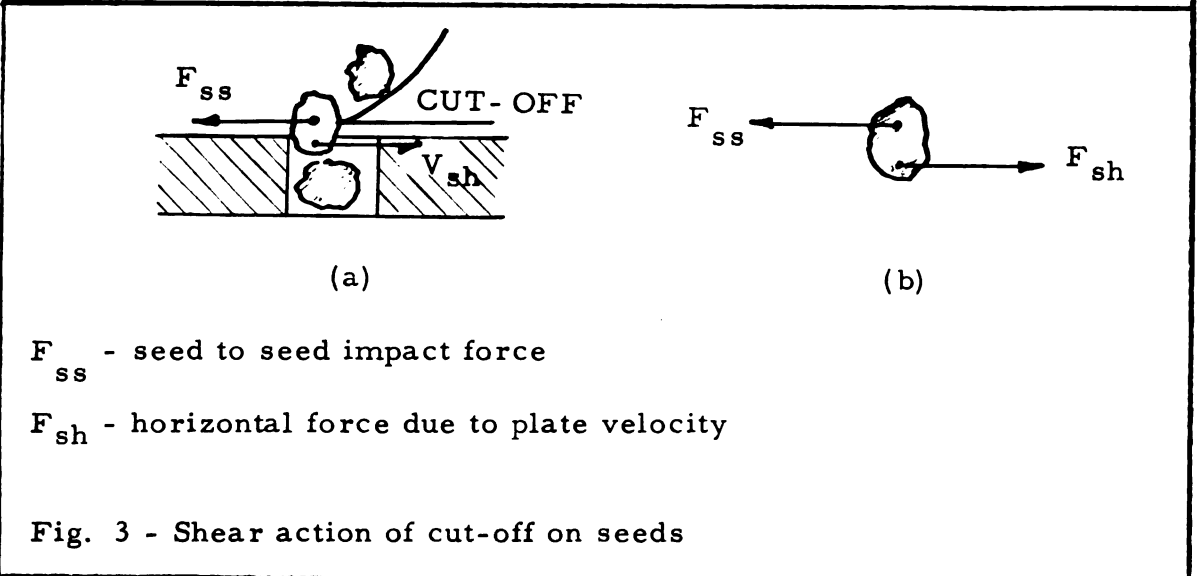
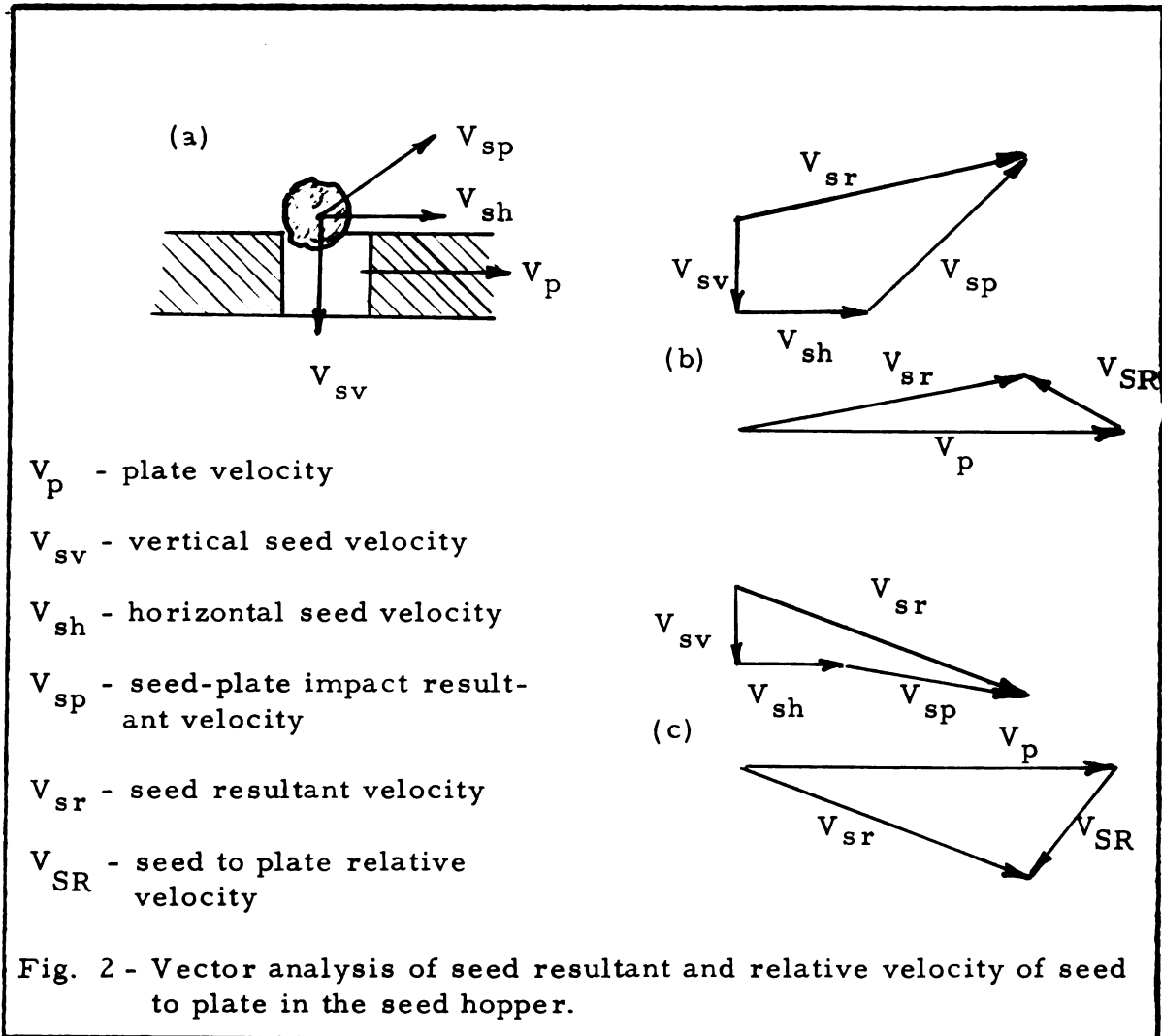
Barmington (1948) showed that the percent fill is proportional to the peripheral velocity of the plate. As the relative velocity (seed to plate) reaches a minimum the percent fill will increase (Fig. 2b). As the horizontal velocity (V_{sh}) of the seed increases the impact velocity will decrease and the resultant velocity will be downward (Fig. 2c). In the case the impact velocity is in a downward direction the resultant velocity

will be downward and the relative velocity will be downward thus increasing the percent fill. In the event that the cell is moving in an inclined plane, the component of the vertical velocity that will force the seed into the cell will decrease, therefore decreasing the percent fill.

Fixed cut-off devices are mainly used in commercial planters. By "fixed" is meant rigid and strong, not flexible. This device is mainly responsible for all of the sheared seeds. Figures No. 3 shows a schematic diagram of a cut-off. The vector analysis shows why the shearing takes place so frequently.

As the velocity of the plate increases, the collision of seeds to seeds increases and a torque is developed in seeds due to the distance between the points where the forces are applied to the seed. This torque will tend to roll the seed backward and thus offering more area to the cut-off to shear it. If no shear occurs, the jamming of two seeds or more might occur in the seed cell and the possibilities are that damage to the seed will be done.

The conveying of the seed from the cell to the bottom of furrow is accomplished mostly by a free fall thru a tube (Fig.4). The word "free" is used because there is no control on the seed after it leaves the cell, either by gravitational or forced ejection. When the seed leaves the cell the velocity of plate throws the seed against the walls of the tube, bouncing it erratically. The place of landing will be deter-



mined by the velocity and direction of the seed when leaving the tube.

The resultant velocity of the seed will be different at all times, therefore the relative velocity of the seed to the ground could not be determined, thus no accuracy can be expected of this system. There is only one condition that will produce the desired result, this is when the relative ground-seed velocity is equal to zero. The inaccuracy of the system is aggravated when a spiral motion is introduced by ribbon tubing. The smoothness and vibration of the tube will greatly affect the uniform fall of the seeds.

Nothing has being said concerning the collision of the seed with the soil. The soil is not uniform in nature, especially when it had been mechanically sheared. The soil texture is formed by clods including some larger in size than the seeds being planted. If the seed hits the surface in such way that it is held between clods there will be no further movement, but if the seed hits a large clod, the direction of the movement of the seed can not be pre-determined. (Fig. 5).

These factors are all working against the planters precision. Buchele, Stout and Morton (1959) studied different ways of controlling the seed scattering by restricting the seed outlet in different ways. In a plain tube perpendicular to the soil surface they got scattering distances up to four and five inches. By reducing the seed free fall they obtained a reduction in the coefficient of variation of 21%.

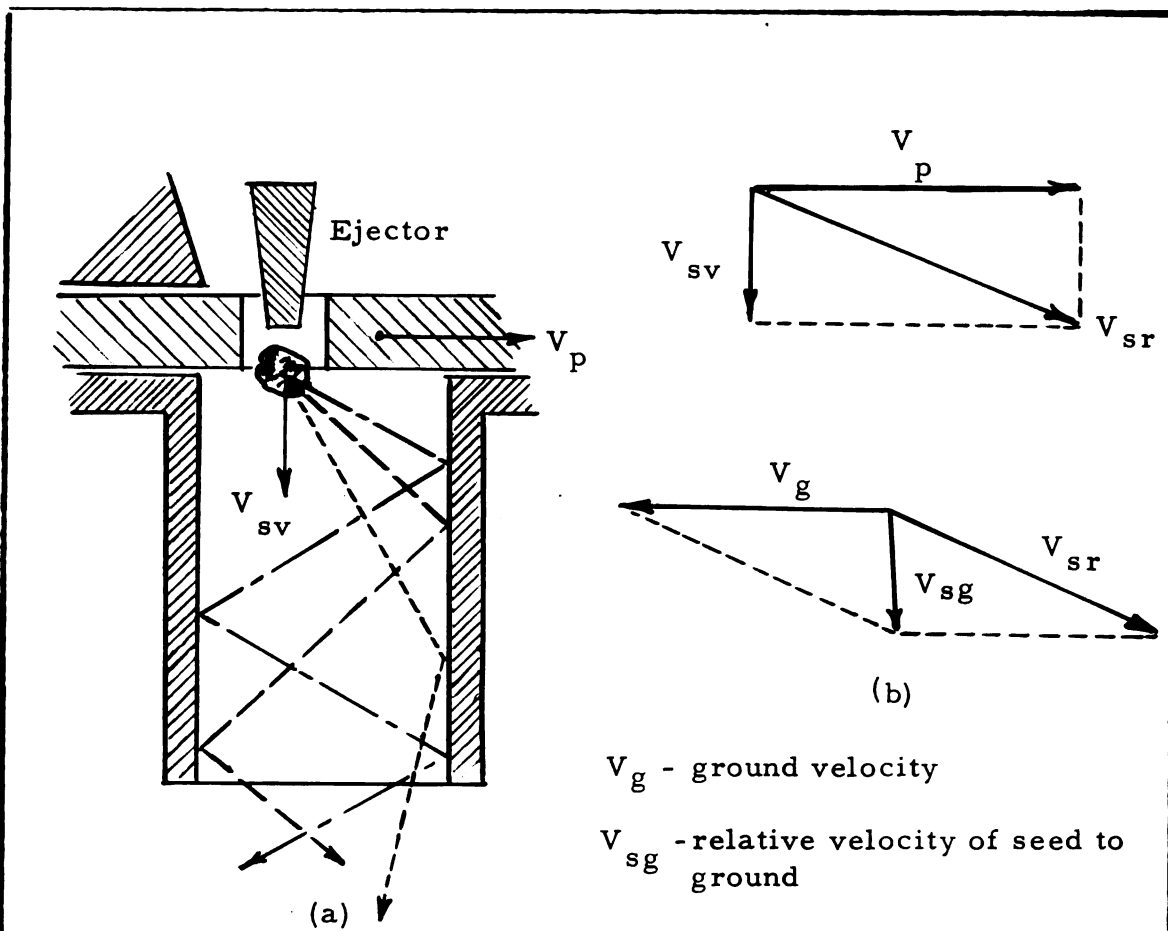


Fig. 4- Free fall in seed conveying tube

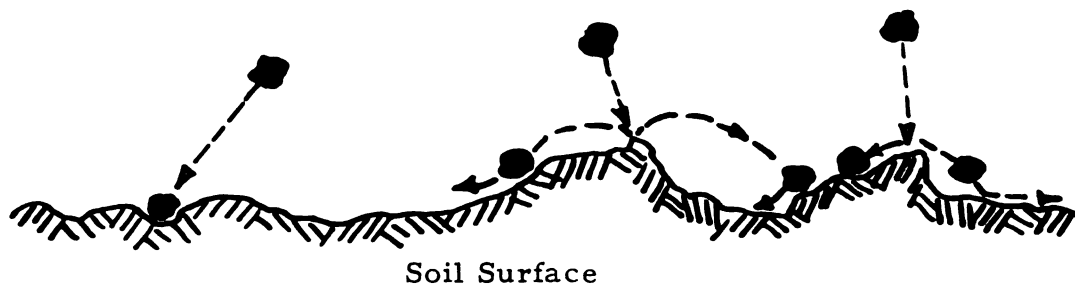


Fig. 5- Seed behaviour when colliding with the soil surface.

These tests showed that as the ejection distance from the soil was reduced the scattering of seed decreased. When the relative velocity (seed to ground) was reduced, the coefficient of variation was decreased.

EXPERIMENTAL STEP PLANTER

Principles and Theory

The design of the Step Planter is based in three basic observations obtained by the analysis of the existing planters. It has already been shown that lower velocities are needed for better seed separation, fixed cut-offs destroys seeds, and seeds should be deposited on the ground at zero relative velocity with respect to ground.

Slow velocities in the separating system are only obtained in the commercial planters by lowering the tractor velocities and or by increasing the seed spacing. But if higher tractor velocities are needed, the only way that lower separating speeds can be obtained is by increasing the space between seeds and plant more than one seed at a time. Planting and spacing ten seeds at a time will cut the separating velocities by ten. A device which will separate more than one seed at a time was designed.

No fixed cut-off is permitted. The seed must be handled in the gentlest possible way. The shape of the seeds used, sugar beets, is approximately spherical. Even though it is not a sphere, when a tangential

force is exerted on its periphery it will act as a sphere and will roll. The higher the speed the smoother it will roll. To create this rolling action a brush could be used, in the form of a roller rotating at higher peripheral speed than the cells and in opposite direction. The rolling action will not damage the seed.

Barmington (1958) wrote, "Every thing went wrong as soon as the seed leave the cell". This statement points out the possibility of keeping the seed in the cell and moving the cell to the soil surface and depositing the seed from the cell directly to the soil. It might seem that this is a complicate problem, but using a four link mechanism the cell can be moved at the desired instant and at the desired velocity with respect to the ground. Using this method the seed can be maintained under control throughout the complete cycle, and whats more important, the seed can be deposited instead of dropped in a free fall, thus preventing scattering.

Model Construction

Plastic Model

To verify the principle and theory of the experimental step planter a plastic model (one third scale) was built. The complete model was made of "pexiglass". This permitted observation of actual operation of all systems.

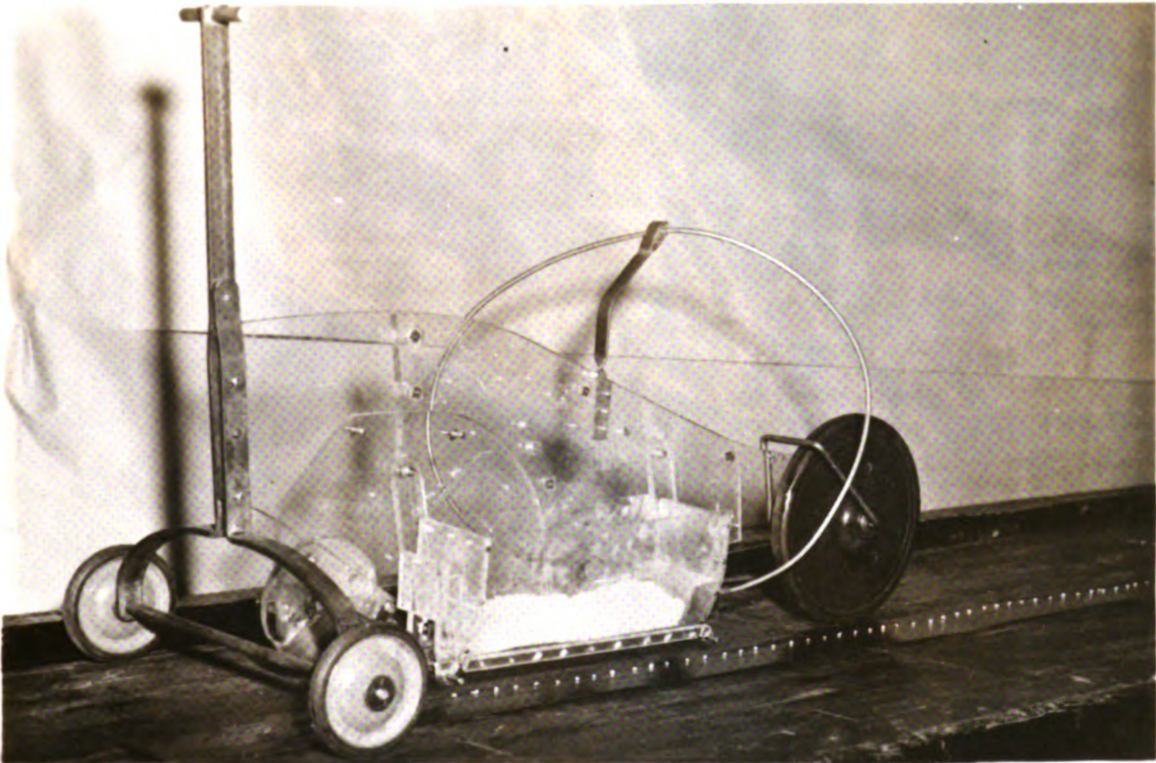


Fig. 6 - Front and side view of the plastic model on the moving belt. Seeds were placed over a greased sheet metal strip.

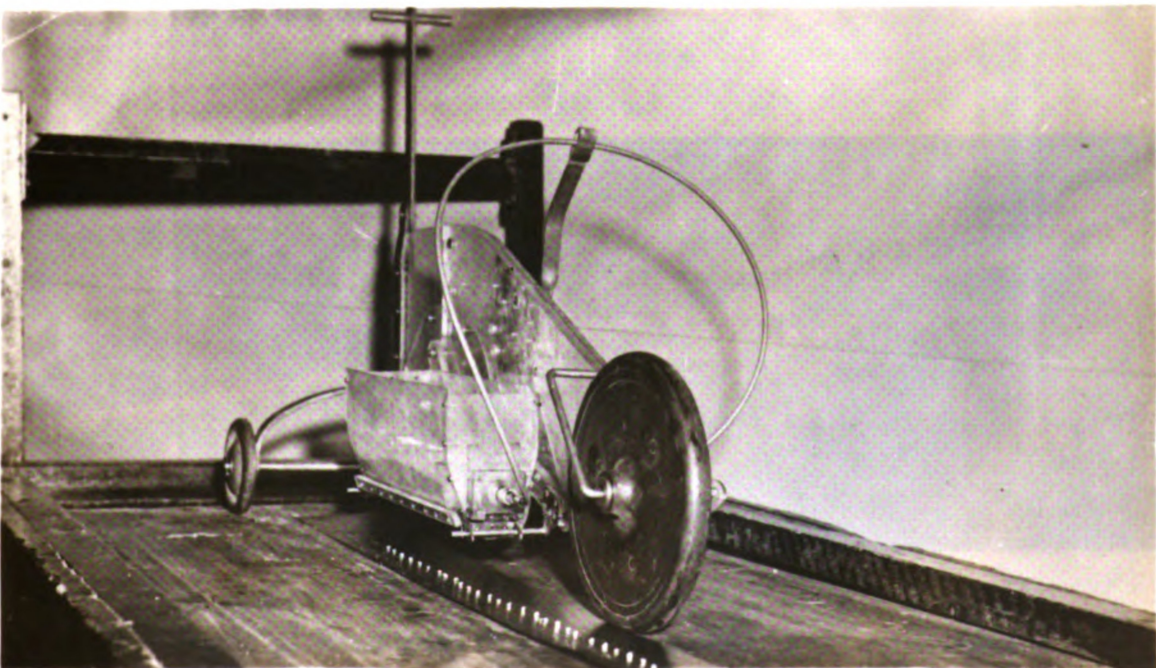


Fig. 7 - Back view of the plastic model in top of the moving belt. Seeds were placed over a greased sheet metal strip.

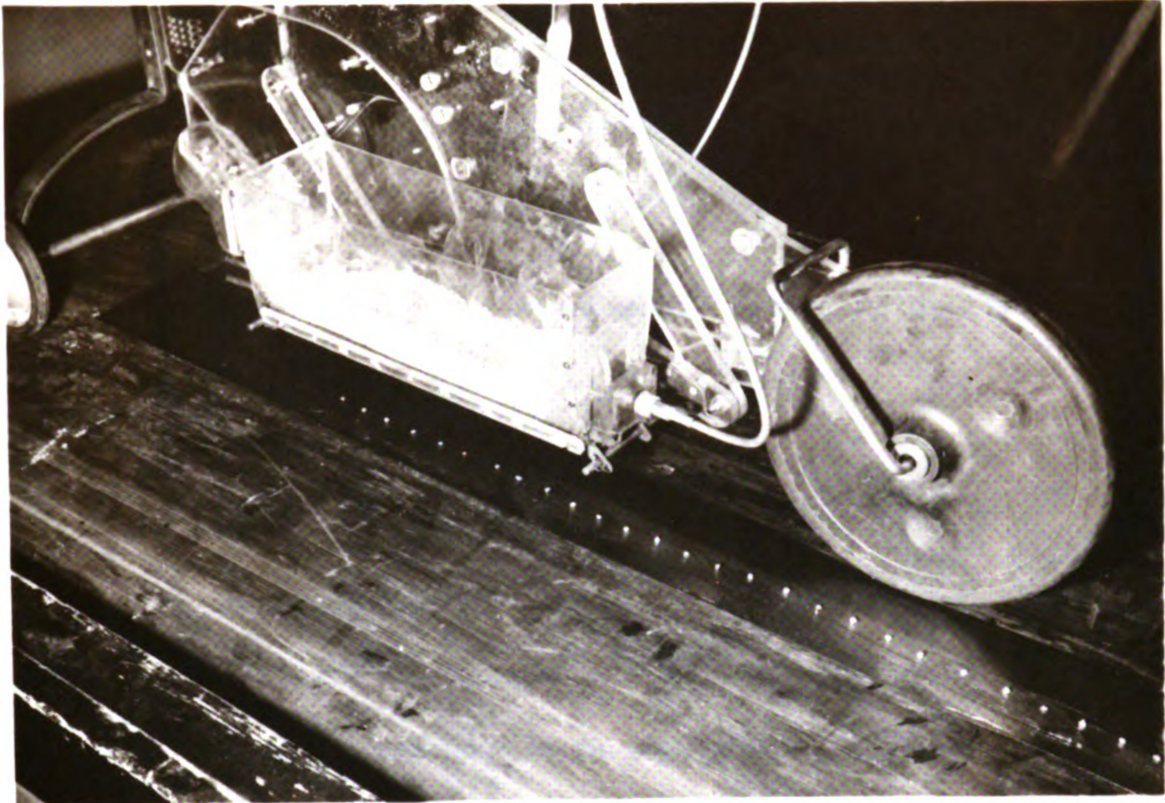


Fig. 8 - Angled top view of the plastic model after depositing seed on top of the moving belt.



Fig. 9 - Seeds planted with the plastic model. Scale provides a comparison means to show its accuracy.

Even when the model proved the principles and theory it could not stand prolonged testing under severe conditions. The spacing and seed separation was excellent. Photographic records were made of the plastic model and its seed distribution and spacing (Fig. 6, 7, 8, 9).

Because of the limitations of the plastic model, further testing required a full scale metal model.

Full Scale Metal Model

A complete set of drawings were required to build a full scale steel and aluminum model. It was necessary to redesign some parts and change gear ratios. The model was built in the Agricultural Engineering Research Laboratory at Michigan State University. (All the following discussion refers to the full scale metal model).

Description and analysis of mechanisms of the Steel Model

Two main sections compose the metering device:

- a) the body or frame (Fig. 10)
- b) the seed separator and spacer (Fig. 11)

To the frame are attached the metering wheel (A), two four bar linkage mechanisms (M), and three sealed boxes (F, D, E), linked by a shaft (C) which contains the necessary gear sets to supply the proper velocity ratios at every point of the planter.

The seed separator and spacer is held by the two four bar linkage

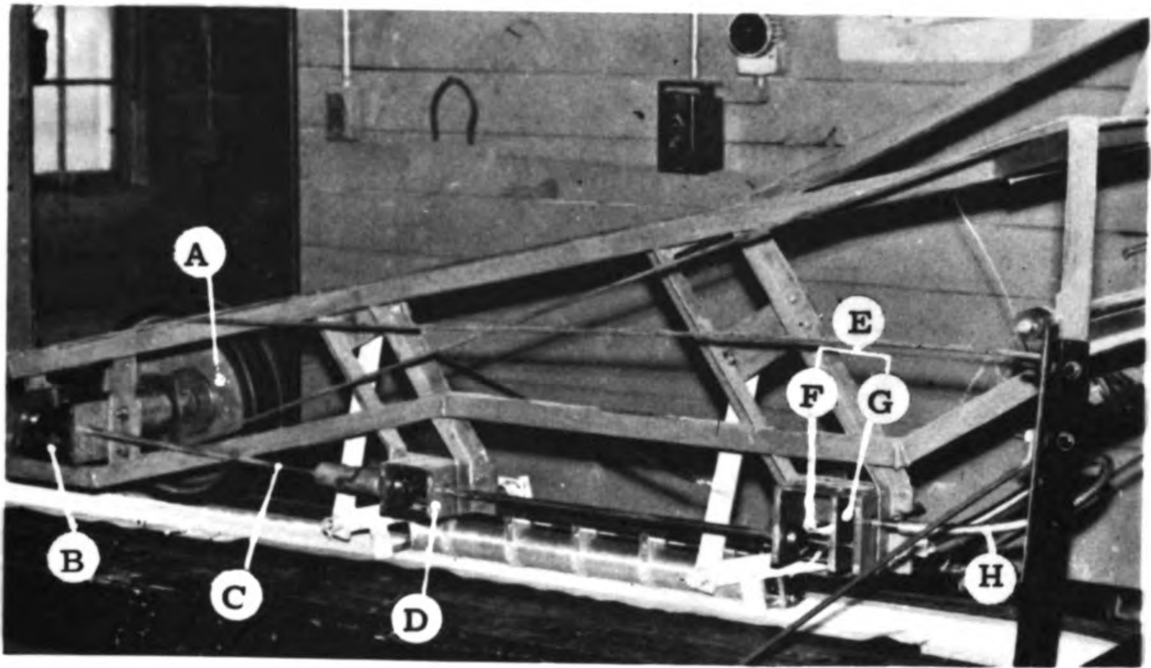


Fig. 10 - Side view of step planter mounted on moving belt table.

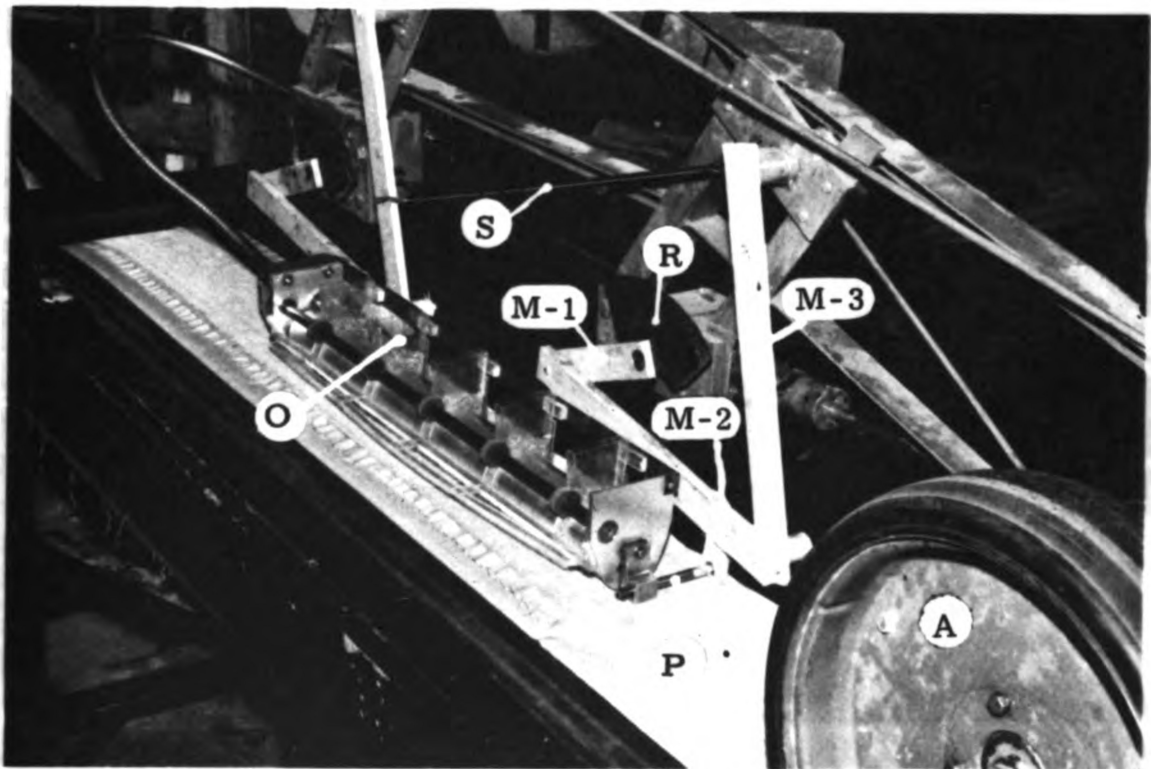


Fig. 11 - Close-up of linkage mechanism and separator and spacer.

mechanism (M), and is powered by a flexible shaft (H) from the front gear box (G). This separator consist of two concentric cylinders (the inner being stationary) (K-2), and rubber brushes (L) of a cylindrical shape mounted on a steel shaft. The outside cylinder (K-1) or tube has twelve lines of five holes each, in its periphery, that serve as seed cells (N). Individual seed hoppers (O) are mounted on top of the outer cylinder exposing the seeds to the cells before reaching the dropping point. Two sets of gears supply the necessary angular velocity to both brush and seed cylinder. The inside cylinder provides a rolling surface to the seed cylinder.

The seed separation process is accomplished by the outer rotating cylinder (Fig. 12). The cylinder rotates at a low angular velocity. Seeds are in direct contact with this cylinder. The cells are shaped in the periphery of it in lines of five cells each at 30° intervals.

The cylinder has a velocity ratio of 6 to 1 with respect to the metering wheel. For every revolution of the metering wheel the cylinder will rotate 60°, 1/6 of a revolution. This greatly reduces separating velocity. The velocity reduction was accomplished by separating and metering five seeds at the same time. The cells are spaced 5" apart along the cylinder. This spacing is the exact distance at which planting is intended. Cell size and shape will be discussed later.

The cut-off or brushing action is accomplished by the use of five

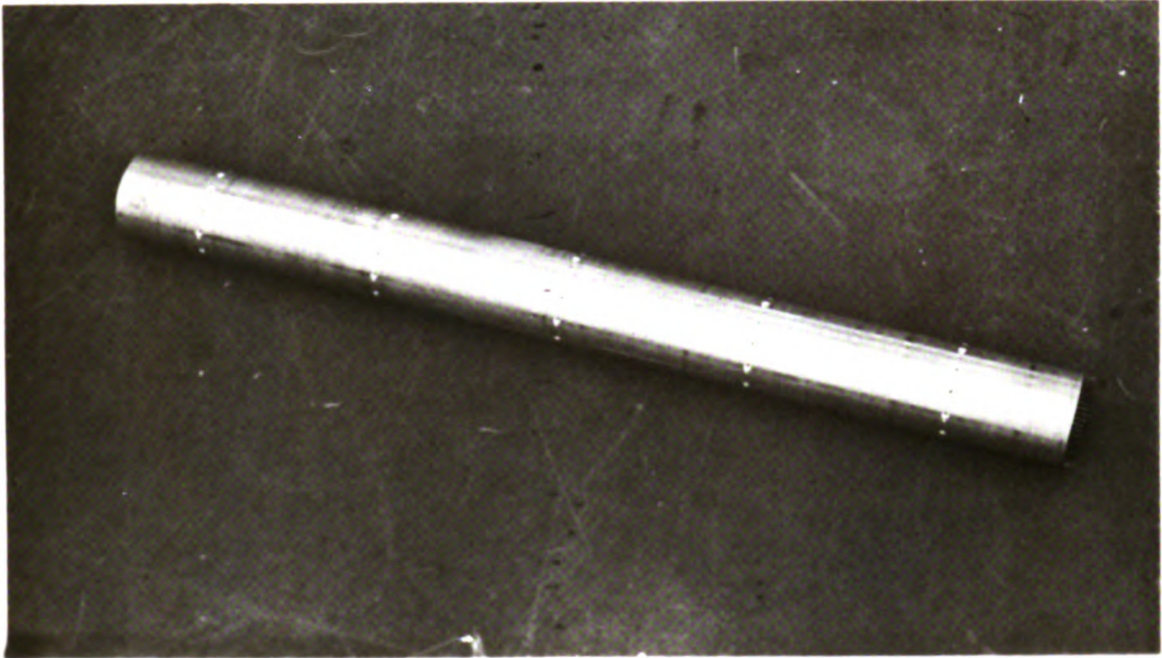
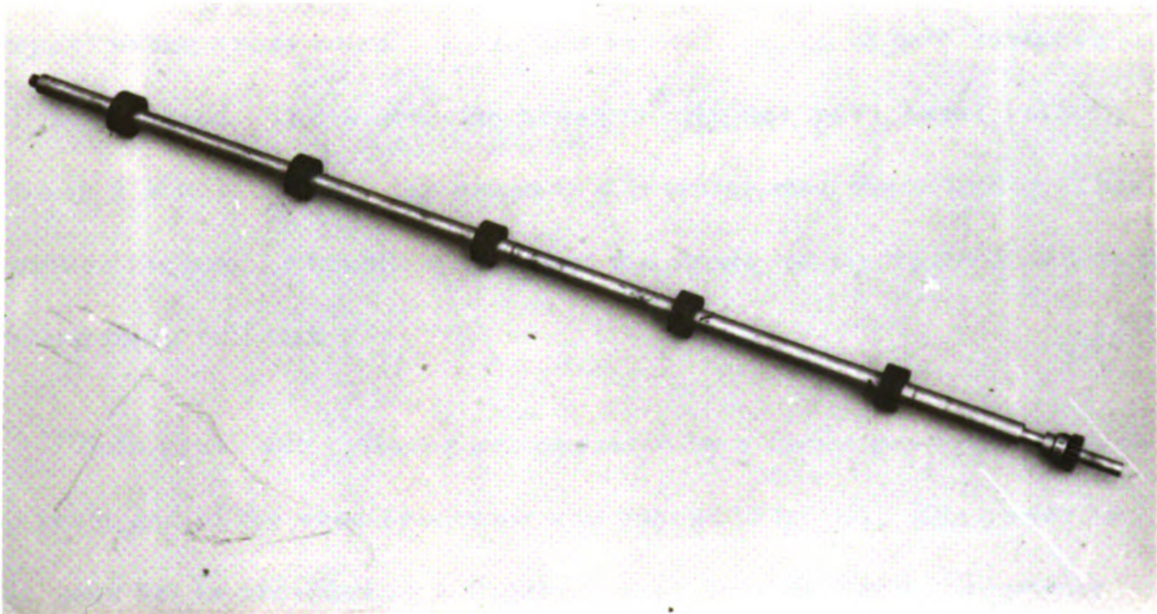


Fig. 12 - Outer rotating cylinder showing seed cells and end gear.



**Fig. 13 - Cylindrical rubber brushes mounted on the steel shaft.
Shaft also shows end gear.**

cylindrical shaped rubber sections mounted on a steel shaft (Fig. 13).

This brush is mounted with its axis parallel to the rotating cylinder and practically in contact with it. Figure 14 shows the mounting position.

The velocity ratio of press wheel to brush is 1 to 2. That is, for every revolution of the press wheel the brush will make two revolutions. The peripheral velocity (V_b) of the 1" diameter brush is πn inches per minute.

$$\text{Where, } V_b = \pi Dn \text{ (inches per minute)}$$

$$n = \text{revolution per minute (rpm)}$$

$$D = \text{diameter (inches)}$$

The 2.5" (outside diameter) rotating cylinder peripheral velocity is $2.5\pi n$. Substituting the velocity ratio of brush and seed cylinder with respect to the press wheel for n , the velocity ratios of both surfaces will be obtained. Therefore, the brush to cylinder peripheral velocity ratio is 4.8 to 1, that is, the brush is 4.8 faster than the cylinder. This provides the proper brushing action of the seeds on top of the filled cells, making them roll fast.

Both brush and cylinder are operated by a set of gears mounted on the front end of the seed separator and spacer (Fig. 15). The power to this gear set is provided by a flexible shaft that transmits the power from the front gear box of the frame.

The moving of the separator and spacer mechanism from and to

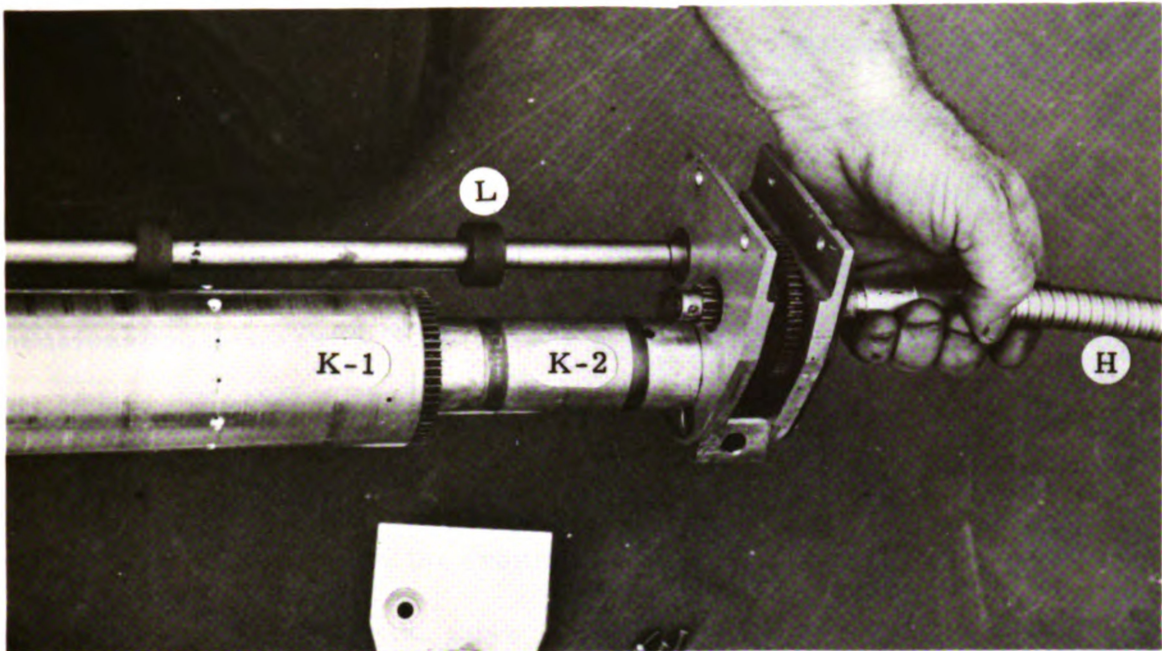


Fig. 14 - Exposed view of separator and spacer.

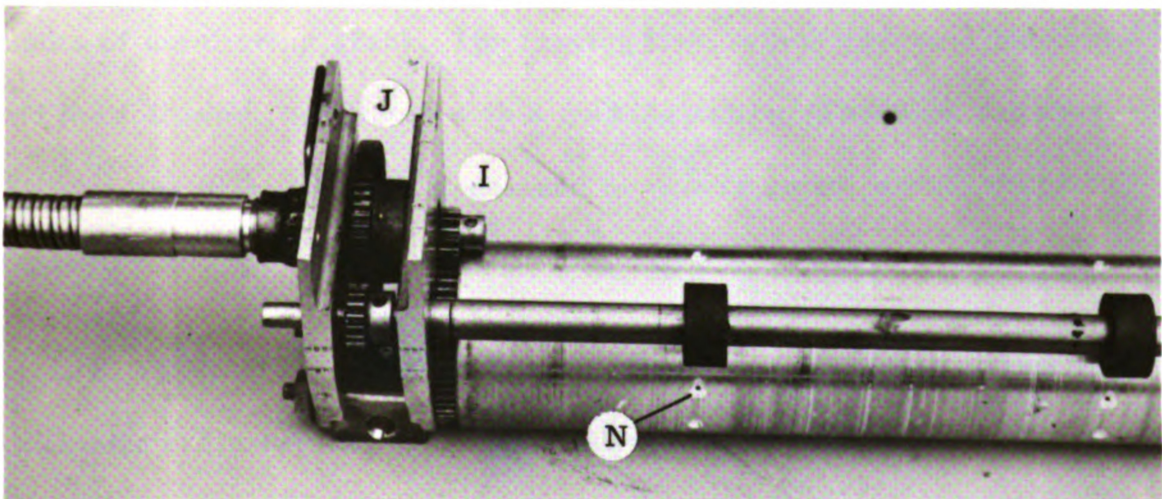


Fig. 15 - Separator and spacer showing cylinders, gear sets and rubber brushes in position.

the ground level is accomplished by two identical four-bar linkage mechanism. (M). Both are driven simultaneously at the same velocity ratio maintaining the separator and spacer always parallel to the ground surface. The two four bar linkage consist of a tracing link (M-2), a follower (M-3), a stationary arm (M-4), and a driving crank (M-1). Their dimensional ratios are 3.5, 3.5, and 3 respectively, compared to the driving crank (unit), see Fig. 16. The stationary arm is the distance between the two pivoting points of the crank and the follower links (line of centers) and is part of the frame or body. The crank, the unit length member, is actuated by two power gear boxes with a velocity ratio of 2 to 1 (crank to metering wheel). This is the only link that rotates 360°. A complete planting cycle is obtained by every revolution of the crank. The follower oscillates 41°. As the name indicates, this link follows the inputs of the driving crank. The tracing link, which connects the crank and the follower, oscillates with a rocking action. This link contains the tracing point to which a desired motion is given, and to which the separator and spacer is attached (Fig. 11).

R. T. Hinkle (1958) stated that " the motion of a point or link in a kinematic chain relative to some other point or link in the same chain is a property of the chain and not of the mechanism". This statement shows that the movement obtained by this link at the tracing point is a property of the whole chain (above ratios) and not of any other four linkage mechanism.

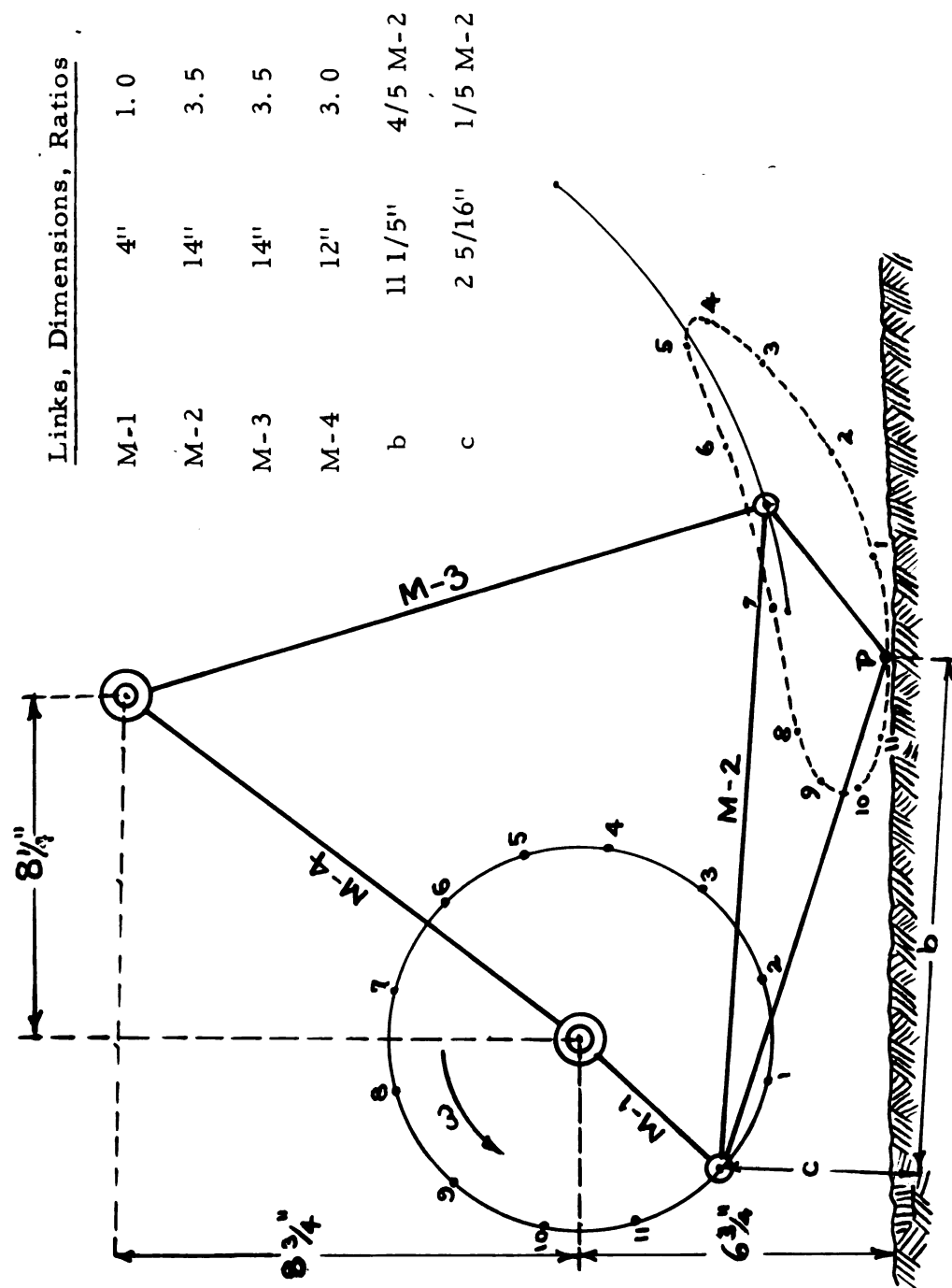


Fig. 16- Four Bar Linkage showing the path of the tracing point (P) at intervals of 30° of the crank (M-1).

Hrones and Nelson (1951) classified this four bar linkage as a class A (crank and rocker link) and described it as follows:

"Determinate linkage motion results when the number of independent input angular motions is two less than the number of links. All links are assumed to be rigid members and are pin-connected to one another. Freedom of relative angular motion exist between any two members at the pin joint. The minimum number of links which will permit relative motion between links is four. In the majority of applications one of the links (the line of the centers) is stationary (stationary arm) while a second link (the driving crank) is driven from an outside motion source. The motion of the remaining two links (the follower and the tracing links) is a function of the geometry of the linkage and the motion of the driving crank and line of centers."

A study of the path of the tracing point shows that the linkage (M-2) when at point P (Fig. 16), reaches a velocity equal and opposite in direction to the tractor velocity. At this point both desired conditions, zero relative velocity with respect to ground and zero dropping distance, are achieved by the linkage system. The planting is accomplished by depositing the seeds, five at the same time, separated and spaced at the desired distance, at this instant.

The velocity of the tracing point at any time is computed by means of a graphical and analytical method. Considering the trajectory in Fig. 18, the point moving along the trajectory covers a distance ab measured along the path in an interval required for the drive crank to move through 5° . If the drive crank is rotating at a uniform angular velocity, the average velocity of the point during this travel is the length $\overline{ab}$ divided by

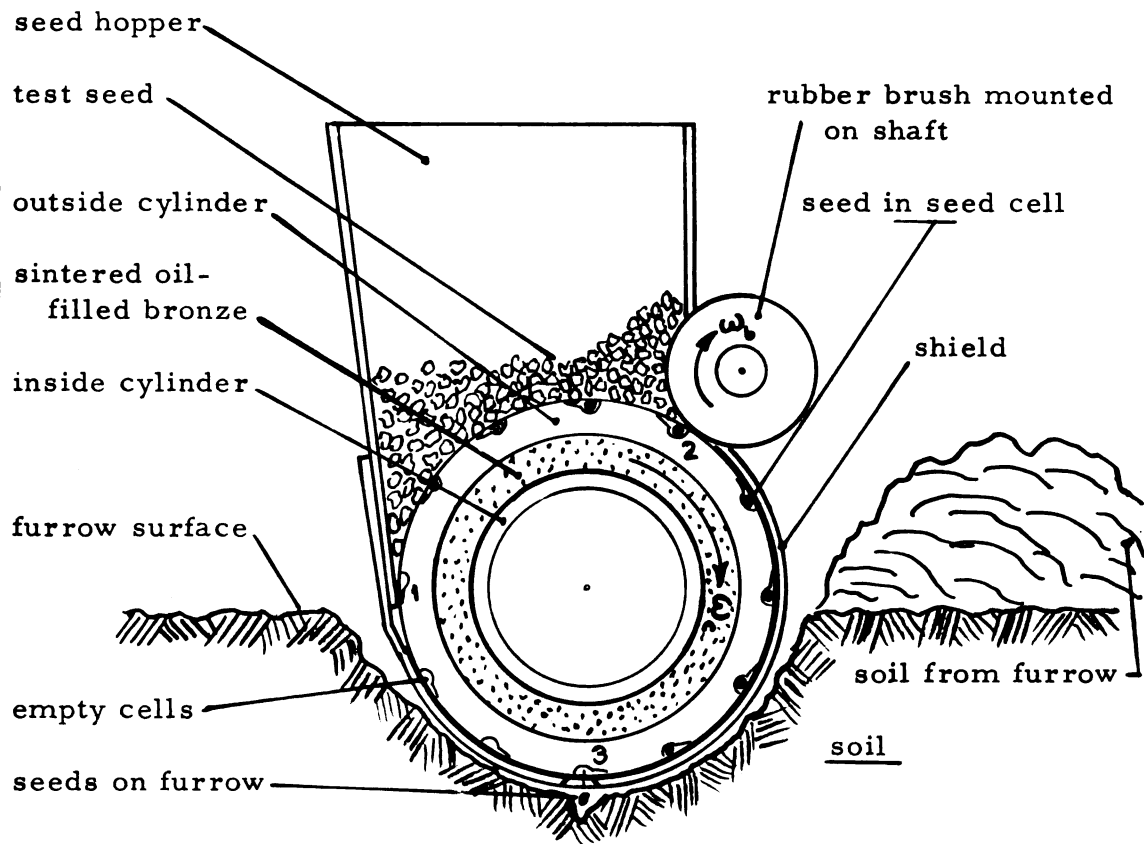


Fig.17 - Separator and spacer at furrow surface level (dropping point)

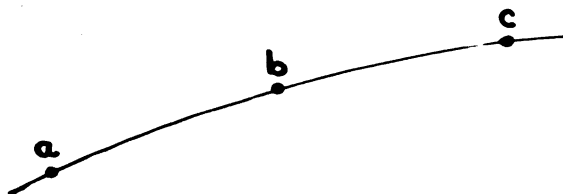


Fig.18- Point moving along trajectory.

by the time the drive crank is require to move 5°.

$$V_{ab} = \frac{(\overline{ab}) \omega}{5}$$

Where, V_{ab} = average velocity of the point moving from point

b (inches per second)

$\overline{ab}$ = length between a and b measured along the trajectory (inches)

ω = angular velocity of drive crank (degrees per sec.)

The acceleration of point moving in the space is defined by,

$$V = \lim \left(\frac{\Delta s}{\Delta t} \right)_{t \rightarrow 0} = \frac{ds}{dt}$$

$$acc. = \frac{dV}{dt} = \lim \left(\frac{\Delta V}{\Delta t} \right)_{t \rightarrow 0}$$

$$\left(\frac{\Delta V}{\Delta t} \right)_p = \frac{V_{bc} - V_{ab}}{t} \left[\frac{(\overline{bc}) \omega - (\overline{ab}) \omega}{5} \right] \frac{\omega}{5} = \frac{(\overline{bc} - \overline{ab}) \omega^2}{25}$$

To compute the velocity of the tracing point at the depositing instant (point P in Fig. 16) a direct measurement of the point path is taken following the trajectory for an angle of rotation not less than 5° of drive crank. Using the above velocity relation, and substituting for the peripheral speed of the metering wheel and the tracing point velocity, the following relation is obtained;

$$V_{tp} = \frac{(\overline{ab}) \omega_{CRANK}}{5} = \frac{(\overline{ab}) 2}{5}$$

$$V_{mw} = \frac{(X) \omega_{WHEEL}}{5} = \frac{(X) 1}{2.5}$$

if, $V_{tp} = V_{mw}$

then, $\overline{ab} = X$

Where, X = distance covered by the metering wheel during the same time interval that the crank rotated 5° .

$\overline{ab}$ = distance measured along the trajectory of the tracing point traversed during the time interval that the crank rotated 5° .

V_{tp} = velocity of tracing point

V_{mw} = peripheral velocity of metering wheel

This points out that when the distances measured are equal, the velocities of the periphery of the metering wheel and the tracing point in this period of time are equal and opposite in direction. The metering wheel circumference is 50 inches. The angle rotated in the time interval was 2.5° , therefore the distance travel by the wheel was 0.347 inches. The distance measured along the path was 0.35 inches. If there is no slip of the metering wheel on the rolling surface, the velocity of the surface will be equal and in the same direction as the velocity of the tracing point path during that time interval. Therefore the relative velocity

of seed to ground is zero. A complete study of the tracing point path showed that the velocity was maintained almost constant for a drive crank angle of about 18° in the region on both sides of the ejection point. This eliminates the necessity of absolute timing of the dropping point. Even when the seed are not deposited at the same instant they will be metered accurately because the linkage system will keep the separator and spacer stationary over the surface during a relatively long time interval. In other words the acceleration is reduced practically to zero at this time interval. A kinematic analysis of velocity and acceleration is included in the appendix.

Operation of the Metal Model

When studying a complete mechanism the interaction between the parts must be considered. The two principal mechanisms of the step planter are:

1. the seed separator and spacer
2. two sets of four-linkage

With these mechanisms working together in the proper sequence, the desired effects and results are produced.

Power Train

The operation of the step planter begins with the press and metering wheel (A) (Fig.11). This wheel has a circumference of 50 inches. Wheel (A)

transmits power through gear box (B) to gear boxes (D) and (E) through shaft (C). The velocity ratio of the bevel gears in box (B) is 2:1 (C:A). In box (D) and gear set (F) of box (E), miter gears provide a 1:1 ratio at 90° to shaft (C). These gears power the link mechanism. The spur gear set (G) in box (E), powers a flexible cable (H) leading to the separator and spacer mechanism in a 1:3 ratio (H:C). This flexible shaft (H) powers two spur gear sets in the forward part of the separator and spacer mechanism. Gear set (I) (Fig. 15) operates the seed cylinder (K-1) at a velocity ratio of 1:4 (H:K-1); gear set (J) operates the brush cut-off (L) (Fig. 14) at a velocity ratio of 3:1 (L:H).

Link Action

The separator and spacer is moved through the prescribed path of the tracing point (P), following the rocking motion of link (M-2) as actuated by link (M-1). The link action is synchronized with the separator and spacer action so that when the tracing point (P) reaches the dropping point the separator and spacer drops the seeds simultaneously (Fig. 16).

Separator and Spacer Action

Fig. 17 shows a cross section of the separator and spacer at the ejection point. At this point the seed separator and spacer is at ground level. The relative velocity of the separator and spacer to ground is

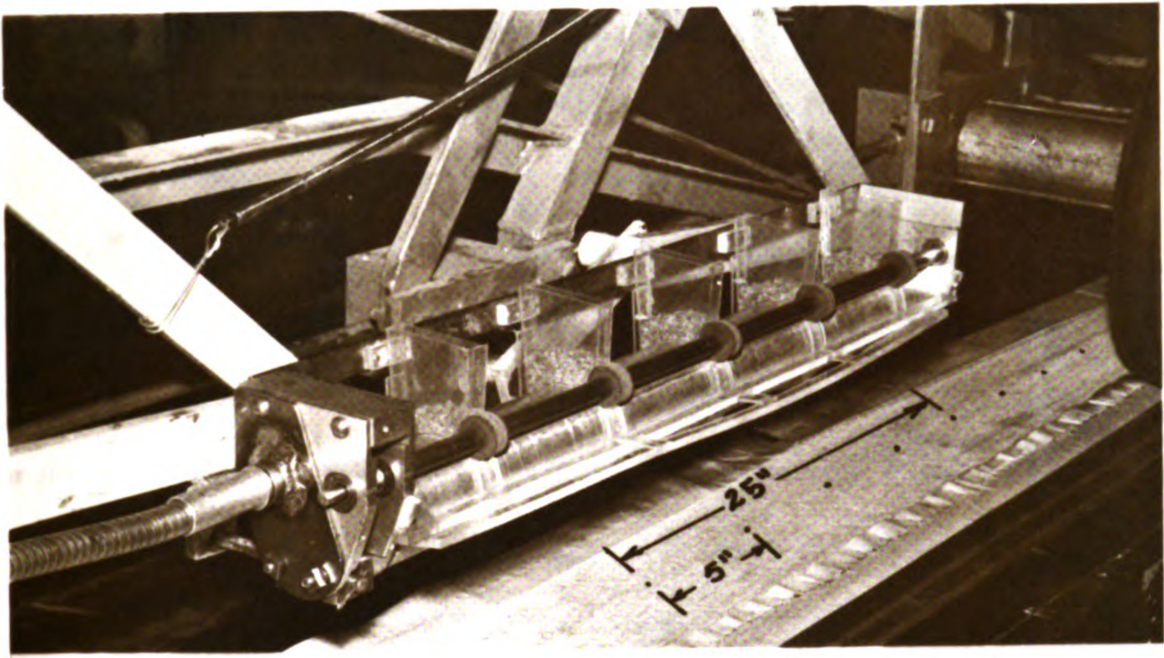


Fig. 19 - Complete separator and spacer showing spaced seeds in position.

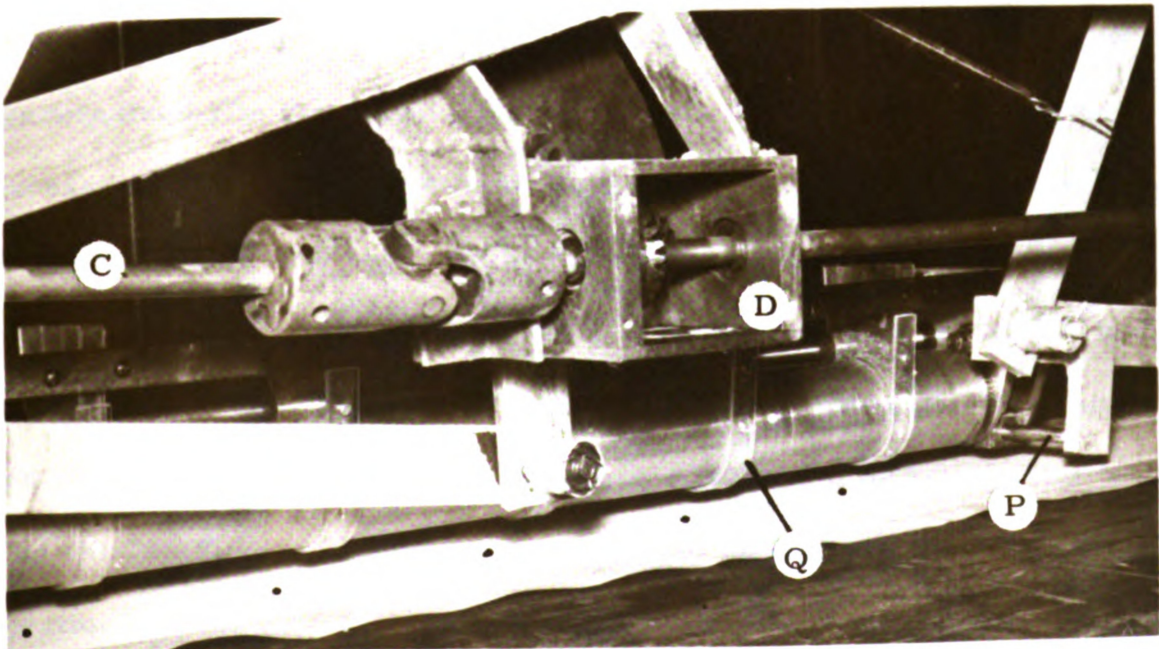


Fig. 20 - Back view of separator and spacer showing shields and spaced seed.

is zero. The seed cylinder (K-1) is rotating at angular velocity ratio of 1:6 (K:A) with respect to the wheel (A), while the brush rotates at an angular velocity ratio of 2:1 (L:A) with respect to the wheel (A). The peripheral velocity ratio of brush (L) to seed cylinder (K-1) is 1:4.8 (L:K-1). This means that for every half revolution of wheel (A) the seed cylinder rotates $1/12$ of a revolution (30°) and the brush makes two revolutions. There are always four lines of seeds cells (N) exposed to the seed in hoppers (O), from point 1 to 2, (Fig.17). The angle of exposure is 120° . The seeds begin filling the cells as soon as the cells are exposed to them (as they pass point 1). The cylinder angular velocity is constant. Therefore, the separating velocity is low and constant with respect to the tractor velocity.

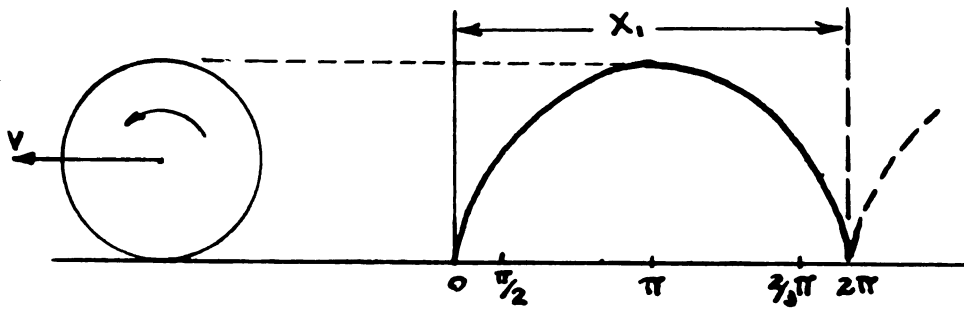
The seed cylinder continues rotation and when the cells in a row (perpendicular to the drawing plane) reaches the rubber brush (L) the excess seed is rolled out (swept) by the higher peripheral velocity of the brush (point 2). The seeds in the cells are now separated from the rest and spaced at an exact spacing of 5 inches between seeds. Beyond the brush, the seed cylinder is shielded by a shield made of plastic shaped and fitted to cover the path of all the seeds from point (2) to point (3). The shield (S) keeps the seeds from leaving the cells before reaching the ejection point (planting point). When the cell reaches the ejection point (point 3), all cells are exposed at the same time. The seeds drop by the gravitational force and by a centrifugal force due to the angular veloc-

ity of the cylinder (very small). A vector analysis of the velocities and forces acting at this instant on the seeds will be presented later. The exposure of the cells is caused by a discontinuity in the shield (Q) at point (3). This opening continues for 5° of the cylinder rotation. In the case a seed is not dropped instantly, the dropping could occur during the next 15° of the crank (M-1) where still the relative velocity of seed cylinder to ground is approximately zero. This 15° are equivalent to 1.5° of cylinder rotation. All seeds dropped will have a free fall from zero to about $1/4$ inch. They are all released from the cells metered accurately to 5 inches. With a small distance of free fall (can be adjusted) and with no movement with respect to ground the seed will remain at rest in the place where they were released.

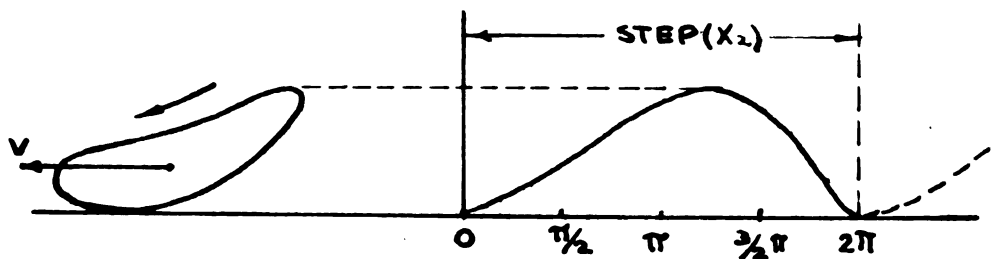
Step Action

The step action, from which the planter was named, is the effect and result of two simultaneous motions. The study of the path traced by a point on the circumference of a circle rolling at a constant velocity, without slippage, is shown in Fig. 21 (a). This motion is called cycloidal motion. This point is in contact with the surface every 360° . The distance between contact points (X_1) is constant. Comparing the behavior of this point with a walking action of a man, it could be called a step.

The four bar linkage mechanism used in the machine produces

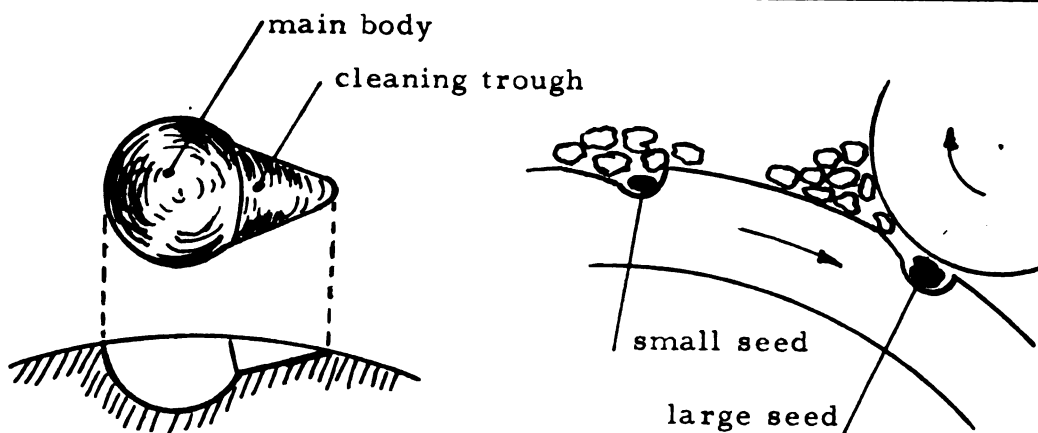


(a) Cycloidal motion traced by a point on a circle



(b) Periodic motion traced by the four bar linkage tracing point

Fig. 21 - Comparison of cycloidal motion with the step periodic motion.



(a) Cross section of seed cell (b) Seed in seed cells

Fig. 22 - Seed cell of the step planter

a similar effect when combined with the linear velocity (V) of the tractor. Fig. 21 (b) shows how it behaves when traced in a vertical plane by the combined action of linkage and the forward tractor movement. The distance (X_2) between points (depositing points) is held constant, regardless of any change in the tractor velocity. The distance (X_2) is proportional to the metering wheel (A) circumference. The distance (X_2) for the step planter is 25 inches. The number of seeds separated and metered are also proportional to the wheel revolutions. Five seeds spaced 5 inches apart (25 inches) is half of the circumference of the wheel (A).

Summarizing, for every half revolution of the wheel (A) (50.3 in. of circumference) the tracing point describes a periodic cycle.

Seed Cells , Shape and Size

To determine the shape and size of the seed cells, tests were conducted by shaping cells in a plastic model in six different cavity shapes with six different diameters. The cells were made small and enlarged slowly until the most efficient size and shape was found.

The seed cells are shown in Fig. 22 . The characteristics of the cells are as follows:

1. Prevents the planting of double seeds.
2. Anticlogging
3. Excellent brush action

The cell is composed of two sections: Fig. 22 (b)

1. main body
2. cleaning trough

The main body is semispherical in shape and the diameter is proportional to the seed diameter. The diameter of the main body was made to accept commercial processed sugar beet seeds. The most common sizes are from $6/64$ to $10/64$ of an inch in diameter. A cell of $12/64$ inches was used without fear of seeds (of the above range) clogging in the cell. The depth of the main body of the cell is $7/64$ of an inch.

The cleaning trough is a projection of the main body. Its tapered shape facilitates the removal of excess seeds from the one separated in the main body of the cell. In Fig. 22 (a), a seed is shown in the cell with other seed laying on top of the separated seed. Note that the seed in the left main body of the cell completely fills the cell while the others are on the seed tube or in the cleaning trough. When the cell passes under the brush, the excess seeds were rolled (swept) out of the tapered surface of the trough. By this means the seeds were not damage by any sharp edges. In the left main body, the seed is smaller and do not fill the cells completely. Even in this case, the seeds on top have enough surface exposed to the brush to be swept out without disturbing the seed in the main body.

Side Effects of Operation

Four major side effects were expected from the operation of the mechanism.

1. shaking action
2. unbalance operation
3. lateral velocity component of seed
4. slippage of press wheel

Shaking action

The shaking action is due to the inertia of the seeds. The crank and rocker action of the linkage system accelerates and decelerates the seeds somewhat violently and proportional to the tractor velocity. To eliminate this side effects small hopper were designed. The seed are restricted in the hopper to 1/2 inch of free space. The friction of seed to seed eliminates the shaking action almost completely.

Unbalancing of the mechanism

Any rotating member is subject to a centrifugal force, (F)

$$F = mw^2r$$

Where, m = mass

w = angular velocity

r = radius

When the member is symmetrical and homogeneous it is said to

be balanced. This means that all forces have an equal and opposite force acting at the center of rotation which will cancel their effects. In the case where all forces are not cancelled, the condition is said to be unbalanced.

The driving crank (M-1) is a rotating member, and besides its own unbalanced weight, a load is applied at a distance of 4 inches from its center of rotation. This load is due to the weight of the separator and spacer assembly and the seeds. The faster the angular velocity of the crank, the greater the unbalanced forces acting in the member. It should be noted that the seed weight is variable and an average weight has to be assumed for any calculations and when balancing is done.

The balancing of the step planter was done by slowly increasing a restricted pivoting vibration absorbers counter weight (R) until a reasonable smooth operation was obtained. Lead weights were used as vibration absorbers. Besides a spring (S) opposing the movement of the linkage system at the forward stroke of the separator and spacer was used to obtain a better balancing at the unbalancing peak of the cycle (Fig. 11).

Lateral velocity component of seed

When seeds are dropped from the cells at the dropping point, a lateral (sidewise) velocity component exists which tends to cause them to be unstable. This velocity component is at right angle to the path of

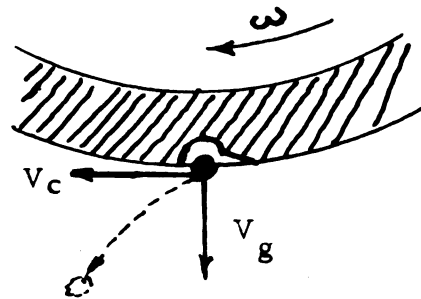
the machine.

The seed cylinder (Fig.17) is rotating in a clockwise direction at a constant angular velocity. The seeds are carried in semispherically shaped cells (Fig.22). Any mass moving in a circular path has a linear velocity component equal to the product of the angular velocity (ω) and the instantaneous radius of rotation (r).

$$V = \omega r$$

Therefore, even at low velocities of the seed cylinder, the seeds in the cells will have a linear velocity equal to the angular velocity of the cylinder multiplied by the instantaneous radius (distance from center of rotation of the cylinder to the center of gravity of the seed). This velocity component is very small, and at low angular velocities can be negligible.

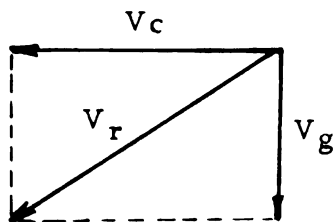
A graphical representation of the velocity components acting on the seed at this instant is given in Fig. 23. The seed, when ejected, is subject to the linear velocity (V_c) and the acceleration due to gravity. The velocity due to gravitational acceleration varies according to the seed mass. At the instant when the seed is released, the velocity due to gravity is zero, assuming negligible centrifugal force acting on the seed. Immediately, the gravitational force acts on the seed, accelerating its mass. The velocity of a free falling object in a vacuum at any instant is



V_c = Linear velocity of the seed due to the cylinder angular velocity (ω).

V_g = Velocity due to the acceleration of gravity

Fig. 23 - Seed trajectory when dropped



(a) Vector summation

$$V_r = \sqrt{V_c^2 + V_g^2}$$

(b) Annalitical summation

Fig. 24 - Resultant velocity (V_r) of seed when dropped

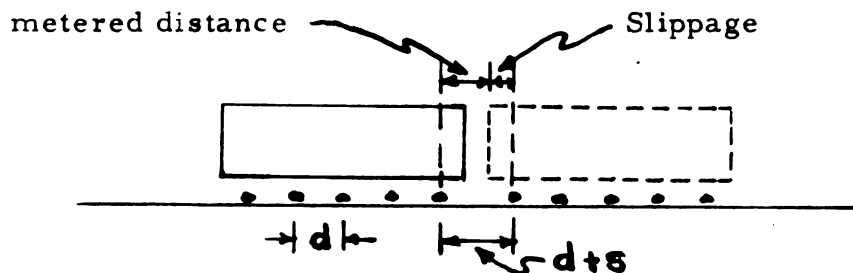


Fig. 25 - Separator and spacer in two different steps when slippage occurs

given by,

$$V = V_0 + g t$$

Where, V = velocity at any instant

V_0 = initial velocity

g = acceleration of gravity

t = time of travel from initial conditon

The fall of the seed can be approximated in this ideal condition and the velocity due to gravity (V_g) at any instant can be computed. The resultant velocity of the seed at any instant in its trajectory is found by adding vectorially or analytically the two velocity components (V_c) and (V_g) (Fig. 24).

Press wheel slippage

Although not wanted, slippage occurs in any traction powered mechanism. In press-wheel- powered planters, slippage is one of the causes of irregular spacing and scattering of the seeds.

The step planter, because of its step action and its pre-determined spacing, behaves in a different manner. Scattering occurs only between steps. When slippage occurs the step is delayed according to the duration of the slip. When the planting takes place, the rear end seed (the one closest to the preceding step) is separated from the front seed

of the preceding step. The distance is equal to the regular spacing plus the slippage distance. The rest of the seed will be exactly spaced in relation to the others in the same step. Figure 25 shows a sketch of the separator and spacer in two different steps when slippage occurs.

Laboratory Test of the Step Planter

Object

The object of this test was to determine the coefficient of variation of the step planter at different velocities and heights of planting with seed size variation.

Equipment and Equipment Layout

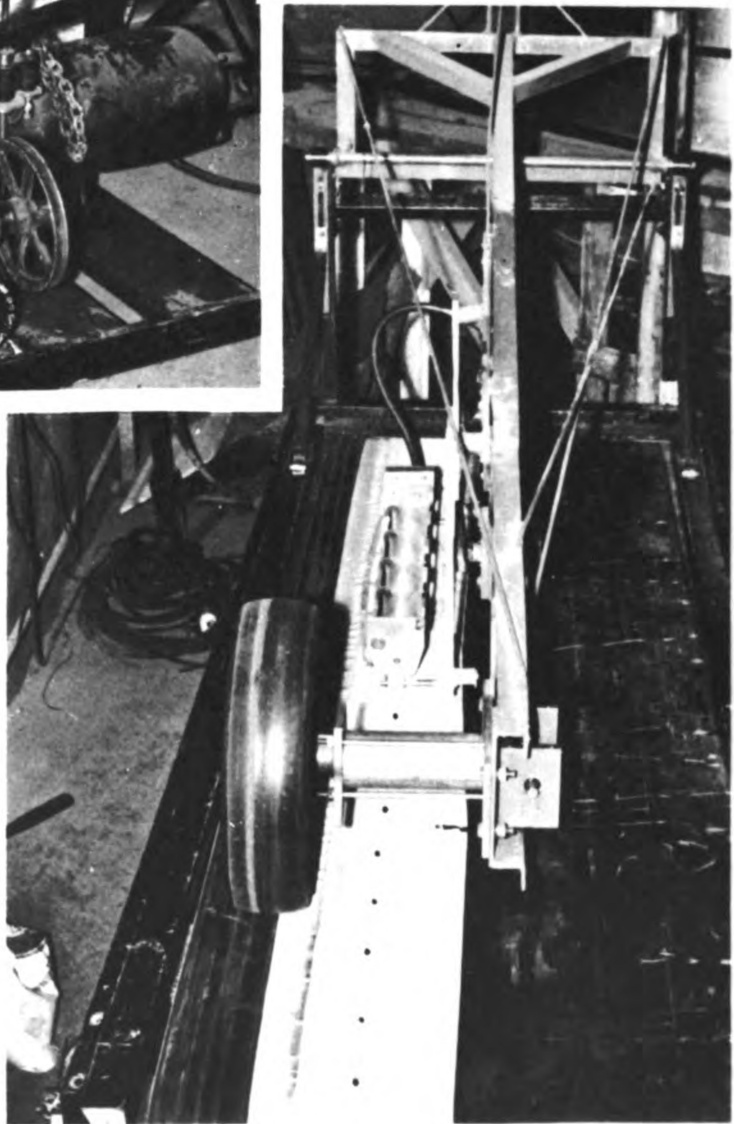
The equipment used consisted of a 16 feet movable rubber table belt powered by a 3 HP, 440 volts, 3 phase, electric motor, with a continuous variable velocity transmission, through a velocity reduction gear set (Fig.26). The belt width is 2 feet. The step planter was attached to this table (as illustrated), therefore receiving the power directly from the rubber belt through the press wheel (Fig.27).

Normally the press wheel is positioned right behind the seed separator and spacer. Fig27 shows how the press wheel was moved to a side so that the seeds were not disturbed after being deposited on top of the moving belt. The rubber belt was dressed with a band of cheesecloth and secured to it with masking tape on both sides. The cheesecloth



Fig. 26 - Moving belt power system and how it is transmitted to the planter's powered system.

Fig. 27 - Rear top view of the planter set-up on the moving belt table. Notice displacement of wheel from the separator and spacer line of action.



provided a rougher surface than the rubber belt to prevent further movement of the seed due to vibration of the moving belt. Besides, the cheese-cloth texture resembles more the soil texture than that of the rubber belt.

Procedure

The seed hoppers were half filled with test seed. The separator and spacer was adjusted to the desired ejection height. The electric motor was regulated to the desired velocity. The motor was started and run for about one minute and then stopped. The last two steps (50 inches) were studied and measurements were done on them.

To obtain the correct position of the seeds and compare to their actual position, the planter was slowly moved to the next step. The correct position was determined from the last seed of this step. This is the seed nearest to the preceding step. The seed's position were determined with respect to each seed's correct position. The positions were recorded on graph paper. This procedure was repeated five times for each case.

Tabulated Results

Typical data recorded are shown in Fig. 28, 29 and 30. With this system the actual position of the seed with respect to the theoretical position is known and any analysis can be made.

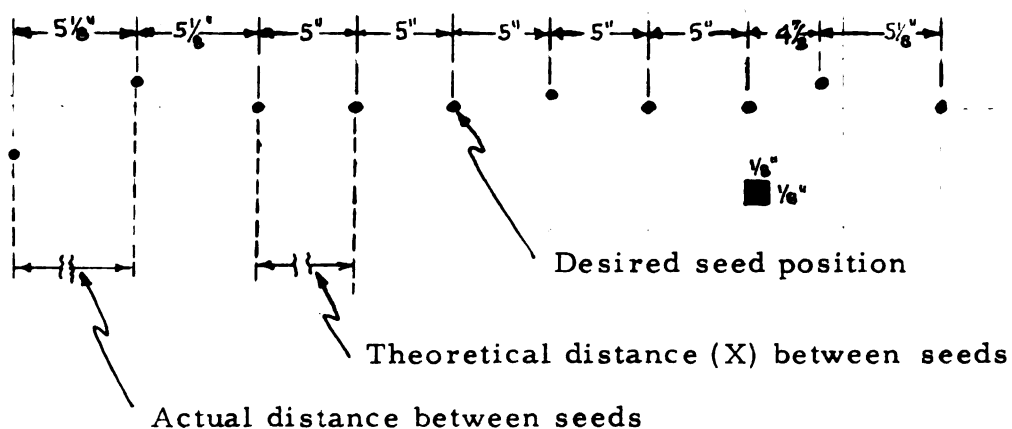


Fig. - 28 - Sample of recorded data using seed size 6-7 at 1/4" dropping distance and at a belt velocity of 0.50 mph.

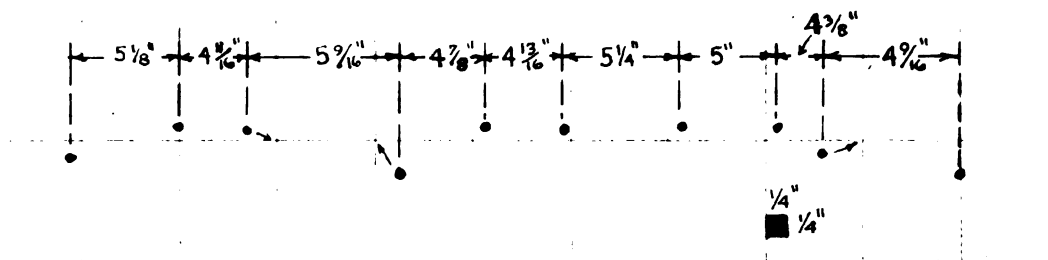


Fig. - 29 - Sample of recorded data using seed size 6-7 at 1/2" dropping distance and at a belt velocity of 1.00. mph.

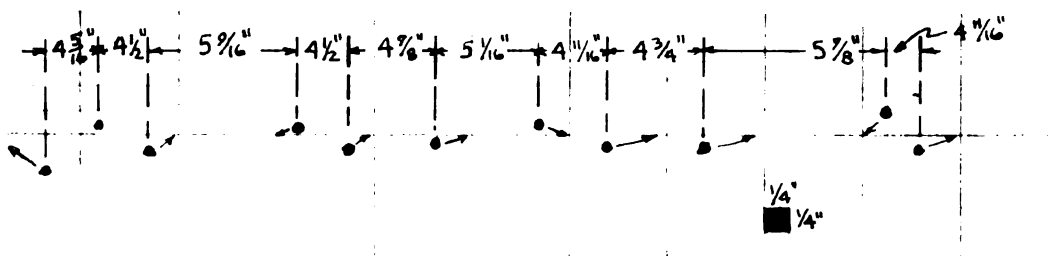


Fig. - 30 - Sample of recorded data using seed size 6-7 at 1" dropping distance and at a belt velocity of 1.50 mph.

Tabulated results are presented in Table 1. These are representative samples of the five measurements made in each case. Besides the mean distance, standard deviation and coefficient of variation, it shows the average coefficient of variation of each group. Table 2 shows the standard deviation of the average distances to the theoretical distance of all representative samples and the maximum standard deviation obtained in each group.

Table 3 gives the weights per hundred (100) seeds, grams per acre and pounds of seed per acre necessary to plant sugar beets at 24 inches between rows for the test seeds.

Observations

The following observations were made during the test:

Favorable

1. No double seeds were obtained.
2. No broken or damaged seed were noted.

Unfavorable

1. Unbalance of the machine became a problem at velocities greater than 1 1/2 miles per hour.
2. Electrostatic charging of the plastic shield prevented good ejection in some cases. Seeds were retained in the orifice of the shield due to attraction of the plastic to

BELT VEL.	SEED DROPPING DISTANCE	0"				1/4"				1/2"				1"			
M. P. H.	SEED SIZE*	6-7	7-8	8-9	All	6-7	7-8	8-9	All	6-7	7-8	8-9	All	6-7	7-8	8-9	All
0.50	MEAN DISTANCE ($\bar{X}_i$)	5.0	5.0	5.0	5.0	5.02	5.04	4.99	5.00	4.96	5.03	4.98	4.91	5.01	4.80	5.05	5.01
	STANDARD DEVIATION (S_i)	0.0	0.0	0.0	0.0	0.0	0.182	0.259	0.106	0.548	0.332	0.380	0.298	0.825	0.817	0.596	0.596
	% COEFFICIENT OF VARIATION	0.0	0.0	0.0	0.0	0.0	3.61	5.19	2.12	11.04	6.60	7.63	6.07	16.47	17.0	11.8	11.9
1.00	MEAN DISTANCE ($\bar{X}_i$)	5.00	5.00	5.00	5.00	4.98	5.02	5.00	5.00	4.94	4.99	5.03	5.02	5.03	5.17	4.93	4.97
	STANDARD DEVIATION (S_i)	0.0	0.0	0.0	0.0	0.106	0.0	0.149	0.106	0.408	0.538	0.350	0.577	0.675	0.527	0.723	0.236
	% COEFFICIENT OF VARIATION	0.0	0.0	0.0	0.0	2.13	0.0	2.98	2.12	8.25	10.78	6.44	11.49	13.4	10.4	14.65	4.75
1.50	MEAN DISTANCE ($\bar{X}_i$)	5.00	5.00	5.00	5.00	5.00	5.00	4.96	5.00	4.96	4.99	5.03	4.83	4.88	5.13	5.10	4.99
	STANDARD DEVIATION (S_i)	0.0	0.0	0.0	0.0	0.0	0.106	0.248	0.248	0.298	0.278	0.394	0.365	0.364	0.737	0.453	0.746
	% COEFFICIENT OF VARIATION	0.0	0.0	0.0	0.0	0.0	2.12	5.00	4.96	6.01	5.57	7.82	7.56	7.45	14.4	8.90	14.95
	AVE. % COEFFICIENT OF VARIATION	0%				2.52%				7.93%				12.15%			

*Measured in 64th of an inch.

Table 1 - Tabulated Results

Mean distance, standard deviation and % coefficient of variation at various velocities and dropping heights with different sizes of seeds. (All measurements in inches).

Dropping Height	X	S'_i	$2 S'_i$	$3 S'_i$	$S'_i(\text{max})$ of Ea. Group
0"	5.00	0.0	0.0	0.0	0.0
1/4"	5.00	0.021	0.042	0.063	0.259
1/2"	5.00	0.066	0.132	0.198	0.577
1"	5.00	0.330	0.660	0.990	0.825

Table 2- Standard deviation of the average distances to the theoretical distance.

the seed. Sometimes the dropping of the seeds were delayed for an instant due to the attraction of the shield surface.

3. Width of the plastic hoppers were near the average width of three seeds. This prevented in some cases, where misses were observed, the filling of the cells.
4. Smaller size seeds missed less than the larger ones. This proved that the preceding observation was valid. When seeds were mixed the planter worked satisfactorily.
5. Seeds were observed to be held inside the cell due to the cuticle which stuck to the irregularity of the seed cell.
6. Misses of the planter were not counted against the planter's precision because of the uncontrolled factors affecting them.
7. Vibration of the moving table belt provoked some dispersion of the seed when dropped.

Discussion of Results

It is interesting that the percent coefficient of variation at zero dropping distance was zero for all velocities and for all sizes of seeds. This group of samples showed that when seeds are deposited at zero relative velocity with respect to ground there is no appreciable dispersion. Seeds are planted exactly at the desired distance.

Comparing the results of the rest of the samples with the zero distance group, a tendency is observed. Computing the average coefficient of variation of each group they show a tendency to increase linearly as the height of seed drop increases. The average coefficient of variation (0, 2.52%, 7.93% and 12.15%) show that the height at which the seed is dropped will be the determining factor, even though the planter is still dropping seeds at zero relative velocity with respect to ground.

It is also significant that the coefficient of variation in each group do not follow a pattern or tendency even when the seed size and the separator and spacer velocity are changed.

The standard deviation of the means ($\bar{X}_i$) with respect to the theoretical distance (X), is used to determine the radius around the theoretical distance which describes the area where practically all seeds will fall. The means are distributed normally around the theoretical points as follows:

- a) 68.26% of the observations deviate $1 S_i$
- b) 95.46% of the observations deviate $2 S_i$
- c) 99.74% of the observations deviate $3 S_i$

The theoretical distance represented the point where the seeds were expected to fall. If we take this point as the center of a circle of $3 S_i$ radius it will draw a circle inside which 99.74% of the seeds should fall. This is true even when dispersion in the direction of travel only

was measured.

In the group at zero height the radius is zero and all seeds will fall exactly on the theoretical distance. The groups at $1/4''$, $1/2''$, and $1''$ height had radii of $1/16''$, $3/8''$, and $1''$ respectively.

Tests were conducted to determine whether the seed hit the belt surface at the theoretical point. For this test a strip of sheet metal with a layer of grease was used. This grease layer held the seed at the impact point. An analysis of the test results proved that the seed were spaced on the grease strip at the theoretical points. This showed that the seeds scattered after impact on the belt.

Double seeds and damaged seeds were not observed throughout the test. Seeds were reused several times and still no apparent damage was done to them. The seed cell design was very satisfactory. The change in seed size did not affect the performance of the cell nor the other mechanisms of the planter.

From the above observations and obtaining the average weight of 100 seeds, of the test seed, the quantity of seeds to be planted per acre was found, (Table 3). Assuming a row width of 24 inches, for average row spacing and planting at 5 inches between seeds, 1.37 to 1.86 pounds of seed per acre will be used, depending on the seed size. In normal operation, assuming some handling losses, 1.50 to 2.00 pounds of seed

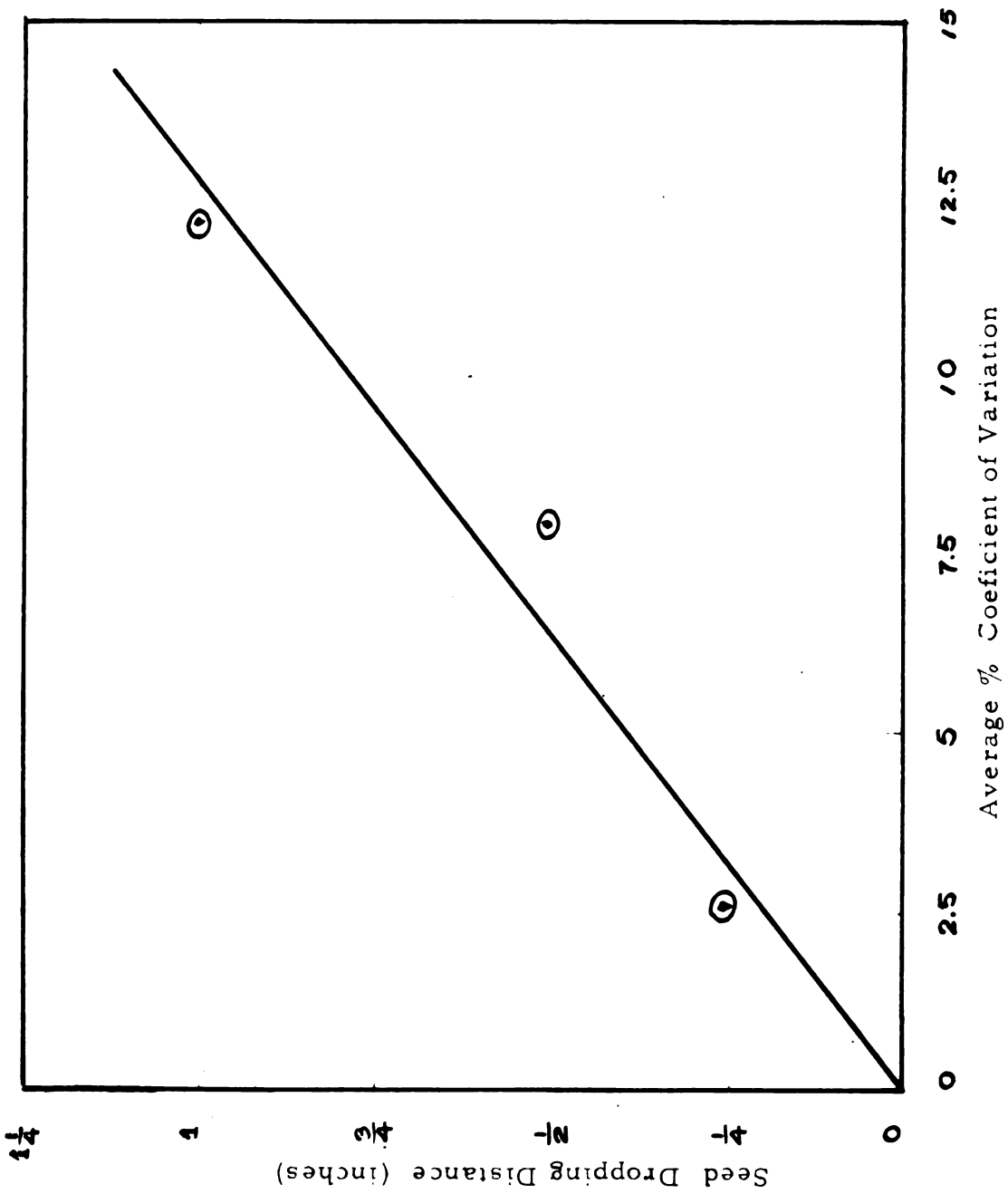


Fig. 31 - Average % coefficient of variation vs seed dropping distance.

Seed size	Weight (gm) of 100 seeds	gm/acre	#/acre
6 - 7	0.713	625	1.37
7 - 8	0.801	702	1.54
8 - 9	0.963	845	1.86

Table - 3 - Seed weight per 100 seeds, and seed weight per acre used in planting at 24 inches between rows with seeds 5 inches apart.

per acre are needed. This compared to U. S. D. A. recommendations for the North Central States, (Farmer's Bulletin No. 2060) 4 to 6 pounds per acre, there is a reduction in seed consumption of $2\frac{1}{2}$ to 4 pounds per acre.

Step Planter Critique

Results showed that the planter proved to work satisfactorily under the conditions it was designed for. The unfavorable observations listed should be studied carefully and a solution to each one should be found.

The planter should be redesigned to prevent excessive vibration due to unbalanced mechanisms. Its weight should be reduced to a minimum, especially the separator and spacer. This will enable the planter to be tested at higher speeds.

APPENDIX

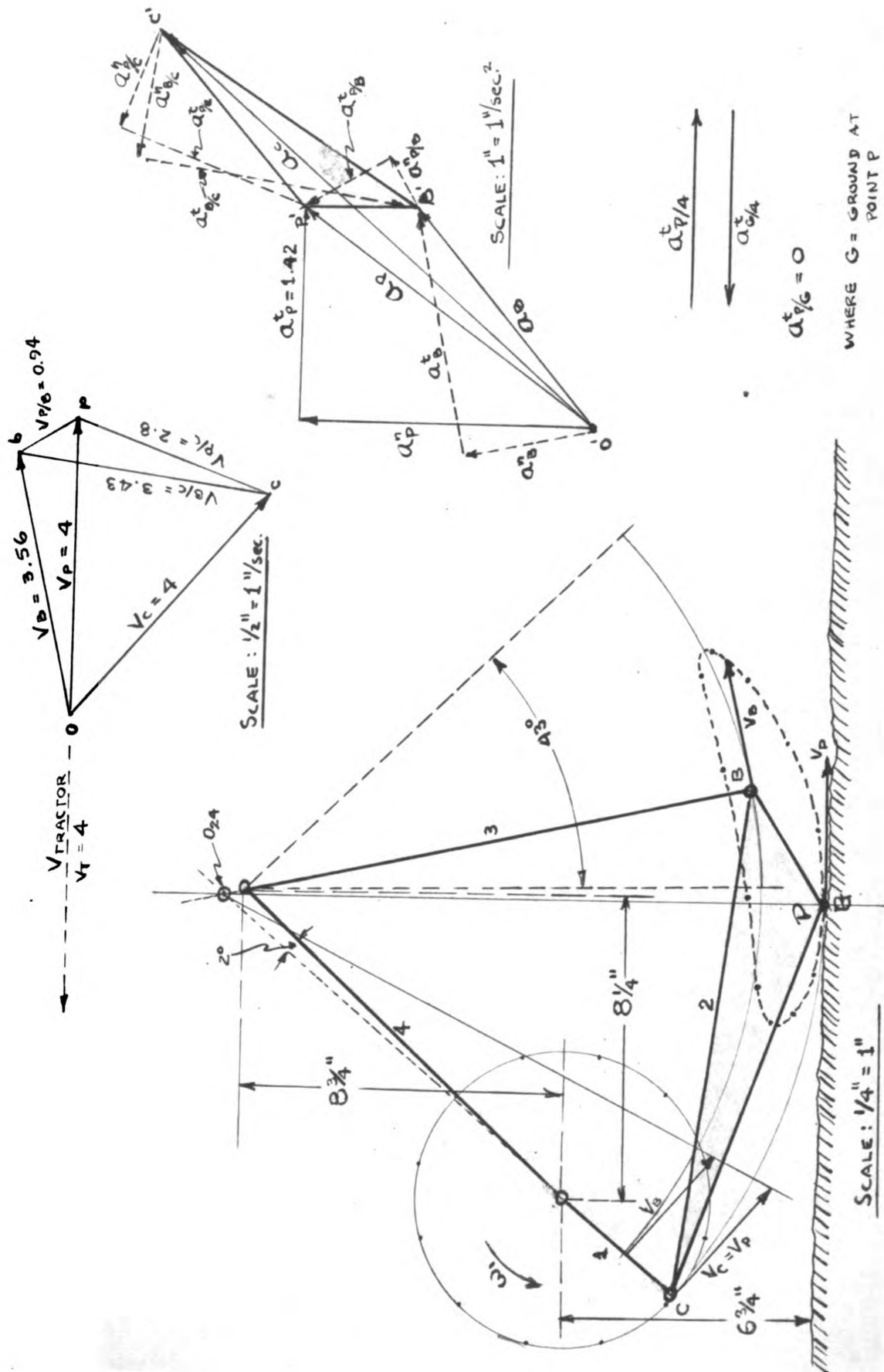


Fig. 32- Kinematic analysis of four bar linkage at dropping point

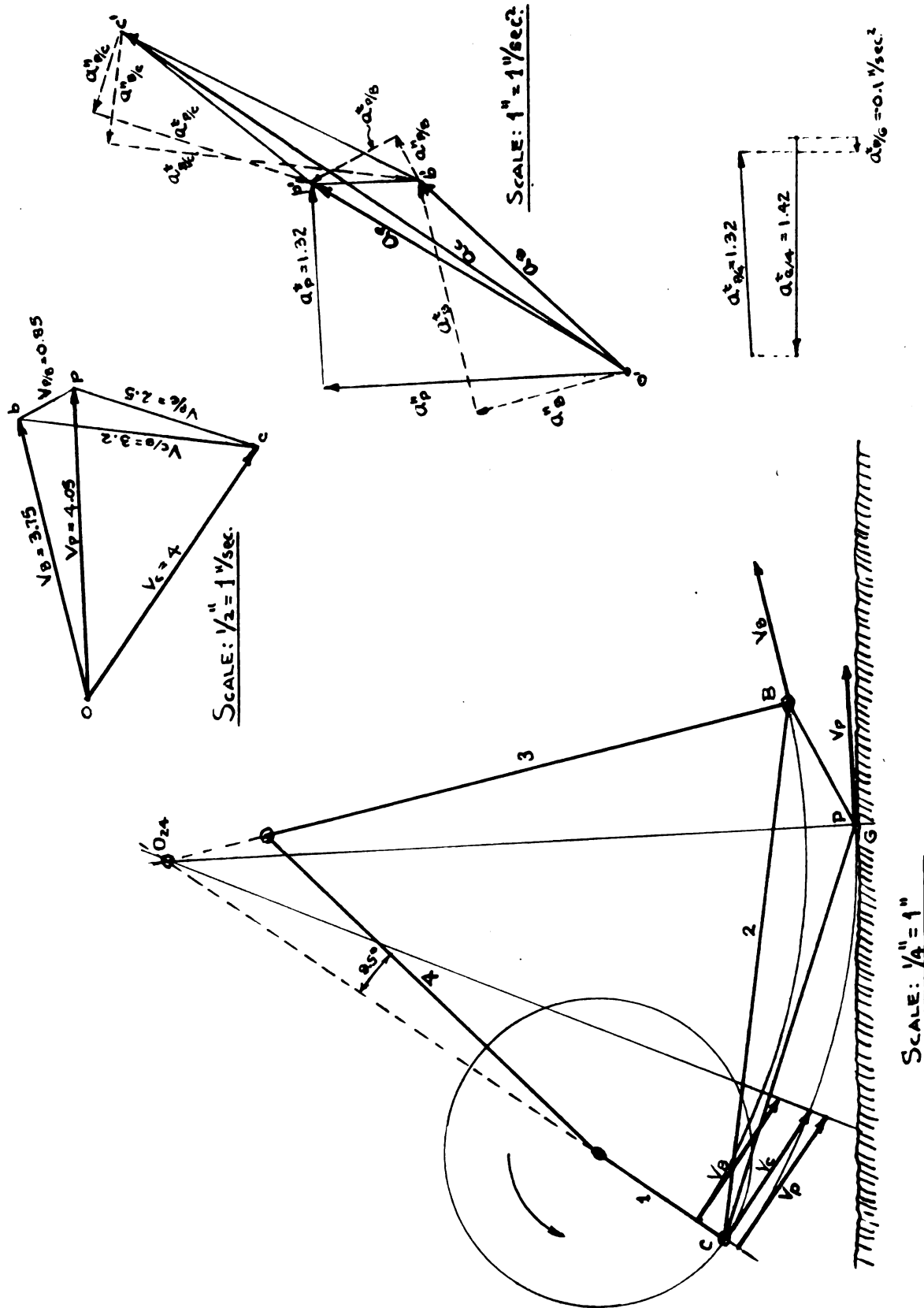


Fig. 33 - Kinematic analysis of four bar linkage 7.5° past dropping point.

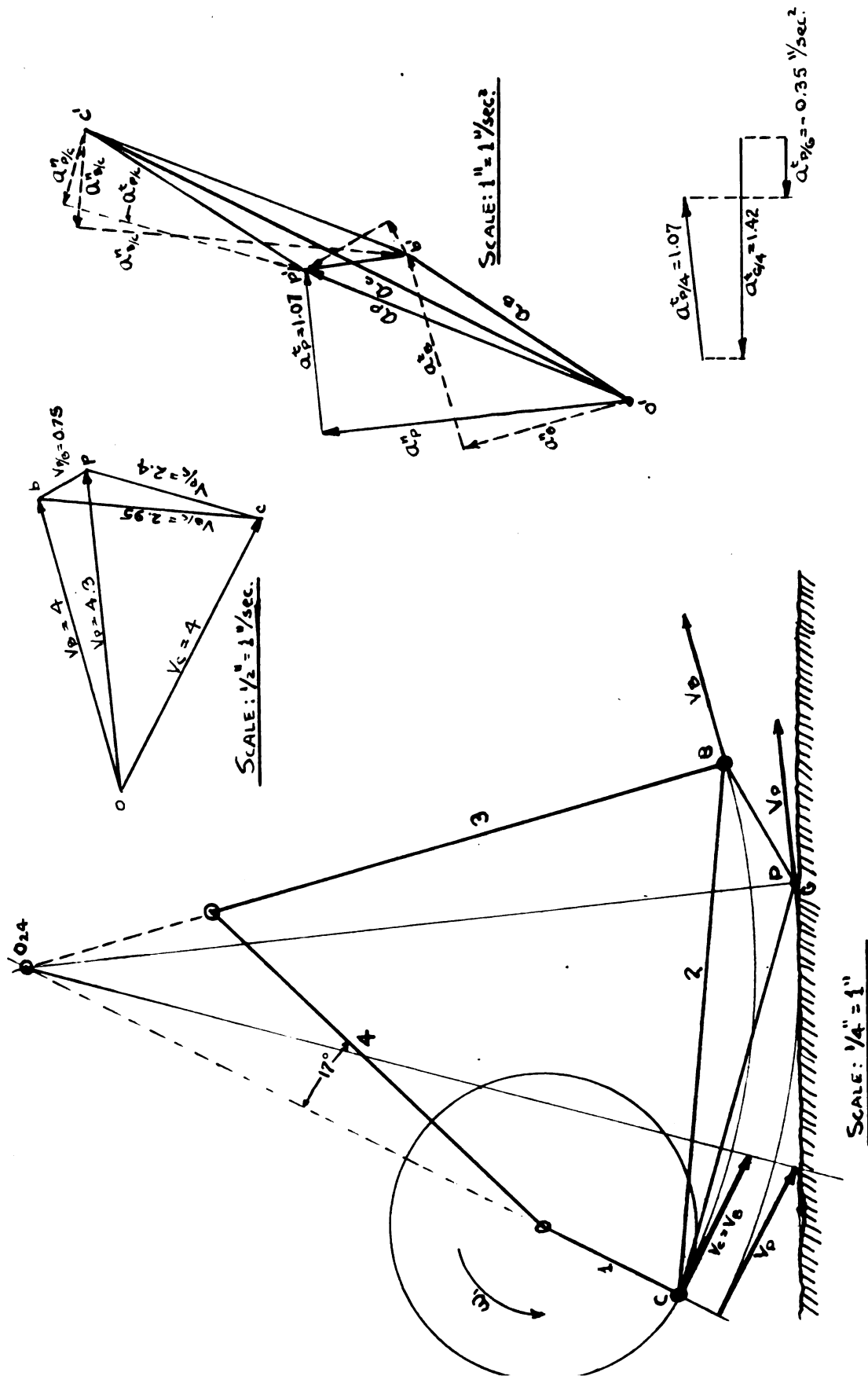


Fig. -34 Kinematic analysis of four bar linkage 15° past dropping point.

SEED SIZE

	6-7			7-8		8-9		ALL	
	BELT VEL. (MPH)	BELT VEL. (MPH)	BELT VEL. (MPH)	BELT VEL. (MPH)	BELT VEL. (MPH)	BELT VEL. (MPH)	BELT VEL. (MPH)	BELT VEL. (MPH)	BELT VEL. (MPH)
X	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
1	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
2	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
3	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
4	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
5	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
6	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
7	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
8	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
9	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
10	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
ΣX	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
ΣX^2	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0

Table -4 Tabulated data at 0" dropping height for processed sugar beet seeds of sizes 6-7, 7-8, 8-9, and all together at 0.50 , 1.00 and 1.50 M. P. H.

Table -5 Tabulated data at 1/4" dropping height for processed sugar beet seeds of sizes 6-7, 7-8, 8-9, and all together at 0.50, 1.00, and 1.50 M. P.H.

SEED SIZE

6-7	7-8	8-9	ALL
-----	-----	-----	-----

	BELT VEL. (MPH)	BELT VEL. (MPH)	BELT VEL. (MPH)	BELT VEL. (MPH)	BELT VEL. (MPH)
X	0.50	1.00	1.50	0.50	1.00
1	4.21	5.13	5.44	4.81	4.56
2	5.63	4.69	4.75	5.81	4.69
3	4.50	5.56	5.00	4.75	5.50
4	5.50	4.88	4.44	4.75	5.25
5	5.06	4.81	5.00	5.13	5.25
6	5.44	5.25	4.81	4.81	5.38
7	4.75	5.00	5.25	5.25	4.38
8	5.00	4.38	4.75	4.75	5.38
9	4.44	4.56	5.25	5.25	5.38
10	5.00	5.13	4.94	4.94	4.13
ΣX	49.57	49.57	49.63	50.25	49.80
ΣX^2	248.0	245.2	247.1	253.5	251.6

Table - 6 Tabulated data at 1/2" dropping height for processed sugar beet seeds of sizes 6-7, 7-8, 8-9, and all together at 0.50, 1.00 and 1.50 M. P. H.

SEED SIZE

	6-7	7-8	8-9	ALL
--	-----	-----	-----	-----

	BELT VEL. (MPH)			BELT VEL. (MPH)			BELT VEL. (MPH)			BELT VEL. (MPH)		
X	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50	0.50	1.00	1.50
1	5.63	6.38	4.31	4.31	5.25	6.00	6.06	5.25	5.44	6.00	5.63	6.56
2	5.00	4.75	4.50	4.50	5.19	4.25	5.19	5.00	4.25	4.25	5.00	4.25
3	5.25	5.00	5.56	5.56	5.50	5.13	5.25	5.25	5.00	5.13	5.25	4.50
4	3.75	4.00	4.50	4.50	4.00	5.00	4.00	4.25	5.25	5.00	4.50	5.00
5	5.00	5.44	4.88	4.88	4.81	5.38	4.75	4.38	4.75	5.38	4.00	4.88
6	5.00	5.44	5.06	4.88	5.50	6.38	5.88	6.56	4.88	5.75	4.88	5.25
7	4.50	4.25	4.69	4.50	4.88	4.75	5.06	4.25	5.38	5.00	4.50	5.19
8	5.63	5.00	4.75	6.38	5.38	5.00	4.69	4.50	5.50	4.38	6.38	5.50
9	4.00	5.25	5.88	5.13	5.50	4.00	4.88	5.00	5.69	4.81	5.13	4.00
10	6.38	4.75	4.69	3.38	5.69	5.44	4.75	4.88	4.81	4.38	3.88	4.81
X	50.14	50.26	48.82	48.02	51.70	51.33	50.51	49.32	50.95	50.08	49.65	49.94
X ²	257.2	256.7	239.5	236.6	269.8	268.3	258.3	247.9	261.4	254.0	242.0	254.4

Table -7- Tabulated data at 1" dropping height for processed sugar beet seeds of sizes 6-7, 7-8, 8-9 and all together at 0.50, 1.00 and 1.50 M. P. H.

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