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ZERO TILL FURROW OPENER DESIGN
FOR HEAVY TRASH AND HARD SOIL
CONDITIONS

by

JOERG MICHAEL BETHGE

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of

MASTER of SCIENCE

Department of Agricultural Engineering

Winnipeg, Manitoba

February, 1985

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a Master's thesis entitled: Zero Till Furrow Opener Design for Heavy Trash and Hard Soil Conditions

submitted by Joerg Michael Bethge

in partial fulfilment of the requirements for the degree of Master of Science

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ZERO TILL FURROW OPENER DESIGN

FOR HEAVY TRASH AND HARD SOIL CONDITIONS

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ABSTRACT

Zero till farming is becoming an alternate practice in the production of commercial crops. Use of the no till concept conserves soil and water and saves fuel, time and money. New herbicides make it possible to control most of the weeds competing with the crop. But seeding in zero till conditions still sets some limitations on the concept. A zero till furrow opener should place seed and fertilizer through a layer of residue into compacted soil creating a favorable seedling environment while producing only a minimum of soil disturbance. Disk type and hoe type furrow openers are not able to fulfill these requirements consistently.

A powered disk furrow opener was designed for zero till seeding. The toothed disk rotated opposite to the direction of forward travel. Soil was lifted from the furrow over the top of the disk, split into two streams and then directed back into the furrow. Fertilizer and seed were introduced under the first and second soil stream, respectively. The powered disk protruded through a base plate into the soil to the desired depth. The base plate served to retain the soil on both sides of the furrow. The base plate also carried the necessary shielding to direct the soil and provided a cutting edge for the disk teeth so that surface residues were cut cleanly.

A prototype furrow opener was tested in a laboratory soil bin and design alterations were made as necessary. Fertilizer and seed placement data were collected and analyzed. Positive fertilizer and seed separation was achieved. The powered disk furrow opener was evaluated qualitatively with respect to its field performance in zero till conditions. Rotary power inputs to the disk were measured in the field under a range of soil compaction levels. The average maximum power input to the disk was 2.6 kW at 5.2 km/h forward speed in clay soil compacted by combine wheels in a barley stubble field.

The powered disk furrow opener was able to cut through large amounts of residue and to penetrate compacted soil well. The unit placed separate bands of fertilizer and seed uniformly in the furrow. The opener created a favorable seedling environment producing only a minimum of soil disturbance.

ACKNOWLEDGEMENTS

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Chapter I

INTRODUCTION

Zero till farming is gaining popularity in the semidry and dryland farming regions of the wheatbelt in North America. It has been proven that untilled soil will have increased soil water content under most conditions. With the introduction of herbicides that control most of the weeds competing with commercial crops one of the major reasons for tilling the soil can be eliminated.

Zero till reduces the risk of soil erosion. With the soil particles protected from wind and rain by the crop residue erosion often is cut to an acceptable level of one to two tonnes of soil lost per hectare per year (Rice and Turner, 1983).

Limitations still exist in the area of seeding a crop under zero till conditions. The major function of secondary tillage is to prepare a favorable seedbed. A desirable seedbed consists of level, easy to penetrate, finely aggregated soils with very little crop residue left on the surface. Seed can be placed exactly for optimum germination and emergence. Conventional seeding equipment operates best under ideal or near ideal conditions.

Manufacturers have developed a large variety of seeding machines for use in zero till seeding. Since zero till seeding often takes place under adverse conditions such as compacted soils or high amounts of crop residue most of the drills are usually built very heavily for the purpose of ensuring penetration and therefore they are rather expensive. A consequence of the high design weight is the high draft force needed to pull these units. The use of high powered tractors and heavy seed drills adds to the problem of excessive soil compaction as well as to the cost factor.

The objective of this project was to design and evaluate a new concept in a furrow opener. The physical principles were investigated first. Then the performance of the powered furrow opener operating as a zero till furrow opener was evaluated. A prototype opener was built and design modifications were made as indicated by test results.

Chapter II

REVIEW OF LITERATURE

2.1 DEFINITION OF ZERO TILL SEEDING

Zero till or no till seeding is the planting of a crop into sod, previous crop stubble or a cover crop where only the immediate seed zone is disturbed. The area disturbed is usually less than 25 percent of the soil surface (Rice and Turner, 1983).

2.2 THE GENERAL CONCEPT OF ZERO TILL FARMING

The major change for zero till farming compared to conventional tillage farming is the elimination of the primary and secondary tillage operations for the purposes of seedbed preparation, fertilizer and herbicide incorporation, weed control and residue management.

Today, many of the field crops such as cereal grains, oilseeds and corn can be grown with zero till farming. If the crop seedlings can be established in a no till seedbed the yields often are comparable or better than under conventional tillage farming.

Guidelines for zero till crop production as stated by the MAN-DAK ZERO TILL FARMERS ASSOC.(1983) are as follows:

1. Residue from the previous crop should be evenly spread on the the soil surface.
2. Weed control measures for summer and winter annual weeds and for perennial weeds should be carried out with the appropriate herbicides in either post harvest, preplant or postemergence operations.
3. Fertilizer should be applied by either broadcasting and/or sidebanding with the seed or by banding fertilizer with special equipment. The application machinery should create only minimum soil disturbance.
4. Seeding should be done with special drills which achieve the required soil penetration to place the seed in a desirable germination and emergence environment. The ability to handle large amounts of residue and to place the fertilizer with the seed or to sideband the fertilizer is also important. The drill should also produce only minimum soil disturbance.
5. Other production procedures, such as crop rotation, should follow the same pattern as with conventional tillage farming practices.

2.3 SEED ENVIRONMENT REQUIREMENTS

In conventional tillage the seed horizon is recompacted to ensure proper soil moisture movement. The soil aggregates are reduced in size so that the existing soil porosity will facilitate drainage of free water and movement of sufficient air. The correct soil porosity also prevents crusting of the soil (Hunt, 1979).

The four variables that influence germination and emergence of all seed species are temperature, moisture, aeration, and mechanical impedance (Bowen and Cable, 1967). All of the soil properties above are closely related. The critical values for each property with respect to the seedling requirements are influenced by soil type and partially by local climate.

1. SOIL TEMPERATURE

Seeds of different plants vary in their ability to germinate at low temperatures. Germination and emergence is a slow process in cold soils. Up to a certain optimum temperature, germination and emergence become more rapid with increasing temperature. The minimum temperatures at which most cereal crops will germinate and emerge are 1-3 degrees Celsius and 2-3 degrees Celsius, respectively. Temperatures of 8-10 degrees Celsius higher than the minimum temperatures are required for optimum germination. The temperature of the soil in the seed horizon is influenced by factors such as soil moisture and soil compaction (Shaykewich, 1984).

2. SOIL MOISTURE

The critical soil moisture content for germination and emergence is the permanent wilting percentage. Most seeds will germinate in soils at the permanent wilting percentage. It has been found that moisture migration out of the seed furrow in the soil has to be limited to ensure the survival of the seedlings. A slow moisture migration means the maintenance of a high relative humidity in the seed furrow. Covering the seed with soil will retain a high relative humidity in the furrow. A seedling can survive over a period of time in this low moisture regime and slowly will extend its root system to pick up water from deeper soil layers. No limitations to germination and emergence exist when the soil water content is well above the permanent wilting percentage (Townsend, 1983; Choudhary and Baker, 1980).

3. SOIL AERATION

Seeds during germination and seedlings require sufficient oxygen for respiration processes. Oxygen reaches seeds and seedling roots by diffusion through air-filled soil pores and through water films in the soil structure and around the seedling roots. Test results have shown that oxygen diffusion rates below $75*10^{-8}$ to $100*10^{-8}$ g cm^{-2} min^{-1} will reduce overall wheat seedling emergence. This value of oxygen diffusion rate corresponds to an air-filled porosity of about 16 percent for silty clay loam and about 25 percent for fine sandy loam (Pakaranodom, 1972).

4. MECHANICAL IMPEDANCE

Mechanical impedance of soil is related to the soil strength. The soil strength is a measure either of the force required to penetrate the soil or of the bulk density of the soil. A soil with a high bulk density offers a high resistance to penetration by plant roots or by tillage tools. Mechanical impedance to seedling growth can take place in two forms:

a. a crust on the soil surface which inhibits the growth of the shoot,

b. compacted seed furrow boundaries which inhibit the growth of the roots.

Canola, for example, will not emerge through a soil crust with a strength of 2 kPa or more whereas bean seedlings will emerge through soil crusts with a strength of over 20 kPa (Shaykewich, 1984). Barley roots will stop development when the bulk density of the soil increases to over 1.65 g cm^{-3}. These results were found in a sandy soil (Pakaranodom, 1972).

2.4 METHODS OF FERTILIZATION

The two main fertilizers applied are nitrogen and phosphate in Manitoba. Phosphate fertilizer can usually be banded with the seed in sufficient quantities in normal dryland farming practices. But many seeds can tolerate only a limited amount of nitrogen fertilizer in close proximity during germination and emergence.

Most of the research done on nutrient uptake indicates that nitrogen fertilizer be placed in a soil layer below the seed horizon. It is also preferable to place the nitrogen fertilizer in narrow bands at low fertilizing rates (Holt, Voorhees and Allmaras, 1967). Results in a winter wheat zero till study showed that the nitrogen fertilizer was used most efficiently when it was banded in the fall as compared to broadcasting in the spring. It was stated that it would be desirable to band all of the fertilizer at the time of seeding to get the best efficiency for fertilizer uptake and equipment use (Stobbe et al., 1981).

The sidebanding of nitrogen fertilizer 50 mm below and 25 mm to the side of the seedrow provides a sufficient distance between the fertilizer and the seed to eliminate any seed burning. But an absolute yield advantage has not been proven with this fertilizer placement (Rice and Turner, 1983).

Broadcasting the fertilizer as compared to banding does not produce lower yields in areas with sufficient rainfall during the growing season (Baeumer and Bakermans, 1973).

2.5 FURROW OPENER REQUIREMENTS

A no till furrow opener must be able to place seed through high levels of crop residue into relatively compacted soils. A good seed-to-moist-soil-contact is important for uniform germination and emergence. Uniform seeding depth is also important. The optimum furrow opener will create a microseedbed with an ideal germination environment with respect to soil temperature, soil moisture, soil aeration and mechanical impedence. The existing soil structure and residue cover that is desirable for later plant growth should be altered as little as possible. These requirments are achieved by reducing the soil disturbance due to the furrow opener to a minimum (W. Richie, 1983, personal communication).

2.6 FURROW OPENERS

Two major groups of furrow openers for zero till can be identified, the disk opener and the hoe opener.

Disk openers work on the basic principle that a slot is cut by single or multiple disks into the soil through a layer of residue. Seed and fertilizer are then introduced into this slot through one or two spouts. A number of different designs fall under the category of disk openers including the standard double disk opener with a narrow angle between the disks or with the disks offset to each other front to back. Other openers utilize a third disk, powered or free rolling, in front of the opener thus creating a triple disk arrangement.

The main characteristic of these designs is that good seed placement can be achieved when the opener is able to cut through large amounts of residue and penetrate compacted soil. One major problem with disk openers is that under very heavy residue conditions or in adverse soil conditions the residue is pushed uncut into the furrow. This is known as the hairpinning effect. Seed placed on top of the uncut residue will often not germinate. High vertical forces on the disk furrow opener are needed to cut through thick layers of residue and/or to penetrate compacted soil.

An advantage of the disk type opener is that little soil disturbance is produced which means that most of the desirable soil structure is retained. The limited soil disturbance also reduces the covering of weed seeds with soil on the soil surface. Weed seeds remaining uncovered on the soil surface often will not germinate and will loose their viability during the growing season of the commercial crop. But with reduced tillage action of openers the seed is insufficiently covered with soil. This will lead to critical germination and emergence conditions in soils with moisture contents near the permanent wilting percentage (Townsend, Bethge and McPhee, 1984; Schwertdle et al., 1984).

The hoe type zero till furrow opener is an arrangement of narrow tipped hoe openers mounted on a frame. Wide spacing of the openers side to side and front to rear is necessary so that residue will clear. Seed and fertilizer spouts are often incorporated in the toolholder. The hoe opener pushes the residue aside and forms a seed furrow. Seed and fertilizer are dropped into this furrow. The hoe opener requires less vertical force to penetrate compacted soil but the draft force requirements are higher compared to a disk furrow opener. Because of the intensive tillage action more soil disturbance takes place with the hoe furrow opener but better seed coverage is achieved. Cutting disks are sometimes mounted in front of the hoe opener to aid in residue handling. Very high amounts of residue will not flow through the hoe openers and the residue is raked by the seed drill. The accumulating residue will eventually interrupt the seeding operation (Lindwall and Anderson, 1977).

The addition of a cutting disk or coulter to a hoe opener is one of the combination designs of disk and hoe openers. Single disk openers with a knife mounted on one or both sides of the disk are also used for zero till seeding. Seed and fertilizer are dropped into the furrow created by the knives and the disk. The knife-disk combination opener performs well from a zero till seeding point of view, but mechanical problems limit the usefulness of the openers. A residue-soil mix accumulates between the disk and the knife eventually stopping the rotation of the disk (J. McCutcheon, 1983, personal communication).

When zero till is used for row crop production special planters are employed. A strong framework supports heavier planter units which are preceeded by coulters. Under some soil conditions rippled or fluted coulters are used even though they are less able to cut through residue. But a desirable pretilled slot for the placement of the seed is created by these coulters (Choi and Erbach, 1983).

2.7 POWER TILL OPENERS AND STRIP TILLAGE

The task of handling high amounts of residue under zero till seeding conditions and the requirement of creating a desirable microseedbed has led researchers to consider the usefulness of power driven attachments. Research done in Saskatoon showed that a power driven coulter did not increase the ability of the coulter to cut residue compared to a free rolling coulter (Kushwaha, Vaishnav and Zoerb, 1983).

Erbach (1978) integrated a hydraulicly driven coulter with a knife type opener on a rowcrop planter. Using the top of the knife as a shear plate the coulter rotated in the direction of travel and cut the residue accumulated in front of the knife. Power measurements showed that the coulter required between 1.1 and 1.4 kilowatts depending on the amount of residue to be cut and the angular velocity of the coulter (Mehdi-Soozani and Erbach, 1982). Work was done by Erbach (1978) in combining a powered coulter with a double disk furrow opener. He also utilized a notched coulter driven opposite to the direction of travel to create a seed furrow for pasture renovation applications.

Preliminary investigations were done on a powered tillage disk (Smith, Haminett and Thomson, 1979). The tillage disk had a diameter of 300 mm and 12 triangular teeth similar to a circular saw blade. A ground drive system to power this tillage disk was used. The disk was mounted in front of a row crop planter and rotated opposite to the direction of travel. In this way the researcher was able to substantially reduce the angular velocity of the disk and still obtain a good performance of the tool. The disk scattered the residue and tilled a shallow layer of soil in front of the disk creating a tilled furrow for the planter shoe.

Work done in Northeast Oregon showed that it was more effective to provide a tilled microseedbed than to follow a conventional tillage program. The use of a strip till planter in dryland cereal production proved more effective in conserving soil moisture. Seed was placed in good contact with moist soil as compared to either zero till or conventional tillage furrow openers (Bolton and Booster, 1981).

Chapter III

BASIC DESIGN

3.1 INTRODUCTION

In general zero till drills have been built very heavily so that the furrow openers will be able to penetrate hard soil. The extra weight of the seed drills requires a strong frame and rather high draft forces are required. High powered tractors with their great mass lead to increased soil compaction.

The disk type furrow opener and the hoe type furrow opener or combinations of the two do not produce all of the requirements for optimum seed germination and early seedling growth environments. Disk furrow openers have difficulty penetrating compacted soils. When the furrow openers penetrate the soil sufficiently seed is placed uniformly with minimum soil disturbance. But seed coverage is often only marginal. Hoe type furrow openers place the seed less uniformly but with good soil-seed contact. The hoe type furrow opener can achieve good soil penetration but only with an undesirable high level of soil disturbance. None of the furrow openers above have been able to handle large amounts of residue efficiently or effectivly.

3.2 INITIAL DESIGN CONCEPT

The ideal furrow opener for zero till seeding should be able to cut through a layer of residue, create a seed furrow in a compacted soil, place separate bands of fertilizer and seed into the furrow and refill that furrow with soil. This whole process should take place with minimum soil disturbance if the existing desirable soil properties due to zero till conditions are to be preserved.

A layer of residue can be cut with a powered disk. The problem is to move soil out of the furrow and then back into the furrow after the fertilizer and seed bands have been placed. A powered disk rotating in the opposite direction to the direction of travel can lift the soil and carry it around the periphery of the disk inside a shield. Seed and fertilizer can be placed in the furrow before the soil is deposited back into the furrow.

The important components in the above design concept are the disk with its specific tooth form, the base plate with a ledger plate, the shielding to guide and split the soil flow and the fertilizer and seed spouts (Figure 1).

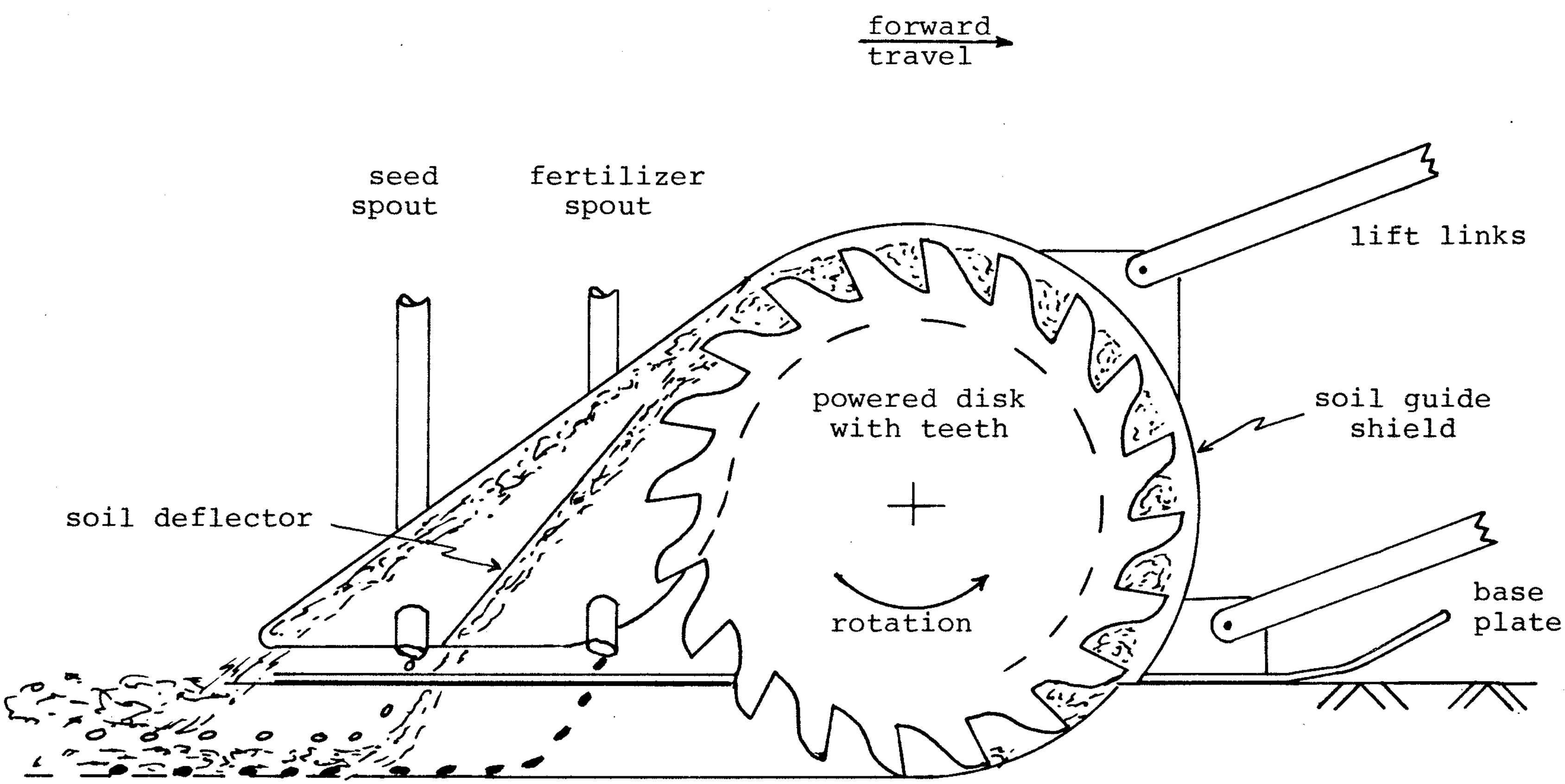

Figure 1: Design concept of the powered zero till furrow opener

3.3 OPENER DIMENSIONS

Since the furrow opener is primarily intended to seed cereal grains under zero till conditions row spacings of 200 mm to 250 mm have to be assumed. Seeding depths of 25 mm to 40 mm have been considered adequate in western grain belt conditions. To achieve good seed placement the furrow width has to be at least 12 mm. This furrow width will provide ample space for the correct placement of seed and fertilizer.

The initial diameter of the disk was 300 mm based on a power till disk design by Smith, Haminett and Thomson (1979). The dimensions of the base plate were set larger than might have been necessary but this was to allow for any design alterations as determined later. The shielding was designed to demonstrate the concept of moving the soil around the periphery of the disk and to guide the soil back into the slot cut into the soil. The discharge angle for the soil streams was set sufficiently large to accommodate a splitting of the flow and to allow for the mounting of the fertilizer and the seed spouts. The prototype was built by connecting most of the components with screw fasteners. This technique allowed alterations to be made easily. Some of the opener dimensions were also governed by the materials available to construct the unit.

3.4 DISK DESIGN

The need to penetrate the soil to a maximum depth of 50 mm determined the overall disk diameter. Furthermore, it was necessary to have a sufficient number of teeth on the circumference of the disk so that residue could be cleanly cut at high forward speeds. A small disk diameter would reduce the height the soil had to be lifted from the furrow. A shorter circumference would reduce the power requirements to overcome the friction forces between the soil and the shield. To achieve the desired furrow shape a disk with a diameter of 300 mm and a thickness of 12.7 mm was used.

To cut efficiently and effectivly through a layer of residue under zero till conditions the cutting pitch of the disk was initially set equal to the diameter of one straw, approximately 5 mm. Another criterion to be met was that the centrifugal acceleration of the soil at the top of the disk should not be less than the force due to gravity. This was necessary to eliminate the possibility that the soil flow would stall during the lifting of the soil in the first part of the guide shield. The minimum limiting angular velocity was calculated as follows:

gravity force = force due to angular acceleration

$$m\ g = m\ r\ w^2 \qquad (1)$$

where m = mass of soil volume, kg

g = gravitational constant, m s^{-2}

(9.81 m s^{-2})

r = disk radius, m

w = angular velocity, rad s^{-1}

Solving for w gives:

$$w = 8.09 \text{ rad s}^{-1}$$

$$\text{or} \quad N = 77.2 \text{ rev min}^{-1}$$

In the course of designing the cutting disk literature was reviewed dealing with the design of rotary tillers. Hendrick and Gill (1971 a,b,c) reviewed several publications for design criteria for rotary tillers turning opposite to and in the direction of travel. Most of the measurement and analyses on the rotary tillers were done with the units running at an angular velocity between 150 and 320 rev/min. The rotor radii of the tillers were between 160 mm and 320 mm. Therefore the angular velocity of the cutting disk was assumed to be 300 rev/min for the initial calculations. The angular velocity of 300 rev/min exceeded the minimum angular velocity of 77 rev/min.

The next factor to be determined in the disk tooth design was the forward speed at which the opener should travel during a normal seeding operation. Six kilometers per hour was assumed to be adequate to obtain a reasonable work rate under actual field conditions. Many manufactures claim that their zero till seeding units will operate effectively at forward speeds in excess of 8 km/h.

With the above information the number of teeth on the blade was calculated with the following formula (Hendrick and Gill, 1971 a):

$$z = (v * 2 * PI * R) / (u * L) \qquad (2)$$

where
- z = number of teeth
- v = forward speed, m s^{-1}
- R = radius of the blade, m
- u = peripheral velocity of the blade, m s^{-1}
- L = cutting pitch, m

The number of teeth on the disk circumference would have to be 66 based on a forward speed of 1.66 m/s (6 km/h), an angular velocity of 300 rev/min and a pitch of 5 mm.

It was concluded from scale drawings that about 20 to 25 teeth could be accommodated on a powered cutting disk with a radius of 150 mm. The powered tillage disk developed to clear residue and to till the soil in front of a furrow opener was designed with 12 teeth on a disk of 150 mm radius (Smith, Haminett and Thomson, 1979). A small number of teeth on the disk would have required a very high angular velocity to keep the cutting pitch reasonable. A disk with

12 teeth operating with a large cutting pitch of 13 mm would require an angular velocity in excess of 630 rev/min.

Another criterion used in selecting the number of teeth on the disk was the amount of soil that had to be lifted out of the seed furrow and accommodated between the teeth. With a small number of teeth on the disk a large amount of soil would have to be moved by each tooth.

A range of inputs was computed using equation 2 to find the best combination for the angular velocity of the disk, the number of teeth on the disk and the cutting pitch. The limits for these inputs were set at 550 rev/min for the angular velocity, 25 teeth for the number of teeth on the cutting disk and 10 mm for the cutting pitch.

The initial design of the powered furrow opener had 20 teeth and was operated at an a angular velocity of 540 rev/min with a cutting pitch of 9 mm. The forward design speed of the furrow opener was 6 km/h. In addition tooth design had to ensure adequate strength to prevent any bending due to very compacted soil or stones. The wear characteristics of the tooth were also considered.

The volume of soil that had to be lifted by each tooth is illustrated in figure 2. The volume was calculated by the following approximate formula (Hendrick and Gill, 1971 a):

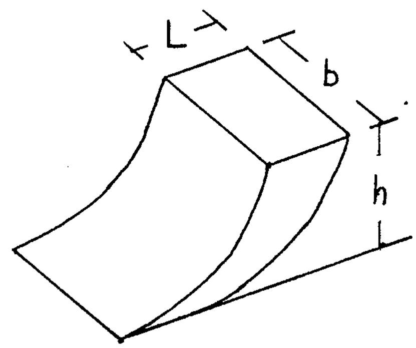

Figure 2: Volume of soil slice

$$\text{Volume} = h * L * b \qquad (3)$$

where h = depth of operation, mm

L = cutting pitch, mm

b = width of cut, mm

The depth of a tooth was approximated by setting the volume of a soil slice cut by one tooth equal to the volume available between two adjacent teeth. The volume between two teeth was approximately a triangular shape, where c was the base, a the height and b the width (Figure 3). A factor of 0.75 was used to provide for a decrease in bulk density of the soil. The soil before cutting would have a higher bulk density than the soil between the teeth of the disk. Furthermore, some clearance was required at the tip of the tooth for cutting the residue. Equating the volume of equation 3 to the volume between two teeth gives:

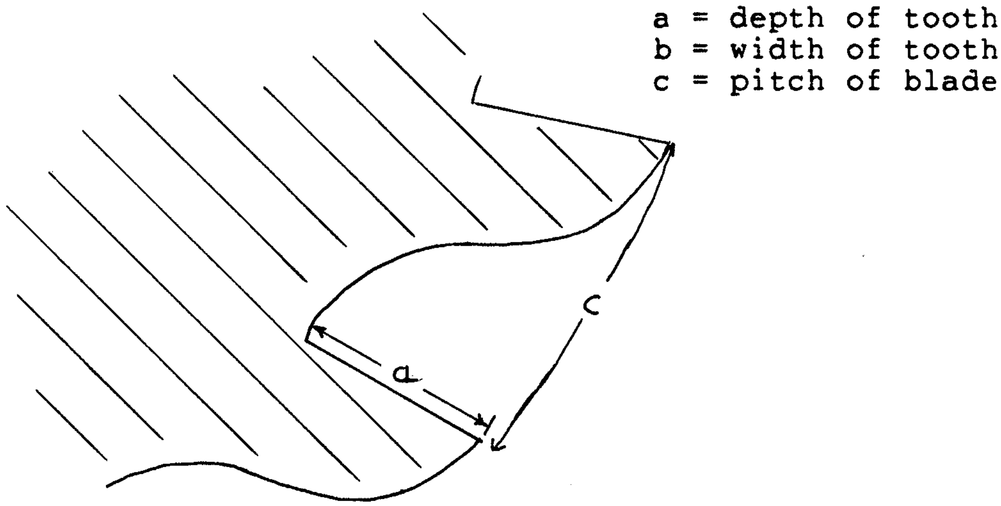

Figure 3: Tooth shape

$$0.75\ (a * b * 0.5 * c) = h * L * b \qquad (4)$$

where a = depth of the tooth, mm

b = width of the tooth, mm

c = pitch of the blade, mm

Solving equation 4 for a gives:

a = 28 mm

The clearance angle of the tooth was obtained graphically by overlaying the pathways of two consecutive teeth tips (Figure 4).

The pathways of two consecutive tooth tips were calculated as curves in an X-Y coordinate system. X and Y were com-

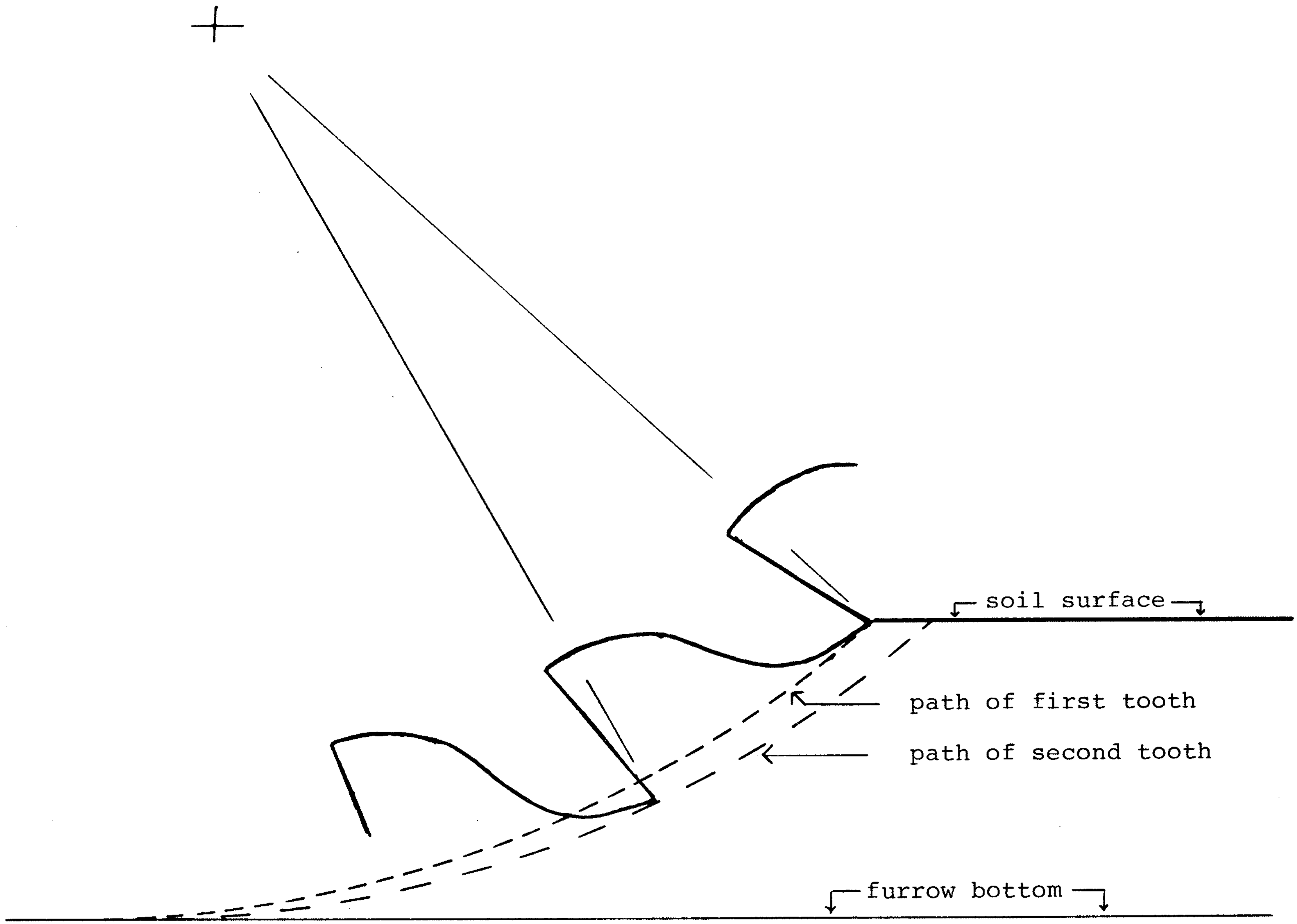

Figure 4: Pathways of two consecutive teeth

puted with respect to time. The origin of the coordinate system was at the center of the disk at time zero. The difference between the first and the second tooth pathways was determined by subtracting the appropriate time lag between the first and second tooth pathways from the equations (Appendix A).

The lead angle of the teeth was limited to 10 degrees. The lead angle ensured a favorable shearing action between the tooth edge and the ledger plate. A greater lead angle would have provided a better shearing action of the residue and a better lifting action of the soil. It was important that all the soil should clear from between the teeth. This would not be ensured with a large lead angle. Also, a large angle would reduce the strength of the tooth.

The disk was mounted on the shaft of a 90 degree angle drive gear box. The gear box was connected to the base plate with a mounting bracket. The gear ratio in the gear box was one to one with the incoming and the outgoing shafts both turning in a counter-clockwise direction. The incoming shaft was in line with the direction of travel. A drive shaft with two universal joints connected the gear box and a mandrel jack shaft on the toolbar. The two universal joints made vertical movement of the opener assembly, with respect to the toolbar, possible. This mounting system made any alterations to components of the unit convenient as the disk and the shield were easily accessible from one side.

To reduce the inertia forces that would develop when a large mass was rotated at high speeds the middle section of the cutting disk was reduced in thickness to 6 mm. The reduction started at a radius of 35 mm and continued to a radius of 110 mm.

3.5 BASE PLATE

The base plate was 200 mm wide, 650 mm long and 6 mm thick. A slot 20 mm wide through which the cutting disk protruded had a length of 475 mm and was open at the rear end. The two functions of the base plate were to form the top edge of the seed furrow and to support a ledger plate against which the residue could be cut.

A tillage tool moving out of the soil in an upward direction would lift an inverted pyramid of soil because the soil would shear in tension at a 45 degree angle to the soil surface. With the soil at the surface confined in the upward direction by the base plate the soil was sheared parallel to the direction of the peripheral movement of the cutting tooth. Therefore soil was lifted only through the slot in the plate and the disk produced a seed slot with a rectangular shaped cross section.

The front of the base plate was bent up in two steps. This allowed the unit to slide easily over the soil surface and over thick layers of residue.

An imbedded ledger plate at the front of the slot in the base plate provided the shearing edges for the cutting of the residue. The length of the ledger plate along the slot exceeded the depth of the teeth by about 5 mm. The clearance between the teeth and the shearing edge on the ledger plate was kept as small as possible to provide for good cutting action. To compensate for a slight amount of off-center rotation of the disk the clearance had to be increased to 1.5 mm. The clearance between the tips of the teeth and the front edge of the ledger plate was 2 mm. The clearance angle at the front edge of the ledger plate was about 5 degrees.

3.6 GUIDE SHIELD

The guide shield began directly on top of the ledger plate. The shield formed a semicircle around 180 degrees of the cutting disk. The clearance between the teeth tips and the shield was 12 mm. After the 180 degree point the top of the shield followed a tangential line creating an angle of 35 degrees to the horizontal. The shield ended 20 mm above the base plate. The width of the top shield was 25 mm. With this width the friction between the soil carried by the teeth and the shield could be reduced. The clearance of 6 mm between the shield and the side of the teeth meant that the tolerances for the construction of the unit could be kept more liberal.

Initially the sidewalls of the shield had a height of 20 mm. Since most of the soil was thought to be transported between the teeth of the cutting disk it was thought that this height would be sufficient. But it was observed that some soil was lifted from the furrow on the side of the disk. This soil was not confined by the sidewalls of the shield and was thrown out to the side of the disk. To confine all of the soil cut and transported by the disk the sidewall height was increased to 55 mm. The region where the soil flow was divided was totally covered by the side shields.

3.7 SEED AND FERTILIZER PLACEMENT

The soil that was picked up and carried around the disk was divided by inserting a soil deflector into the soil stream. The flow was divided horizontally, that is the left half of the soil stream was diverted downward by the soil deflector whereas the right half of the flow continued on its path along the tangential section of the shield.

The soil deflector was attached to the top shield at the transition point between the arc section and the straight section of the shield. The deflector formed an angle of 50 degrees with the horizontal and ended 20 mm above the base plate. A fertilizer tube was placed closely behind the cutting blade and ended 10 mm above the base plate. A seed spout was located directly behind the soil deflector and also ended 10 mm above the base plate. To minimize any interference of the soil flow by the spouts the spouts were mounted vertically on the outside of the sidewalls of the shield. The spouts were bent at 45 degrees about 40 mm above the base plate so that their discharge points were directly over the soil slot.

3.8 MOUNTING OF THE OPENER

The powered furrow opener was mounted for testing on a toolbar with a parallelogram linkage. Because of this linkage the base plate followed the soil surface closely. The base plate remained relatively parallel to the soil surface so that the disk penetration depth was not affected. If the furrow opener had tipped down at the front of the base plate it would have started to push residue ahead of the furrow opener.

Chapter IV

TEST PROCEDURES

4.1 INTRODUCTION

The testing of the powered zero till furrow opener was done in three steps. First, the basic physical principle was evaluated. Second, the specific components of the design were tested and alterations were made where required. Third, the powered furrow opener was assessed as a zero till seeding implement.

4.2 TESTING OF THE PRINCIPLE

Prior to the construction of the prototype a handheld circular saw was used to investigate the physical principle of transporting soil around the periphery of a cutting disk. The electric saw was equipped with a guide shield around a standard saw blade with a diameter of 177 mm. This shield was similar to the guide shield used with the power till furrow opener. The saw had a power rating of approximatly 1000 W and a no load angular velocity of 5800 rev/min. The saw was set at a depth of 40 mm and was run in the soil of a soil bin. Only very slow forward speeds could be achieved before the saw motor would stall. The test did indicate that the principle of moving soil around the periphery was valid.

The prototype of the powered furrow opener was tested in the soil bin located in the laboratory of the Agricultural Engineering Department. The soil bed was 1500 mm wide, 15000 mm long and contained sandy loam (Elm Creek sandy loam) to a depth of 600 mm. The soil moisture content ranged between 8 and 12 percent. The soil bin carriage could travel over the full length of the soil bed with speeds from 0.2 to 1.7 m/s (Figure 5).

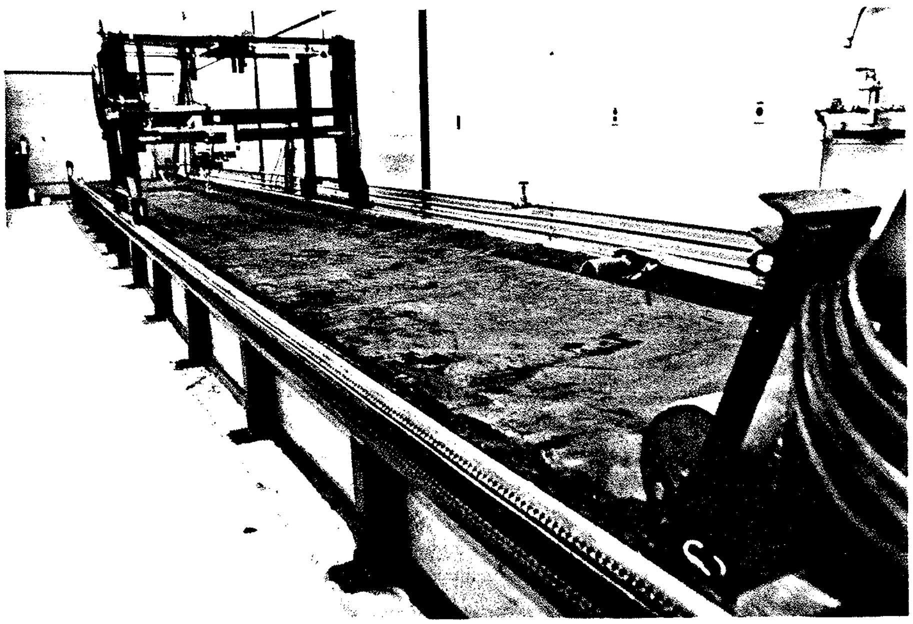

Figure 5: Soil bin with carriage

During all of the tests in the soil bin the powered opener was mounted on the carriage toolbar and driven by a 750 W electric motor. The motors angular velocity was 1700 rev/min. A V-belt and pulley speed reduction unit was used to drive the opener drive shaft at 500 rev/min. The first trial runs with the furrow opener were taken in soil that had been compacted to a compaction level comparable to levels found in a stubble field with the same soil type. The performance of the power till furrow opener was observed in order to make a qualitative assessment of the opener concept. The design of the individual components was altered as necessary. This procedure was repeated until the general performance of the opener was acceptable. Then the locations of the soil deflector and the mounting of the seed and fertilizer spouts were determined following the same procedure.

4.3 SEED AND FERTILIZER PLACEMENT

To determine the uniformity of the seed and fertilizer placement the soil bin carriage was fitted with a seed box assembly (Figure 6). The seed box metering system was driven with an electric gearhead motor. The seed rate and fertilizer rate were set at approximately 180 kg/ha when the carriage traveled at a forward speed of 5 km/h with a row spacing of 200 mm. Plain seed wheat was used in the seed spout and wheat treated with food colouring was used for the fertilizer spout.

The first run was taken at a speed of 2 km/h in very compacted soil. Three more runs were taken at 3, 4 and 5 km/h in less compacted soil. The seed and fertilizer placement

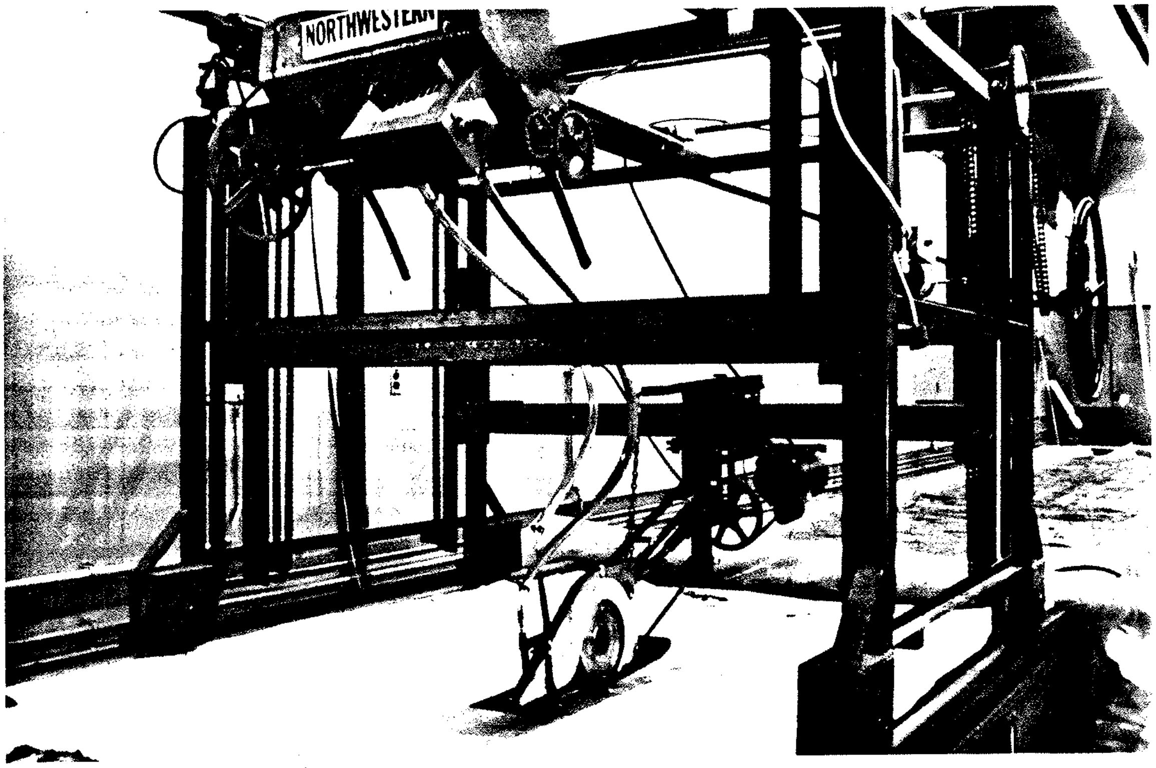

Figure 6: Seeding apparatus

values were obtained by digging up the kernels representing seed and fertilizer. Two 500 mm long furrows were dug up for each run and the depth of each kernel was recorded. A relationship between forward speed and seed placement was investigated.

4.4 FIELD TESTS

The powered furrow opener was evaluated in two steps under field conditions. The opener was mounted on an auxilary toolbar. The auxilary toolbar was attached to the three-point-hitch of a 150 MASSEY FERGUSON tractor. The auxiliary toolbar consisted of a three point mounting triangle with a connecting frame to the toolbar and two gage-wheels for depth control. A platform on the connecting frame was used to transport the recording instruments during the second set of field trials (Figure 7). The powered furrow opener was driven with the tractor power-take-off (pto) through a drive shaft.

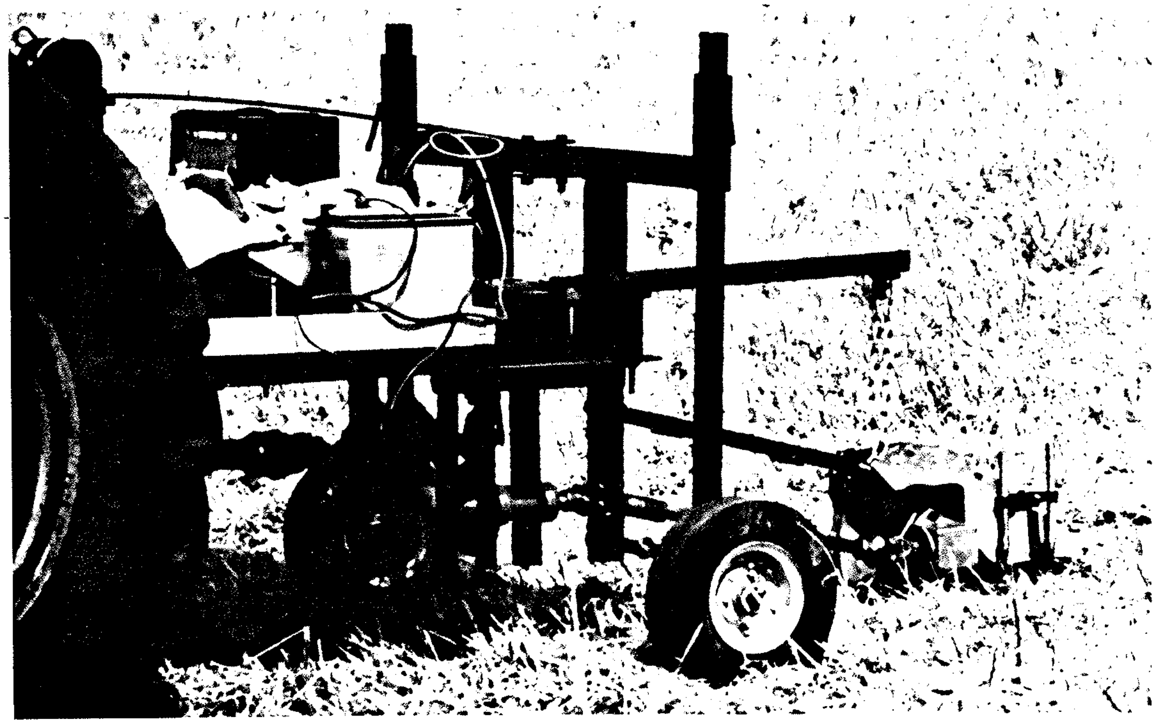

Figure 7: Field apparatus with instrumentation

The first field tests were performed without any instrumentation. The purpose of the tests was to obtain a qualitative evaluation of the unit under field conditions. The test field was a 5 year old pasture of crested wheatgrass. The soil moisture content was estimated at 12 percent and the field was very compacted. The surface residue consisted of 50 mm long grass. There was also a well developed sod layer. The focal point of the test was to observe the ability of the powered furrow opener to penetrate compacted soil and to cut through a layer of residue. Runs were taken at forward speeds of about 3, 4.2 and 5.2 km/h.

4.5 MEASUREMENT OF THE POWER REQUIREMENT

The second field tests dealt with the evaluation of the opener in stubble field conditions. The powered furrow opener was instrumented to measure the power input. The instrumentation consisted of a torque transducer and an angular velocity meter. The torque transducer was a cantilever arm mounted radially on the drive shaft connected to the tractor pto shaft. The cantilever arm drove a sprocket that was free to rotate on the drive shaft.

The incoming torque from the tractor pto was transmitted through the cantilever arm to the sprocket. A roller chain transmitted this torque from the first sprocket to a second sprocket fixed to the opener drive shaft. The sprocket-roller chain assembly had a one to one speed ratio. When the tractor pto had a speed of 540 rev/min, the cutting disk operated at 540 rev/min. The torque transmitted from the drive shaft to the sprocket through the cantilever arm induced a bending moment in the cantilever arm.

The strain due to the bending moment was sensed with strain gages mounted on both sides of the cantilever arm. The amplified signals from the half bridge were recorded on the first channel of a two channel BRUSH MARK 220 recorder. A calibration curve related pen displacement to torque.

The angular velocity was sensed by a reed switch circuit. A magnet was mounted on the circumference of a 120 mm diameter disk turning with the pto drive shaft assembly. A reed switch completed a circuit when the magnet passed by the switch once per revolution and sent a pulse to the second channel of the recorder. The angular velocity of the shaft was determined by relating the number of pulses per 100 mm of chart paper to the chart paper feed rate.

The tests were done in a barley field that had been harvested 10 days prior to the testing date. The field was located in the Winnipeg Fort Garry area and the soil type was classified as Red River clay. The soil moisture content at the time of testing was 20.5 percent. Cone index values increased with increasing depth (0 mm to 70 mm) from 0 kg/cm^2 to 14.3 kg/cm^2 for the looser soil and from 0 kg/cm^2 to 24.1 kg/cm^2 for more compacted soil. The cone index measurements were done according to the ASAE Standard: ASAE S313.1.

The yield of the barley crop was about 3600 kg/ha. Assuming a ratio of 1 to 1.1 grain-to-straw the residue cover was approximately 3900 kg/ha. The height of the anchored stubble averaged about 200 mm and the residue had been spread reasonably well by the combine straw chopper. Five tests were made for data collection. Two forward speeds of

2.81 km/h and 5.16 km/h were used. Due to the gear ratio of the tractor it was not possible to travel at 6 km/h. The first test was used to adjust the instruments properly. The other four tests were run at two speeds in either relativly loose soil or in firm soil. The firm soil conditions were encountered in areas where the combine wheels had traveled during the harvest operation. Data were collected for each test from the torque transducer and the angular velocity meter. In addition the performance of the opener with respect to penetration and residue handling was qualitatively evaluated for each test run.

Chapter V

RESULTS

5.1 PRINCIPLE DESIGN

The tests of the powered furrow opener in the soil bin showed that the cutting disk and guide shield assembly was able to cut a furrow in compacted soil and was able to transport soil around the periphery of the cutting disk and to reintroduce the soil into the furrow.

Only low forward speeds could be used in the more compacted soil in the soil bin. The power requirements for the opener were greater than the 750 W available with forward speeds greater than 3 km/h. The side shielding had to be increased in size because soil was thrown out from under the shielding. The expanded shielding was required mainly in the front area of the guide shield where the soil was lifted up. The tests also revealed that the clearance between the top shield and the tooth tips could be reduced to 5 mm.

Soil was deposited on the inside of the shield and formed a molded channel with a very small clearance to the tooth tips. This phenomenon persisted during all of the test runs in the soil bin and to a lesser degree in the field tests. Very dry conditions in the field tests in the pasture resulted in no deposit of soil under the front part of the shield.

The furrow cut by the disk had a rectangularly shaped cross section. This furrow was nearly completely refilled with the soil transported around the periphery. No bridging of the soil took place within the furrow. The recompaction of the furrow was so complete that the shape of the furrow was barely distinguishable when a furrow cross section profile was taken during the soil bin trials. The shape of the furrow was noticeable in the field trials as the soil in the furrow was looser with finer aggregates compared to the undisturbed soil next to the furrow. Since the bulk density of the replaced soil was less than the bulk density of the undisturbed soil next to the furrow a ridge of soil was left on top of the furrow.

The first tests with the soil defector produced a problem. The initial deflector design had the leading point approximately half as wide as the shield width increasing to the full shield width at its endpoint 20 mm above the base plate. Since the sandy loam in the soil bin had no natural soil structure and was rather adhesive even at low moisture content the soil tended to accumulate under the shielding. This resulted in plugging of the triangular opening along the side of the soil deflector. The soil flow was not divided and all of the soil was refilled into the furrow at the front of the soil deflector. Increasing the size of the opening between the deflector edge and the side shielding reduced this problem in the soil bin trials and the soil flow was nearly evenly divided. This problem was not encountered in the field trials. Some residue started to accumulate at the trailing edge of the triangular opening and possibly could have caused plugging.

The tooth design proved to be adequate for the transport of the soil around the periphery of the disk. At the correct speed of the disk the soil was transported between the teeth and discharged nearly completely at the point where the top shield changed from the curved to the straight section. Only a small amount of soil stayed on the cutting surface of the teeth and at the bottom of the teeth notches. This was mainly soil with a higher moisture content and higher adhesive characteristics. But soil did not accummulate over time in these areas.

An endurance test was not planned for this prototype opener. But the location of the polished areas on the cutting disk showed that the tips and edges of the teeth would wear the most.

5.2 SEED AND FERTILIZER PLACEMENT

The four seed placement tests showed very good separation between the fertilizer band and the seed band. The differences between the depth of seed bands and the depth of fertilizer bands was significant at the 0.1 percent level for all four tests. The fertilizer banding depths had low variances compared to the variances of the seed banding depths.

Since a different soil deflector was used during the 2 km/h seed placement run compared to the other runs, only the 3, 4 and 5 km/h runs were analyzed statistically.

It was not possible to test the seed placement at a forward speed of 6 km/h. Therefore, the seed placement at forward speeds of 3, 4 and 5 km/h was analyzed to confirm that postive seed placement took place. Positive seed placement means that seed is placed into its final position not only by gravitational forces but also by presswheels, airstreams or as in this case by a soil stream.

The positive placement due to the soil stream occured when the first half of the soil stream was introduced back into the furrow pushing the fertilizer band onto the bottom of the furrow. The second half of the soil stream forced the seed band into position. Since the splitting of the soil stream was independent of the forward speed of the opener it was concluded that the seed placement data at 3 km/h forward speed would be very similar to the data at 6 km/h forward speed. The analysis of variance table showed that the seed band depths did not differ for the three forward speeds of 3, 4 and 5 km/h (Appendix B).

5.3 FIELD PERFORMANCE

Soil penetration could only be evaluated in field trials. The penetration in the soil bin was always excellent because the soil surface was level and the forward speeds of the opener for runs through firm soil were less than the design speed. The soil penetration in the field was reduced either by very compacted soil, an uneven soil surface or a thick layer of residue. The penetration of the powered opener was good even in the very hard soil conditions of the pasture.

When the soil was very hard, as in the pasture or in very compacted areas of the barley field, the cutting disk required high input torques. The reaction torque in the parallelogram linkage tended to twist the opener assembley and lifted the base plate off the soil surface on one side. This resulted in reduced penetration of the cutting disk. An alternative drive system, for example a chain drive such as used on the JOHN DEERE POWR TILLER (PAMI report E2577), could eliminate this problem.

The unit showed good ability to cut through residue. The residue in the 13 mm wide path of the furrow was mulched into small pieces and transported with the soil stream back into the furrow. The residue was cut cleanly at the edges of the furrow and the adjacent residue was not disturbed to any great degree. It was noted that the stubble on the barley field reerected itself after the opener passed over it. Only a 35 mm wide strip of the residue layer was actually effected by the powered opener.

Similar observations were made with respect to the soil disturbance due to the opener. A slot 13 mm wide was tilled intensively. Some soil not replaced into the furrow was scattered over a width of approximately 25 mm. A very distinct furrow was cut into rather hard soil and there was no soil shattering apparent in the soil adjacent to the furrow.

The power measurements showed that the power requirements depended more on the compaction level of the soil than on the forward speed of the opener. Only the direct power input to the disk for rotation was measured. The measurement of the draft requirements for the opener was not done. The power inputs to the opener varied substantially during each test run (Appendix C). This was due to the variation in soil compaction and in the thickness of the residue layer. The variation in soil compaction could be identified on the recorded chart. Sections of larger or smaller deflections on the chart paper corresponded to the opener being operated in firmer or looser soil during a test run. Average readings were taken over the sections. Peak torque readings were neglected for the calculation of the input power even though they were substantial in some instances. These peak torque readings would have to be considered in the design of the drive train to the opener. The input power was calculated using the measured angular velocity of the cutting disk and the high average reading of input torque for each run. The input power for loose soil conditions was 0.990 kW and 1.260 kW at forward speeds of 2.8 km/h and 5.2 km/h, respectively. In firm soil the power requirements increased to 1.700 kW and 2.600 kW at 2.8 km/h and 5.2 km/h forward speeds, respectively.

Chapter VI

CONCLUSION

The concept of transporting soil out of a furrow around the periphery of a cutting disk and back into the same furrow proved to be feasible. The soil stream was guided over the cutting disk and replaced into the furrow in two portions using a shield and soil deflector system. In this way a band of seed and a band of fertilizer were separated with a layer of soil.

This design of a powered furrow opener could be adapted as a zero till furrow opener. The unit is capable of penetrating compacted soil through large amounts of residue, placing and covering separate bands of seed and fertilizer uniformly with only minimum soil disturbance. The power requirements for this powered furrow opener were up to 2.6 kW per opener which is considered reasonable for zero till seed drills.

Chapter VII

RECOMMENDATIONS

1. For a better understanding of the powered furrow opener's capabilities under zero till conditions more tests are required under different field conditions.
2. A design modification is needed to permit changes in seeding depth. The adjustment could be accomplished either with an adjustable soil defector or by setting different penetration depths of the cutting disk.
3. If the unit were to be used as an opener on a zero till drill the dimensions of the base plate, the drive assembly and the mounting system would have to be reevaluated. Surface hardening of the teeth on the cutting disk, of the ledger plate edges and of certain guide shield areas would be required for adequate service life.

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Appendix A

CUTTING TOOTH DESIGN

Pathways of Two Consecutive Teeth

The pathway of one tooth is calculated first. The origin of the X-Y coordinate system is at the center of the cutting disk at time t=0. The X coordinate is equal to 0.150 m and the Y coordinate is equal to 0 at time t=0.

X and Y are calculated with respect to time by the following equations:

$$x = v*t + r*\cos(w*t)$$

$$y = r*\sin(w*t)$$

where v = forward speed, m/s
r = radius of the disk, m
w = angular velocity, rad/s
t = time, s

The pathway of the second tooth is calculated by introducing a time delay equal to the time required for the disk to turn one twentieth of a revolution.

$$t_2 = t_1 - ((1/9) * (1/20))$$

Appendix B

SEED AND FERTILIZER PLACEMENT

<u>Raw Data (Fertilizer)</u>

Number of Kernels per Depth Zone

Depth (mm)	Forward speed (km/h) 2		3		4		5	
	Samples							
	I	II	I	II	I	II	I	II
0-5	-	-	-	-	-	-	-	-
5-10	-	-	-	-	-	-	-	-
10-15	-	-	-	-	-	-	-	-
15-20	-	1	-	-	-	-	-	-
20-25	-	-	-	-	-	-	-	-
25-30	2	2	-	-	-	-	-	-
30-35	1	-	-	-	-	-	-	-
35-40	1	-	-	-	5	-	-	-
40-45	13	7	6	2	15	5	8	4
45-50	38	46	21	20	25	21	20	12
50-55	6	8	5	16	-	4	3	1
total number of kernels	61	64	32	38	45	30	31	17
weighted average depth (mm)	45.9	46.5	47.3	49.3	44.7	47.3	46.7	46.6

Raw Data (Seed)

Number of Kernels per Depth Zone

Depth (mm)	Forward speed (km/h) 2		3		4		5	
	Samples							
	I	II	I	II	I	II	I	II
0-5	–	–	–	–	–	–	–	–
5-10	–	–	–	–	–	–	–	1
10-15	–	–	–	–	–	–	–	1
15-20	–	4	5	–	2	3	3	4
20-25	15	20	16	3	10	4	7	5
25-30	40	52	14	13	15	13	20	16
30-35	22	24	12	19	13	9	7	8
35-40	3	5	–	10	7	9	2	4
40-45	–	–	–	4	–	–	–	–
45-50	–	–	–	1	–	–	–	–
50-55	–	–	–	–	–	–	–	–
total number of kernels	80	105	62	50	47	38	39	39
weighted average depth (mm)	28.3	27.8	28.5	32.7	28.9	29.7	27.2	27.0

T-Test for Fertilizer and Seed Placement

Calculation: 3 km/h forward speed sample I

fertilizer

$n_1 = 38$ $\bar{x}_1 = 49.48$ $s_1^2 = 8.677$

seed

$n_2 = 50$ $\bar{x}_2 = 32.70$ $s_2^2 = 30.571$

$$s^2 = ((n_1-1)s_1^2+(n_2-1)s_2^2))/(n_1+n_2-2) = 21.155$$

$$s_{12} = (s^2(1/n_1+1/n_2))^{0.5} = 0.9898$$

$$t = (\bar{x}_1 - \bar{x}_2)/s_{12} = 16.85$$

$$t_{.001,120} = 3.373$$

forward speed 2 km/h sample I: $t = 23.83$

forward speed 4 km/h sample I: $t = 16.47$

forward speed 5 km/h sample I: $t = 20.08$

The t-tests show that the depth of the fertilizer bands and the seed bands are different at all four forward speeds.

F-Test for Seed Placement Uniformity

The ANOVA table is based on the mean depth of the seed bands for the runs at 3, 4 and 5 km/h forward speed.

ANOVA Table

	df	SS	MS	F
Treatment	2	12.31	6.155	
Error	3	9.35	3.116	1.975
Total	5	21.66		

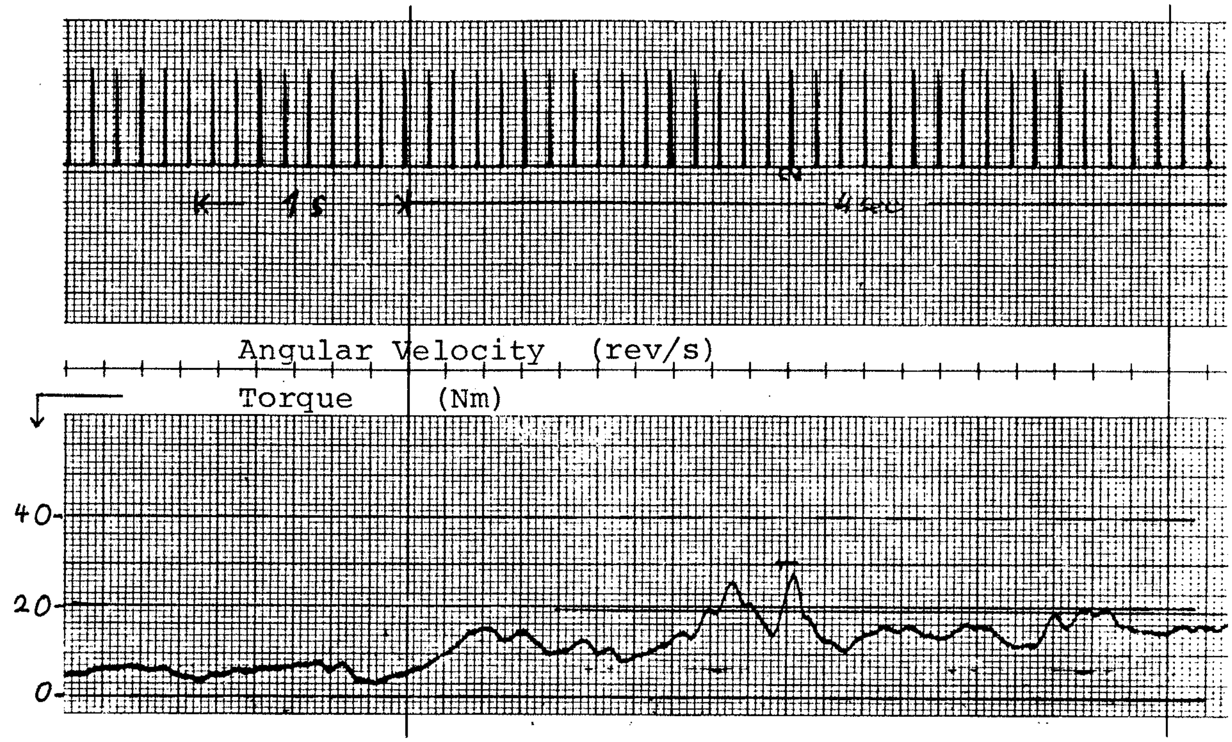
$F_{2,3,0.1} = 5.46$

We reject that the seed placement depths are different.

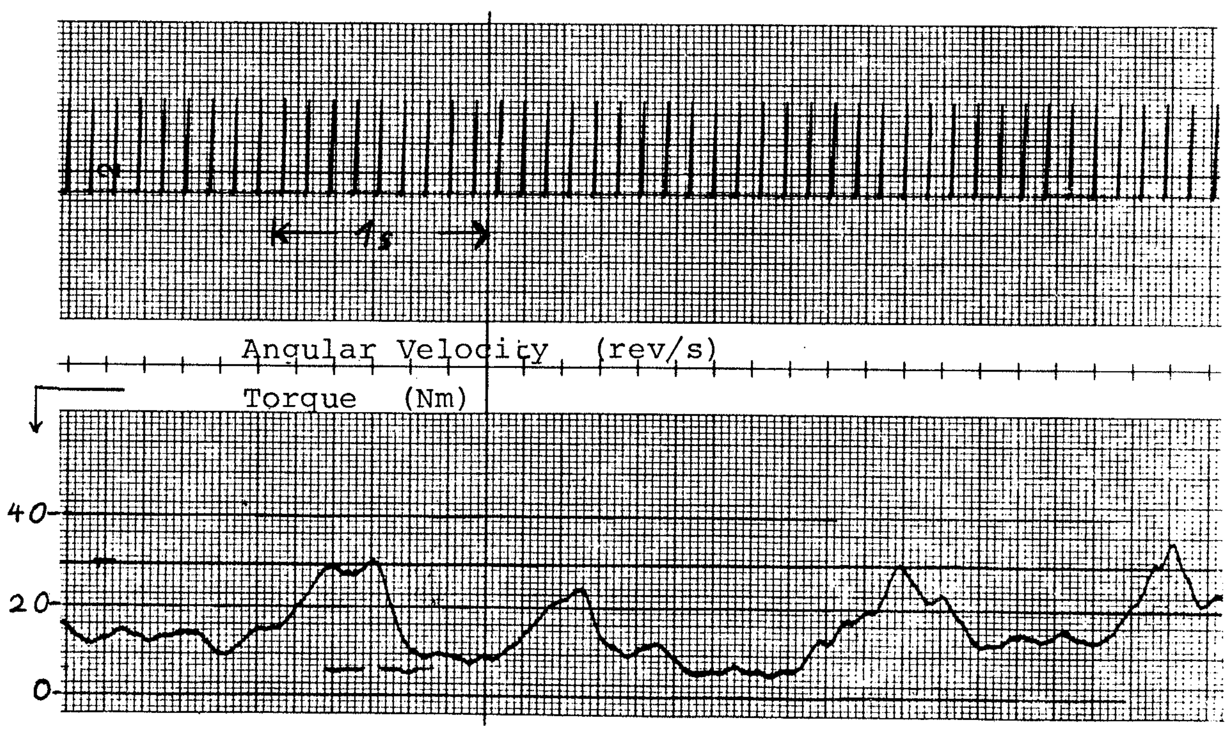
Appendix C

POWER INPUT MEASUREMENTS

Raw Data - Samples of the Recorder Output



Run I , loose soil, 2.8 km/h forward speed, test 1



Run IV , firm soil, 2.8 km/h forward speed

Power Input Data

Runs

I loose soil, 2.8 km/h forward speed, test 1

II loose soil, 2.8 km/h forward speed, test 2

III loose soil, 5.2 km/h forward speed

IV firm soil, 2.8 km/h forward speed

V firm soil, 5.2 km/h forward speed

Power calculation:

$$p = d * s * w * 2 * PI$$

where p - power input to the disk, W

d - value of the high average deflection on the chart, mm

s - calibration equation slope at either 50 mV or 100 mV instrument sensitivity, Nm/mm

w - angular velocity of the disk measured as pulses per chart distance times the chart feed rate, rev/s

Power inputs

run	d (mm)	s (Nm/mm)	w (rev/s)	p (W)
I	17	1.31	9.0	1259
II	6.5	2.32	9.25	990
III	13	1.31	9.0	963
IV	22	1.31	9.25	1675
V	36	1.31	8.75	2592

Error Analysis

The uncertainties of the power input measurements originate from the reading of the deflection, Δd, the calibration of the transducer, Δs, and the determination of the angular velocity, Δw. This error analysis applies to individual power measurements only. Average power measurements over a test run vary as the soil compaction continually varied.

Sample calculations of the uncertainty of the power input for run IV.

p = d * s * w * 2 * PI

d = 22 mm	±	0.5 mm
s = 1.31 Nm/mm	±	0.03 Nm/mm
w = 9.25 rev/s	±	0.25 rev/s

$$\Delta p = ((A\ \Delta d)^2 + (B\ \Delta s)^2 + (C\ \Delta w)^2)^{0.5}$$

Note: A, B and C are partial differential equations.

A = dp/dd = 1 * s * w * 2 * PI
= 1 * 1.31 * 9.25 * 2 * 3.1415
= 76.14

B = dp/ds = d * 1 * w * 2 * PI
= 22 * 1 * 9.25 * 2 * 3.1415
= 1278.63

C = dp/dw = d * s * 1 * 2 * PI
= 22 * 1.31 * 1 * 2 * 3.1415

$$= 181.08$$

$$\Delta p = ((76.14*0.5)^2+(1278.63*0.03)^2+(181.08*0.25)^2)^{0.5}$$

$$= 70.50 \quad W$$

$$p = 1675 \quad W$$

The percent uncertainty for this specific measurement of power input was probably no larger than ± 4.2 percent.

The measurements of the specific power inputs involved the following uncertainties:

Uncertainties of the power inputs in Watts

	I	II	III	IV	V
p	1259	990	963	1675	2592
Δp	58.54	72.75	50.73	70.50	96.72
precent	4.6	7.3	5.3	4.2	3.7

The values above refer to the specific calculation from the high average torques. The variation in the input torque and therefore in the input power was not considered in this analysis.

No great emphasis was placed on the measurement of the power input. The data obtained in the testing represent a reference point for assessing the feasibility of the powered disk furrow opener for use as a zero till seeding unit.