THE UNIVERSITY OF MANITOBA

DESIGN AND TESTING OF ZERO - TILLAGE PLANTING EQUIPMENT

by

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ABSTRACT

Zero-tillage studies have indicated advantages over conventional methods in reducing costs and labor requirements for seedbed preparation, in reducing soil erosion and in increasing soil moisture for plant growth and crop yield. There has been no machinery specifically designed for zero-tillage planting.

In this study a zero-tillage planting machine was designed by attaching cutting disks ahead of the furrow-openers on a standard pressdrill. The function of the cutting disks was to cut heavy trash and to open a small furrow for furrow openers to put seed into the soil. The additional horsepower required for the cutting disks was measured. The relationship between the additional horsepower required for the cutting disks and the depth of penetration was determined.

The machine operated very well and the cutting disks had good penetration on very fine sandy loam soils at Carman. Good penetration of the cutting disks was not initially obtained on Red River clay soil at Glenlea. Adequate penetration was obtained after the drill was ballasted with additional weight.

The additional horsepower required for the cutting disks depended on the depth of penetration, the type of soil and the speed of operation. The machine could also be used for both conventional and zero-tillage purposes.

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CHAPTER I

INTRODUCTION

Tillage has been considered one of the most important operations in crop growing. A lot of time, money and effort are spent in tillage to prepare a suitable seedbed. Tillage methods, to provide a good seedbed for plant growth, have been extensively studied. However, there is no tillage method which is suitable for all soil conditions. An unsuitable tillage method can destroy soil physical properties and soil organic matter.

In recent years, zero-tillage methods have been introduced in the United States of America in order to reduce soil disturbance, soil erosion and time and cost of seedbed preparation. Zero-tillage corn acreages in Ohio were less than 1500 acres in 1964 but they were about 50000 acres in 1969. These figures show a good acceptance of zero-tillage methods. Studies of zero-tillage in the US, Europe and Canada have indicated that zero-tillage as well as other tillage methods were not suitable for all soil conditions. Zero-tillage methods appear to have advantages on silt-loam textured soils. However, there still are two main problems with zero-tillage methods. These problems are:

1. Present herbicides have not been able to control all weeds (4).

2. There is no machine specifically designed for zero-tillage purposes.

This study was designed to overcome this second problem. The two main objectives were:

1. To fit a standard double disk pressdrill with cutting disks so that the drill would be able to plant cereal grains and oil seeds in zero-tillage conditions with heavy trash cover.

2. To determine additional horsepower requirements for operation with the cutting disks.

CHAPTER II

REVIEW OF LITERATURE

2.1. Definition of Tillage

Tillage may be defined as the mechanical manipulation of soil for any purpose. In agriculture some of the objectives of tillage are (8):

1. To develop a desirable soil structure for a seedbed or a rootbed.
2. To control weeds or to remove unwanted plants.
3. To manage plant residues.
4. To minimize soil erosion by following such practices as contour tillage, listing and proper placement of trash.
5. To establish specific surface configuations for planting, irrigating, drainage, harvesting operations, etc.
6. To incorporate and mix fertilizers, pesticides or soil amendments into the soil.
7. To accomplish segregation. This may involve moving soil from one layer to another, removal of rocks and other foreign objects, or root harvesting.

2.2. Tillage Systems

Most tillage can be classified into three different systems:

1. Conventional tillage includes primary and secondary tillage for seedbed preparation. A primary tillage

operation constitutes the initial, major soil-working operations; it is normally designed to reduce soil strength, cover plant materials and rearrange aggregates. Secondary tillage operations are intended to create refined soil conditions following primary tillage (8).

2. Minimum tillage provides the minimum of soil manipulation necessary for crop production under existing soil and climatic conditions. Minimum tillage does not define a system of tillage, but generally refers to a system with fewer tillage operations than some conventional tillage systems. This implies the employment of substitute techniques for weed control and/or seedbed preparation (15). The major objectives of minimum tillage are (8):

(a) To reduce mechanical energy and labor requirements.

(b) To conserve moisture and reduce soil erosion.

(c) To perform only the operations necessary to optimize the soil conditions for each type of soil within a field.

(d) To minimize the number of trips over the field.

3. Zero-tillage or no-tillage has the same purposes as minimum tillage but in this system there is no soil preparation. In other words, zero-tillage is a system in which a crop is planted directly into a seedbed which is untilled since the harvest of the previous crop.

2.3. Characteristics of zero-tillage

A comprehensive discussion of zero-tillage can be found in reference number one. The main characteristics of zero-tillage as discussed in the above reference are summarized in the following.

2.3.1. Historical background

In 1927, Garber successfully introduced a legume into an unproductive grass sod without tillage. He used simple techniques such as close grazing or burning and heavy seeding rates to manipulate the competition between the old grass and the surface-sown forage. This idea was believed to be the first introduction of a zero-tillage system. Zero-tillage systems became more feasible in the 1950's when selective herbicides were improved.

2.3.2. Operation of zero-tillage systems

Zero-tillage machinery should perform three tasks in one operation. The three tasks are to open the soil for seed insertion, to place the seed properly and to cover the seed adequately. Before planting, nonselective herbicides with short residual effects must be applied to completely destroy the initial vegetation. Selective herbicides are also needed during subsequent growth phases.

2.3.3. Comparison of environmental conditions in tilled and untilled soils

Research has shown that untilled soil surfaces were relatively smooth, even and more dense than tilled soil surfaces. Thus soil aeration under untilled soil was reduced (1). Differences in soil moisture content were relatively small between tilled and untilled soil. With a similar soil moisture content, untilled soil generally had less resistance to water uptake by plants.

Mulch cover on untilled soil acted as an insulator. Thus soil temperature on the surface of untilled soil was lower than in tilled soil. In the subsoil the reverse was found. Resistance to soil erosion by both water and wind was larger for untilled soil due to mulch cover and dense soil surface conditions.

Higher decomposition rates and lower concentration of available nitrogen were also observed in untilled soils.

2.3.4. Effects of zero-tillage on plant growth Higher numbers of emerged plants were observed under zero-tillage on light to medium textured soils with sod cover and friable soil surfaces. But thick mulches may smother emerging plants. Zero-tillage crops were observed to grow faster due to an increase in available water and suitable root zone environment.

Root growth was lower for zero-tillage due to high resistance to root growth in undisturbed soil especially during early vegetative phases (1). Annual and perennial weeds increased in zero-tillage systems due to faulty weed control by chemical means.

2.3.5. Crop yields Crop yields under zero-tillage systems have depended largely on the type of soil. On soils that range from clay to clay loam, zero-tillage crops produced less than conventional tillage crops. On medium textured soils, zero-tillage crops generally produced equal or higher yields.

2.4. Advantages of Zero-Tillage System

2.4.1. Soil moisture content under zero-tillage systems was increased due to killed sod cover. Soil moisture in the top 0 to 8-cm soil layer under zero-tillage was significantly higher than under conventional tillage throughout the entire growing season (3).

2.4.2. Soil aeration was improved since excessive tillage produces small pore spaces which tend to retard seed germination and early growth (2). Repeated tillage operations can result in soil compaction.

2.4.3. Zero-tillage practices resulted in less soil resistance to root penetration throughout the growing season and lower bulk density as compared to conventional tillage (10).

2.4.4. An experiment in the western corn belt showed that seed zone temperature in zero-tillage systems was lower than in conventional systems (9). Soil temperature under zero-tillage systems was slightly lower than under conventional systems early in the growing season (10). Reduced soil temperature may have advantages in hot regions but may be detrimental in warm or cold regions.

2.4.5. Soil erosion at the rate of 0.06 tons per acre was found with zero-tillage while it was 2.8 tons per acre with conventional tillage (7). The resistance to erosion was due to the mulch cover. Soil loss of 0.4 tons per acre was found with soil which had mulch cover whereas soil loss with no cover was 2.8 tons per acre (11).

2.4.6. Zero-tillage systems generally produced higher corn yields during years of either poor or favorable rainfall distribution (3). Crop yields with zero-tillage have generally equalled or exceeded those obtained with conventional tillage (14).

2.4.7. Zero-tillage reduces the number of field operations, labor, machinery requirements and also saves fuel (5).

2.5. Disadvantages of Zero-Tillage System

Zero-tillage methods cannot be applied to all types of soil. The most suitable soil types for zero-tillage have been light to medium textured soils. Zero-tillage methods have been most successful with crops having small seeds (1).

CHAPTER III

DESIGN OF ATTACHMENT

A zero-tillage planting machine was developed from a standard press drill by attaching coulters or cutting disks ahead of each double disk furrow opener to cut crop residues or trash. The coulters were designed to raise and lower to the desired depth of penetration into the soil independently from the double disk furrow openers.

A press drill which had double drawbars for each double disk furrow opener was more convenient for adaption because the coulters could be placed between the drawbars of the double disk furrow openers. This made it easy to line up the double disk furrow openers with the coulters.

An International 620 press drill was selected to be adapted in this study. All attachment parts are shown in Drawing No. 1 (see back cover).

3.1. Adaption of Drawbar of Double Disk Furrow Openers

Originally, the arrangement of the drawbars of the double disk furrows openers were staggered (Fig. 3.1). The shorter drawbars of the double disk furrow openers were lengthened to be the same length as the longer drawbars (Fig. 3.2). This provided space for the coulters ahead of each double disk opener.

3.2. Coulter Gang

Disks of 17 in. diameter were selected as coulters

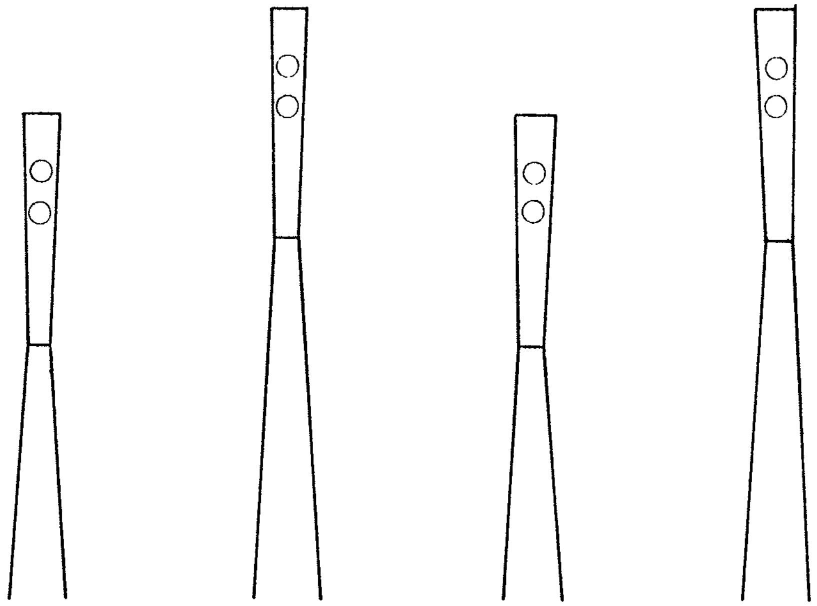

Figure 3.1. Drawbars of the double disk furrow openers before adaptation (top view).

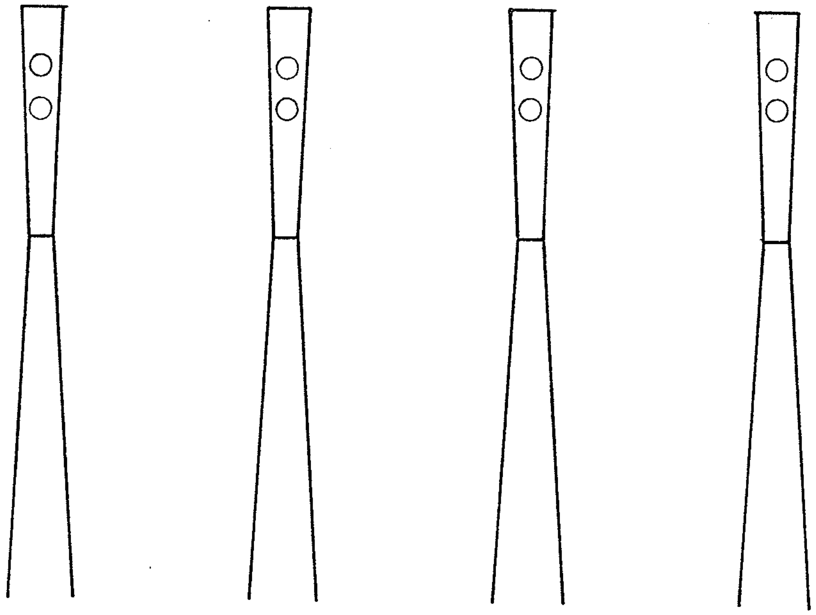

Figure 3.2. Drawbars of the double disk furrow openers after adaptation (top view).

which were mounted on four gangs of four. Each gang consisted of four cutting disks 6 in. apart. Each disk was sandwiched by two collars (3/8 in.x4 in. diameter). The collars were welded to a spacer (1 in. XS pipe). Each gang was held together by a 3/4 in. diameter bolt running through the spacers. Centering washers were used at both ends of the gangs to hold the bolts on center. Coulter gang drawbars were made of 3/8 in. x 3 in. mild steel with one end connected to the spacers by means of a bearing mount and the other end welded to a bearing pipe (2 in. XS pipe).

3.3. Shaft Support

The shaft supports consisted of 1/2 in. x 3 in. x 3/6 in. channels 12 in. long and two pieces of 2 in. XS pipe 4 in. long for upper and lower shaft support bushings. The upper shaft support bushing was welded on the front of the channel and the lower shaft support bushing was welded on the back of the channel.

3.4. Rotation Linkage

The rotation linkage consisted of double upper lift arms, a connecting link and double lower lift arms. All of these were made of 5/16 in. x 2 in. mild steel and were connected by pins.

The maximum depth of penetration of the coulters into the soil was designed to be three inches. The coulter gang drawbars were 10.90 in. long. This length was graphically determined so that there was no interference between the coulters and the drawbars of double disk furrow openers when they were raised and lowered. The maximum clearance of the coulters above the ground level was 3.4 in. This meant that the coulter rotated 42 degrees from transport position to maximum operating depth.

The upper and lower lift arms were arbitrary designed to be 6.35 in. and 6.875 in. long (center to center) respectively. The lower lift arms were positioned in a horizontal position when the coulters were at the maximum depth position. Graphical methods were used to size the connecting link at 8.25 in. long (center to center). The angle between the lower lift arm and the coulter gang drawbar was 124 degrees. The upper lift arm rotated 47 degrees for the 42 degrees rotation of the lower lift arm.

3.5. Hydraulic Cylinder Support

A hydraulic cylinder was used to raise and lower the coulters. An eight inch stroke double acting hydraulic cylinder was selected. The hydraulic cylinder attachment was determined by two conditions:

(1) The hydraulic cylinder had to be fully retracted when the coulters were at the maximum depth position.

(2) The hydraulic cylinder had to be fully extended when the coulters were in transport position.

With these two conditions, the coulters stopped automatically at the maximum depth position and at the transport position without any interference with the drawbars of the double disk furrow openers. Depth of penetration of the coulters into the soil could be controlled at any depth up to the maximum depth.

The hydraulic cylinder supports consisted mainly of a column and a hydraulic control lever. The lengths of the column and the hydraulic control lever were determined graphically to be 24.25 in. and 11.5 in., respectively. The angle between the hydraulic control lever and the upper lift arms was 86 degrees.

3.6. Assembly

The shaft supports were attached to the drill frame at spacings shown in Drawing No. 1. The coulter gangs were placed beneath the drawbars of the double disk furrow openers supported by the lower shaft (1 1/2 in. XS pipe). The lower shaft had a free running fit with the bearing pipes and the lower shaft support bushings. To prevent the coulter gangs from moving from side to side, two locking collars were used at each end of the bearing pipes. Before the locking collars were locked, each coulter gang was lined up with the double disk furrow openers. The upper shaft (1 1/2 in. XS pipe) was run through the upper shaft support bushings. The rotation linkages were fixed to the upper shaft and to the bearing pipes at the spacing shown in Drawing No. 1. The hydraulic control lever was fixed to the upper shaft and the hydraulic cylinder support was mounted on the drill frame.

3.7. Analysis of Design

The design of the machine elements was determined largely by the kinematic requirements. The actual sizing of the members was based on materials that were in stock or were readily available. The design was further complicated by the fact that the loading of the various members was unknown.

The loading of the attachment parts would be determined by the loads transferred to the coulter gangs by the penetration resistance force of the soil. The maximum loading, neglecting impact loading, would occur if the sixteen coulters were to support the total loaded weight of the press drill in a situation where there was no penetration of the coulters due to extremely hard soil conditions. Under these severe conditions the vertical load on each coulter would be approximately 300 lb (full load capacity of the drill plus total weight of the drill). The positions of the machine elements are shown in Figure 3.3.

The stresses were estimated for the machine elements that were considered critical. The allowable design stresses are listed in Table 3.1. These values were calculated with a factor of safety of three (N = 3) based on ultimate stress and using allowable bearing stress equal to the allowable tensile stress. The torsional deflection allowed was one degree per foot.

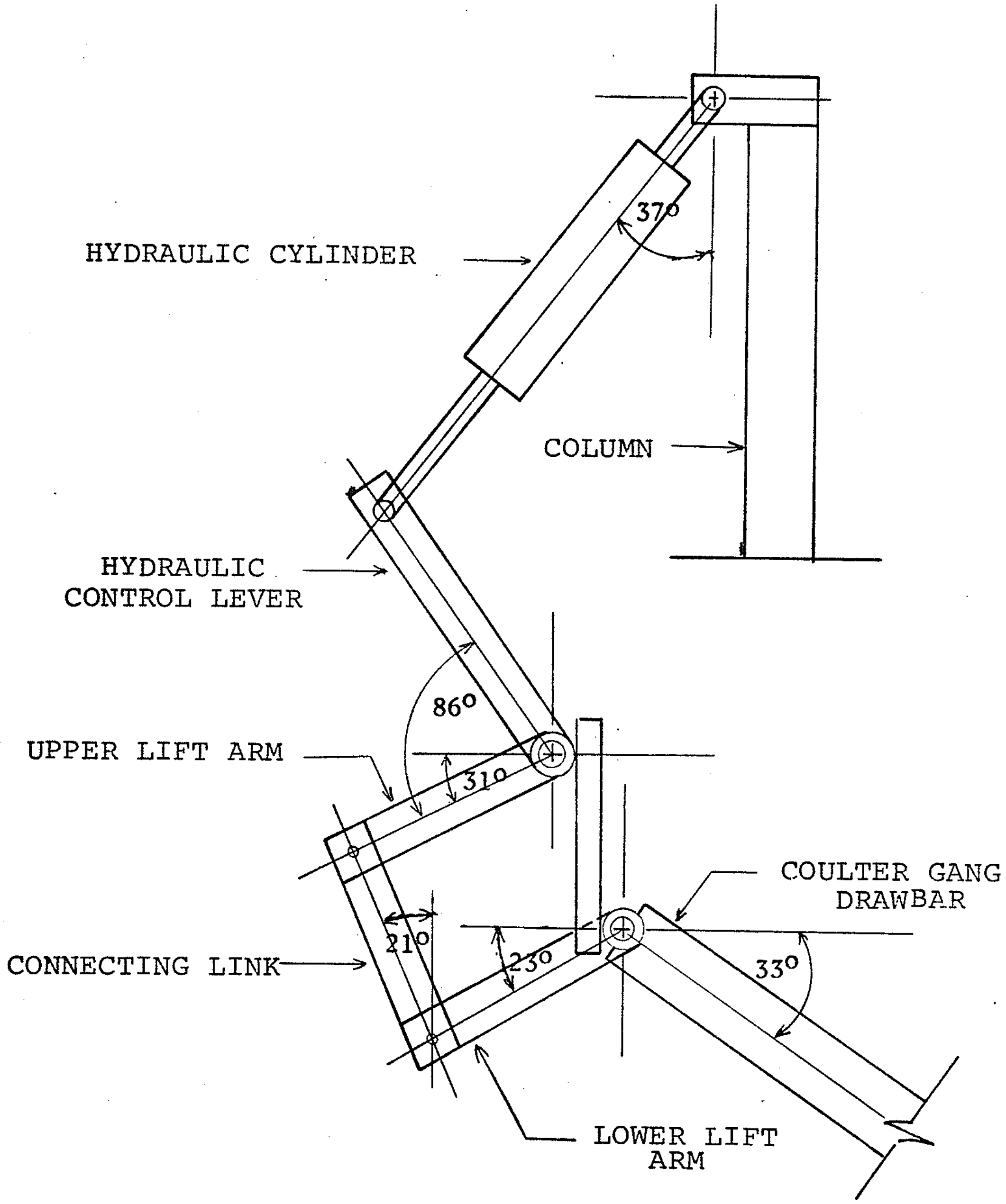

Figure 3.3. Machine elements in maximum load position.

The AISI specification for the materials used and the properties of the pipes used are shown in Table 3.2 and Table 3.3, respectively.

TABLE 3.1. Allowable Design Stresses (6)

Materials (AISI No.)	S_u (ksi)	S_s (ksi)
C 1020 steel, as rolled	22	16
C 1035 steel, as rolled	28	21
C 1045 steel, as rolled	32	24

S_u = allowable design stress in tension
S_s = allowable design stress in shear

TABLE 3.2. AISI Specifications for Materials Used

Name	Size	AISI No.
Spacer	1" XS pipe	C 1020
Coulter gang drawbar	3/8" x 3"	C 1035
Lower lift arm	5/16" x 2"	C 1045
Connecting link	5/16" x 2"	C 1045
Pin	1/2" diameter	C 1020
Upper lift arm	5/16" x 2"	C 1045
Upper shaft	1-1/2" XS pipe	C 1020
Hydraulic control lever	3-5/16" x 2"	C 1045
Column	2-3/8" x 3"	C 1035
Bracing	3/4" x 3/4"	C 1035

TABLE 3.3. Properties of XS Pipes Used

Nominal diam. in.	Outside diam. in.	Inside diam. in.	Thickness in.	I $in.^4$	A $in.^2$	r in.
1	1.315	0.957	0.179	0.106	0.639	0.41
1-1/2	1.900	1.500	0.200	0.391	1.068	0.61
2	2.375	1.939	0.218	0.868	1.477	0.77

3.7.1. Stress analysis of the coulter shaft assembly

It was assumed that the coulter shaft spacers carry the vertical loads. The coulter gang bolt was assumed to carry no load. The loading on the coulter gang was assumed as illustrated in Figure 3.4.

The coulter shaft assembly was assumed to act as a continuous beam. The resisting force on each coulter gang drawbar was R_D = 600 lb and acted as shown in Figure 3.4.

$$\text{Maximum moment} = 300 \times 9 - 600 \times 7 + 300 \times 3$$

$$= 600 \text{ in.-lb}$$

$$s_{max} = \frac{Mc}{I}$$

$$= \frac{600}{0.106^*} \times \frac{1.315^*}{2}$$

$$= 3721.70 \text{ psi}$$

$$= 3.72 \text{ ksi}$$

$$Q = \frac{2}{3}(r_o^3 - r_i^3)$$

$$= \frac{2}{3}\left[\left(\frac{1.315}{2}\right)^3 - \left(\frac{0.957}{2}\right)^3\right]$$

$$= 0.116 \text{ in.}^3$$

$$S_s = \frac{VQ}{Ib}$$

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*Value taken from Table 3.3.

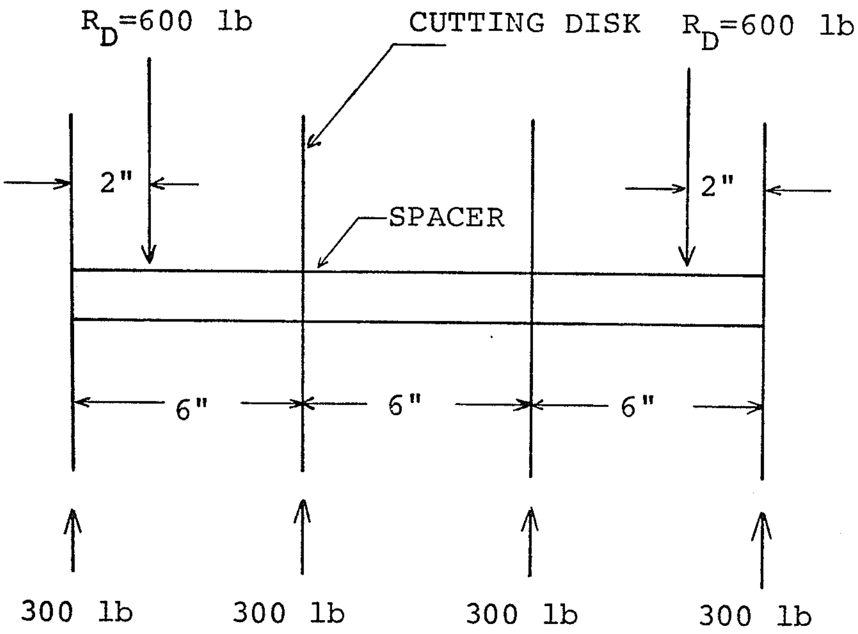

Figure 3.4. Free body diagram of the coulter shaft assembly

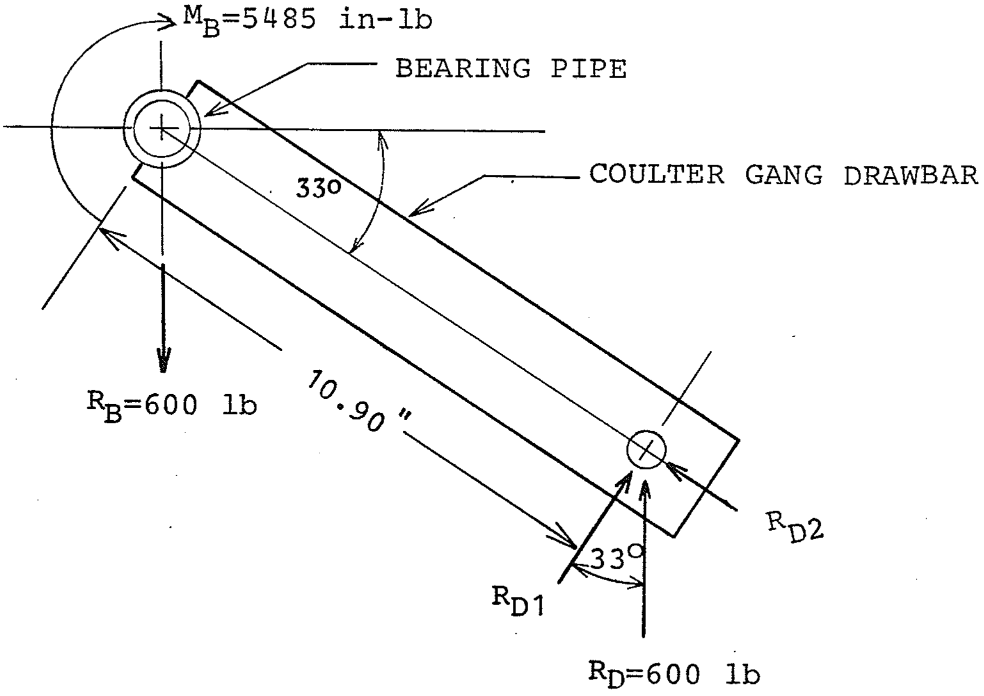

Figure 3.5. Free body diagram of the coulter gang drawbar.

$$= \frac{300 \times 0.116}{0.106^* \times (0.179^* \times 2)}$$

$$= 917 \text{ psi}$$

$$= 0.92 \text{ ksi}$$

According to Table 3.1, the coulter shafts were adequate.

3.7.2. <u>Stress analysis for the coulter gang drawbars</u> The free body diagram for a single coulter gang drawbar is shown in Figure 3.5.

Maximum force applied on the drawbar, $R_D = 600$ lb

$$R_{D1} = 600 \cos 33$$

$$= 503.20 \text{ lb}$$

$$R_{D2} = 600 \sin 33$$

$$= 326.78 \text{ lb}$$

Maximum moment, $M_B = 503.20 \times 10.90$

$$= 5485 \text{ in.-lb}$$

$$I = \frac{1}{12} bd^3$$

$$= \frac{1}{12} \times \frac{3}{8} \times 3^3$$

$$= 0.84 \text{ in.}^4$$

$$r = (I/A)^{1/2}$$

$$= (0.84/(\tfrac{3}{8} \times 3))^{1/2}$$

$$= 0.864 \text{ in.}$$

Slenderness ratio; $\frac{l}{r} = \frac{10.90}{0.864}$

$= 12.62$ (Column action can be neglected)

---

*Value taken from Table 3.3.

$$
\begin{aligned}
S_{max} &= \frac{Mc}{I} + \frac{P}{A} \\
&= \frac{5485 \times 1.5}{0.84} + \frac{326.78}{3/8 \times 3} \\
&= 10084.93 \text{ psi} \\
&= 10.08 \text{ ksi}
\end{aligned}
$$

Comparing with Table 3.1 the coulter gang drawbars were adequate.

3.7.3. Stress analysis for the lower lift arms

The lower lift arms were made of two pieces of 5/16 in. x 2 in. C 1045 steel. Each lower lift arm transferred the loads to each coulter gang drawbar. A free body diagram of the lower lift arm is shown in Figure 3.6.

Maximum moment for each piece of the lower lift arm, M_B = 5485 in.-lb, $\Sigma M_B = 0$;

$$
\begin{aligned}
F_{c1} \times 6.875 &= 5485 \\
F_{c1} &= 797.82 \text{ lb} \\
F_c &= \frac{F_{c1}}{\cos 2} \\
&= 798.29 \text{ lb} \\
F_{c2} &= F_c \sin 2 \\
&= 27.86 \text{ lb} \\
I &= \frac{1}{12} bd^3 \\
&= \frac{1}{12} \times \frac{5}{16} \times 2^3 \\
&= 0.21 \text{ in.}^4 \\
S_{max} &= \frac{Mc}{I} + \frac{P}{A} \\
&= \frac{5485 \times 1}{0.21} + \frac{27.86}{5/16 \times 2} \\
&= 26163.15 \text{ psi} \\
&= 26.16 \text{ ksi}
\end{aligned}
$$

The lower lift arms were considered adequate.

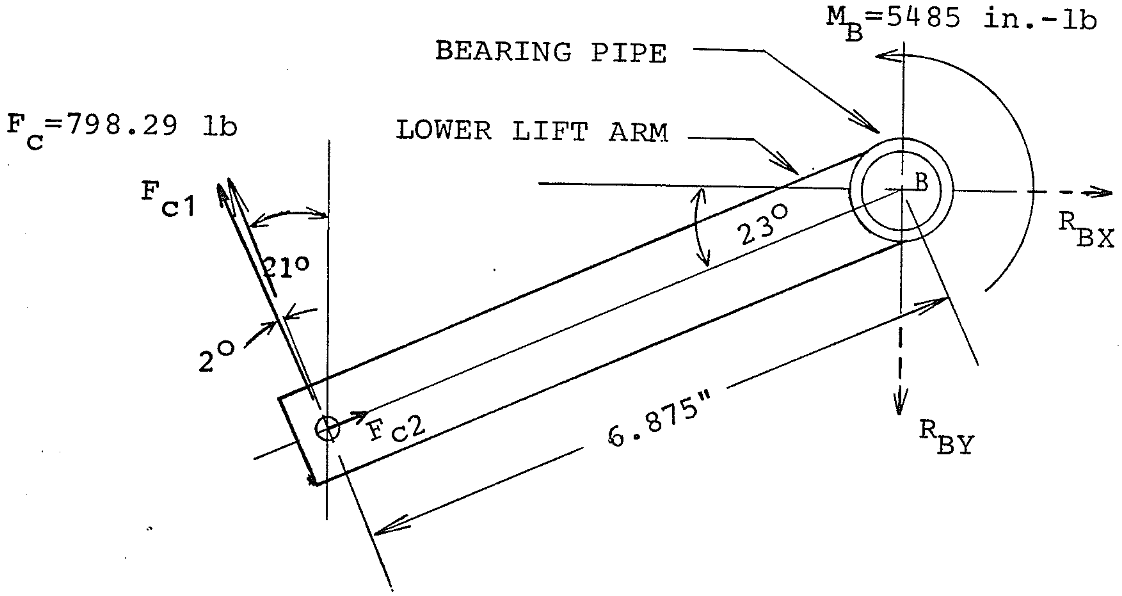

Figure 3.6 Free body diagram of the lower lift arm

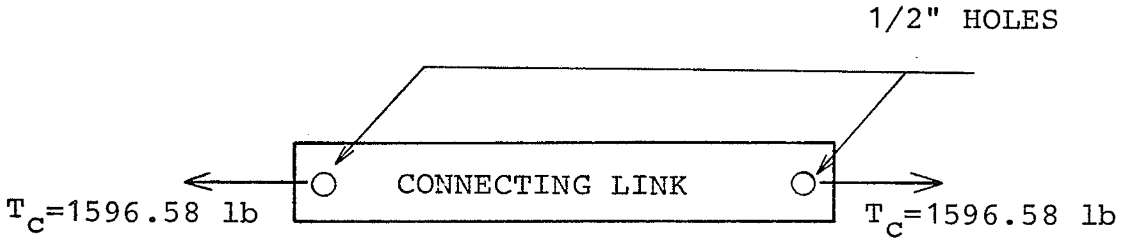

Figure 3.7 Free body diagram of the connecting link.