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Abstract
The draft of a moldboard plow increases with forward speed. It has been demonstrated that this increase in draft can be controlled by reducing the lateral cutting angle as speed increases. This paper describes some spring-damper mechanisms used to control the lateral cutting angle of a moldboard plow bottom.

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ABSTRACT

The draft of a moldboard plow increases with forward speed. It has been demonstrated that this increase in draft can be controlled by reducing the lateral cutting angle as speed increases. This paper describes some spring-damper mechanisms used to control the lateral cutting angle of a moldboard plow bottom.

INTRODUCTION

High-speed tillage is a desirable way of increasing field plowing capacity because it helps to reduce soil compaction problems produced by the massive tractors required to pull wide, high draft tillage equipment. The draft increase associated with the increase in forward speed has been one of the major hurdles to high-speed tillage.

Tests by Eidet (1974) showed that the increase in draft at high speeds can be reduced without adversely affecting plowing performance by reducing the lateral cutting angle of the moldboard plow.

Plows designed to operate at high speed may not give acceptable results when speeds are reduced at the ends of the field and in instances where power is limiting because of difficult plowing conditions. Thus it is desirable to design a plow that performs adequately at variable speeds. A high-speed plow design that works well in a certain soil type and condition may give poor performance in another soil type and condition.

There is, then, a need for an automatic mechanism that rotates the plow bottom as a function of speed and soil type and condition to adjust the lateral cutting angle to provide minimum draft for the existing soil conditions.

Observations from previous tests by Eidet (1974) showed that the side force on the plow bottom was directly proportional to plow speed and that proportionality changed from soil to soil. This means that, in a certain soil type and condition where the side force increases sharply with speed, a high reduction in the lateral cutting angle is needed, while in another soil where the side force increases only slightly with speed, only a slight decrease in the lateral cutting angle is needed.

Considering these observations, a spring-damper mechanism has been designed to use the side force to rotate the moldboard plow bottom about a vertical hinge. The spring is precompressed to resist the initial side force at low speeds. As the speed increases, the side force increases, compresses the spring further, and reduces the lateral cutting angle. With a decrease in speed, the spring force will push the plow bottom back to the original position. The function of the damper in the mechanism is to provide smooth performance and stability.

DESCRIPTION OF THE VARIABLE-ANGLE PLOW

A high speed moldboard plow bottom (Allis-Chalmers production model 392) was chosen for the test of the spring-damper device. This bottom was selected because it originally was designed for high plowing speeds. Its lateral cutting angle was 35 deg. A hinge was placed above the share point, 25.4 cm ahead of the moldboard shin, in such a way that the axis of rotation of the hinge nearly passed through the share point (Fig. 1). Two extended arms were used to connect the hinge to the frog, which was cut to provide free rotation of the moldboard about the hinge.

To allow for proper rotation of the moldboard as a function of the resultant side force, a spring and damper mechanism was fitted to the bottom. Provision was made on the spring support to provide different amounts of precompression to suit different soil conditions.

FIELD TEST

The plow was tested in the field at the Agricultural Engineering-Agronomy Research Center, Iowa State University. Qualitative tests were conducted in which...
The furrow profile was inspected at different speeds. The speeds 6.4, 9.7, and 12.9 km/h (4, 6, and 8 mph) were of interest because they represent both common and high-speed plowing. The flexible plow bottom was mounted behind a general purpose plow bottom to control the width of cut. The width and depth of cut were determined at 25 cm and 15 cm, respectively, in all field tests.

The field tests were conducted on ground that had been cropped with corn the previous year. The ground was disked before the test to ensure a relatively level surface with a light covering of weeds and cornstalks.

In the first few runs, the spring was observed to compress completely at low plowing speeds. Further testing showed that one tension spring, located as shown in Fig. 2, working together with the original compression spring was enough to give the proper rotation of the plow bottom.

The shape of the furrow profile was established with the aid of a grid board inserted in the plow furrow. Photographs were taken of the grid board positioned in the furrow to record the profile (Fig. 3). The test consisted of six runs, two for each speed. Three furrow profiles for each run were recorded at three randomly chosen positions.

The field tests were repeated with an air cylinder connected to a small air reservoir instead of the spring-damper mechanism. The new device (Fig. 4) was expected to give improved results because the proper rotation resistance and precompression force can be provided by varying the reservoir volume and pressure. The air cylinder used in the test has a diameter of 3.8 cm and a stroke of 23.5 cm. After some experimentation, reservoir volume of 688 cm$^3$ was found to provide the proper spring rate. This volume was used for all field tests.

Three test runs were conducted, one for each speed. An initial air pressure of 620 kPa was used in all tests.

The air cylinder then was replaced by an air-adjustable shock absorber (MONROE MAX), Fig. 5, to provide damping in the system. The air cushion of the shock absorber was connected to the small reservoir to provide a pneumatic spring. The new device performed more smoothly and helped to eliminate the pulsing caused when the plow encountered a very hard portion of the soil.

**NATIONAL TILLAGE MACHINERY LABORATORY TESTS**

The plow bottom with the air-adjustable shock absorber was tested at the National Tillage Machinery Laboratory (NTML), Auburn, AL. A complete description of the NTML is contained in USDA publication ARS 42-9-2.

The plow was run in a Norfolk sandy loam soil bin at speeds up to 12.9 km/h. Forces in the three mutually perpendicular directions and lateral cutting angle were measured as functions of velocity. A complete description of the NTML signal recording system is contained in SAE Paper No. 770509 (Schafer and Bailey, 1977). For a 30 cm width of cut and 15 cm...
FIG. 6 Plow draft vs. speed for the plow with the air-adjustable shock absorber tested in Norfolk sandy loam at different air pressures (688-cm³ air reservoir volume).

FIG. 7 Plow side force vs. speed for the plow with the air-adjustable shock absorber tested in Norfolk sandy loam at different air pressures (688-cm³ air reservoir volume).

FIG. 8 Plow lateral cutting angle vs. speed for the plow with the air-adjustable shock absorber tested in Norfolk sandy loam at different air pressures (688-cm³ air reservoir volume).

depth, the plow draft force, side force and the lateral cutting angle versus speed, at different air pressures, are shown in Figs. 6, 7, and 8 for the 688 cm³ air reservoir.

RESULTS AND DISCUSSION

The field tests indicated that the lateral cutting angle was changing according to speed and soil condition and that the lateral and vertical movement of the soil at high speed was less than it would have been with a rigid bottom.

The results of the runs for the compression-tension spring mechanism showed that the furrow profiles at 6.4 and 9.7 km/h were almost the same, which leads to a conclusion that the reduction in the lateral cutting angle was effective at 9.7 km/h and gave the same plowing performance as that of the 6.4 km/h speed, i.e., no increase in the lateral and vertical movement of the soil.

A comparison between the furrow profiles at 6.4 and 9.7 km/h with that at 12.9 suggests that at 12.9 km/h the acceleration forces on the soil were high, throwing the soil far away from the furrow wall. The pneumatic spring (air cylinder) gave better results at 12.9 km/h. A comparison of the furrow profiles at 6.4, 9.7, and 12.9 km/h showed a similarity between the furrow profiles at 6.4 and 12.9 km/h from which we can conclude that the acceleration forces of the soil at 12.9 km/h have been reduced significantly.

The NTML tests for the plow with the air-adjustable shock absorber showed that the plow lateral cutting angle decreased as a function of speed up to a 12 deg reduction at air pressure of 138 kPa and speed of 12.9 km/h, Fig. 8. The draft force and side force generally have been reduced relative to the rigid bottom, especially at higher speeds, Figs. 6 and 7. The percentage reduction in draft and side force increased with the decrease in the air pressure. Too low pressures (< 138 kPa) caused sluggish returning of the plow to its original position.

With the 688-cm³ air reservoir, the reduction in draft relative to the rigid bottom was as much as 44.4 percent at a pressure of 138 kPa and speed of 12.9 km/h (Table 1). At a pressure of 138 kPa, the draft increased 10.8 percent from 6.4 to 9.7 km/h speed and remained constant from 9.7 to 12.9 km/h, while the draft of the rigid bottom increased 43.3 percent from 6.4 to 9.7 km/h speed and 96.2 percent from 6.4 to 12.9 km/h, Fig. 6.

SUMMARY AND CONCLUSIONS

A spring-damper mechanism was designed to control rotation of a moldboard plow bottom about a vertical hinge as a function of the resultant side force acting on the bottom. The resultant side force increased with increasing draft.

The performance of the controlling device was tested in the field at the Agricultural Engineering and Agronomy Research Center, Iowa State University. The field tests qualitatively evaluated plowing performance as a function of speed. A high-speed moldboard plow (Allis-Chalmers production model 392) was used to test the spring-damper mechanism. The furrow profiles at speeds of approximately 6.4, 9.7, and 12.9 km/h were observed. A comparison of these furrow profiles showed that the plow gave the same performance at speeds of 6.4 and 9.7 km/h

<table>
<thead>
<tr>
<th>Air pressure, kPa</th>
<th>6.4 km/h</th>
<th>9.7 km/h</th>
<th>12.9 km/h</th>
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<tr>
<td>138</td>
<td>2.6</td>
<td>24.6</td>
<td>44.4</td>
</tr>
<tr>
<td>207</td>
<td>1.3</td>
<td>14.8</td>
<td>18.3</td>
</tr>
</tbody>
</table>

*Compared with draft of the rigid bottom.

TABLE 1. PERCENTAGE REDUCTION IN DRAFT FOR THE PLOW WITH THE AIR-ADJUSTABLE SHOCK ABSORBER AT TWO DIFFERENT PRESSURES AND THREE DIFFERENT SPEEDS (688-cm³ AIR RESERVOIR VOLUME)
but that it threw the soil far away from the furrow wall at 12.9 km/h. In later tests, a pneumatic spring (air cylinder) was used instead of the coil spring to provide proper spring stiffness. The pneumatic spring gave better results at 12.9 km/h.

The NTML tests showed a draft reduction relative to the rigid bottom up to 44.4 percent at a pressure of 138 kPa and a speed of 12.9 km/h. The draft curve at 138 kPa gave almost a straight-line relationship with speed with an increase of only 10.8 percent from 6.4 to 9.7 km/h speed, and draft remained constant from 9.7 to 12.9 km/h.

The results indicated that the variable lateral cutting angle plow could eliminate the need for production of several different bottoms, each designed to operate at a specific speed. The variable angle plow limited the increase in acceleration forces, which tend to throw the soil farther at higher speeds, and reduced the increase in draft associated with high acceleration forces.

References