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ABSTRACT

FUNDAMENTAL design considerations for powered rotary tillage blades are presented and discussed. The relationship between blade angular velocity and the geometric dimensions of cutting edges is specified for tillage blades rotating counter to the direction of travel and assuming a typical forward speed for tillage.

Analyses showed that a powered blade rotated opposite to the direction of travel can be operated at relatively lower angular velocities than can one rotated in the direction of travel to achieve equivalent blade velocity and acceleration relative to the soil. Furthermore, a blade rotated opposite to the direction of travel requires relatively lower power to achieve equivalent blade velocities relative to the soil. Experiments revealed that, in order to minimize power requirements, the ratio of the tangential velocity of cutting edges on a blade divided by the ground speed should be as low as possible as long as a proper tillage action is obtained.

INTRODUCTION

There is a noticeable trend toward reduced primary tillage in the production of some crops, including corn, soybeans, and pasture and hay crops. In many instances primary tillage is eliminated altogether. Most manufacturers of farm machinery are marketing "no-till" planters which enable farmers to plant certain crops in fields where no primary tillage has been done.

The use of the term "no-till" in the description of these planters is really a misnomer because these planters must be equipped with a tillage device which is not found on conventional planters used in tilled fields. This device must accomplish sufficient tillage to place the seeds into the soil where they can germinate and the seedlings can emerge and grow.

Contemporary tillage devices such as passive rolling coulters and rigid chisel-type furrowers are used on most "no-till" planters. Passive rolling coulters of various shapes are most common, and the design of the "no-till" planter frame must include extra weight to obtain penetration into untilled soil with these coulters.

Smith, et al. (1967, 1969, 1973, 1977) developed a powered tillage blade for use on a grassland renovation seeding machine. The powered tillage blade is superior to the passive rolling coulter with respect to the depth and uniformity of penetration as well as penetration through heavy surface trash. Analyses and results of tests to determine the relationships between torque required to turn the powered tillage blade and the angular velocity of the blade will be discussed in this paper.

REVIEW OF LITERATURE

Smith, et al. (1968) developed the powered tillage blade for use in interseeding legumes into existing grass swards. Accurate control of tillage depth under adverse surface and soil conditions was of primary concern in this development. Smith, et al. (1967) presented an analysis and test results for operating the powered tillage blade at such high angular velocities that the soil failed in nearly pure shear as the cutting teeth tilled the soil. When the powered tillage blade was incorporated into a field machine (1973, 1976, 1976) high angular velocities were impracticable because of inertial imbalance and excessive wear on the cutting teeth.

Bucher, et al. (1975) used powered tillage blades on the Powr-Till* seeder. On this machine, the blades rotate at an angular velocity of 740 r/min in the direction of travel. This seeder is being purchased by farmers and used to interseed forage crops into existing grass fields. Smith, et al. (1976) described the proper procedure for using this seeder to renovate grass fields and suggested a procedure for maintaining the powered tillage blades against wear.

Research is under way at the University of Kentucky to adapt the powered tillage concept on "no-till" planters for planting corn and double-crop soybeans. This research has revealed the need for a more critical analysis of the powered tillage blade with respect to angular velocity and direction of rotation of the blade, and shape of the cutting teeth on the blade.

ANALYSIS

One primary advantage of the powered tillage blade as compared with the passive rolling coulter is that the relative motion between the blade and the soil can be controlled. The relative motion provides the shearing action to till the soil. This relative motion can be described by the velocity of the shearing or cutting edges on the blade relative to the soil.

A cutting edge on the periphery of a round blade (Fig. 1) has a tangential velocity equal to the radius of the circle through all cutting edges on the blade multiplied by the angular velocity of the blade about its center of rotation. From the instant a cutting edge passes below the soil surface, the horizontal and vertical components of this velocity relative to the soil are constantly changing, and the corresponding accelerations relative to the soil

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The use of trade names is for informational purposes only and is not intended as an endorsement of any product.

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*Powr-Till is a trademark of Deere and Company.

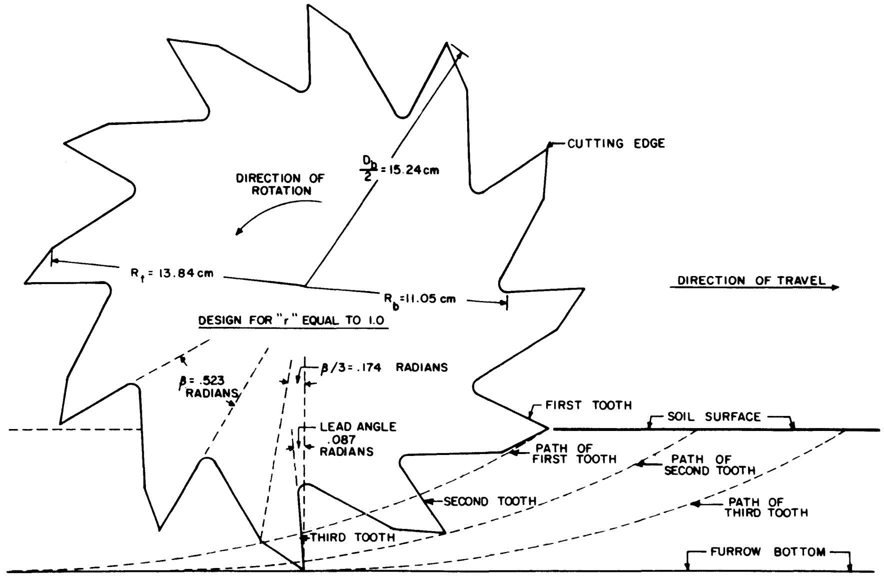

FIG. 1 Powered tillage blade design for a ratio of actual angular velocity to free roll angular velocity (r) of unity and tillage depth of 7.62 cm, where r is the ratio of actual angular velocity to free roll angular velocity R_t is the radius to the heel of the cutting edge, and R_b is the radius of a base circle from which the cutting teeth are formed.

provide the cutting force or action to till the soil.

The horizontal component of velocity of a point located on a cutting edge (below the soil surface) relative to the soil is as follows:

$$V_h = V_s + (-1)^n V_t \cos\theta \quad \text{[1]}$$

where

V_h = horizontal velocity of the cutting edge relative to the soil.

V_s = velocity of the center of rotation of the blade parallel to the soil surface, (this is the ground speed of the frame that is carrying the tillage blade and is usually constant),

V_t = tangential velocity of the cutting edge about the center of rotation of the blade,

θ = angular displacement of the cutting edge measured from a point vertically beneath the center of rotation of the blade, and

n = 0, if the blade rotates in the direction of travel 1, if the blade rotates opposite to the direction of travel (sign convention is that of a right hand coordinate system).

The acceleration of the cutting edge in a horizontal direction relative to the soil is the rate at which the horizontal velocity is changing with respect to time.

$$A_h = \frac{d V_h}{dt} = -(-1)^n \frac{V_t^2}{R} \sin\theta \quad \text{[2]}$$

where

A_h = horizontal acceleration of the cutting edge relative to the soil, and

R = radius from center of rotation to the cutting edge.

The vertical component of velocity of the cutting edge relative to the soil is as follows:

$$V_v = (-1)^n V_t \sin\theta \quad \text{[3]}$$

where

V_v = vertical velocity of the cutting edge relative to the soil.

The acceleration of the cutting edge in a vertical direction relative to the soil is as follows:

$$A_v = \frac{d V_v}{dt} = (-1)^n \frac{V_t^2}{R} \cos\theta \quad \text{[4]}$$

where

A_v = acceleration of the cutting edge in a vertical direction relative to the soil.

Careful examination of equations [1] through [4] reveals that the cutting action of the blade is much more effective when the blade is rotated in a direction opposite to the direction of travel. The horizontal component of velocity between the cutting edge and the soil is much greater, and the acceleration of the cutting edge in a vertical direction relative to the soil provides a lifting force to help in shearing (tilling) the soil. Examination of these equations also reveals that the angular velocity of the blade can be much lower when the blade is rotated opposite to the direction of travel. This can be quite significant in terms of wear on the cutting edges.

The shape of the cutting teeth on the powered tillage blade has to be related to the angular velocity of the blade, the velocity of the center of rotation of the blade parallel to the soil surface, and depth of cut into the soil. Clearances must be provided so that the cutting edge on each tooth is always leading and is not interfered with by other parts of the blade. Details concerning tooth and blade design are presented by Smith et al. (1979).

Fig. 1 shows a powered tillage blade designed to operate at 126 r/min, at a ground speed of 7.24 km/h and at a depth of 7.62 cm in the soil. The blade is 30.48 cm in diameter and an angular velocity of 126 r/min at a ground speed of 7.24 km/h is the free roll angular velocity off the blade. Free roll angular velocity is achieved when the tangential velocity of each cutting edge is equal to the linear velocity of the center of rotation of the blade, i.e., the tangential velocity of the blade is equal to the ground speed. The proper clearance angles from the leading and trailing sides of the cutting edge and paths of three successive teeth are shown in Fig. 1.

A series of tests have been conducted to determine the

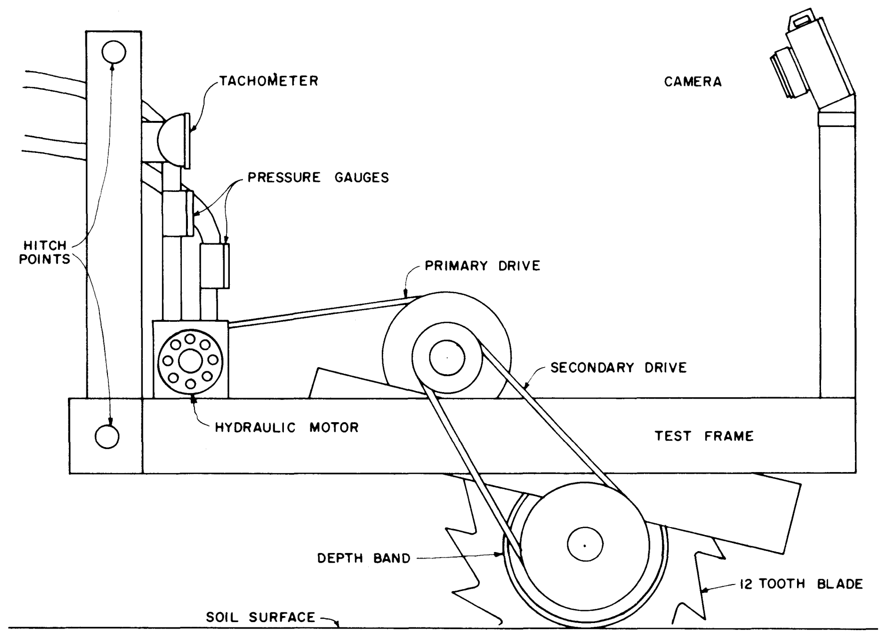

FIG. 2 Diagram of experimental equipment.

relationships between the torque required to rotate the powered tillage blade (with properly designed teeth) and the angular velocity of the blade. Results of these tests reveal the basic shape of the torque curve at much lower velocities than were used in previous analyses and tests (Smith, et al. 1967).

EXPERIMENTAL PROCEDURE

An experiment was conducted to determine the relative torque and horsepower required to operate a powered tillage blade at seven different angular velocities. The experimental design was a randomized block with four replications. The angular velocities were 93, 126, 155, 188, 215, 254 and 383 r/min, and the ratios of these velocities to free roll angular velocity were 0.74, 1.00, 1.24, 1.50, 17.2, 2.03 and 3.14, respectively. The ground speed was maintained at 7.24 km/h, and the tillage depth was maintained at 5.72 cm during the experiment. The experiment was conducted on a heavy fescue sod in Maury silt loam soil.

A diagram of the experimental equipment is shown in Fig. 2. A hydraulic motor was used to power the tillage blade. Power was transferred through a roller chain drive train, and different sprockets were used to obtain different angular velocities of the tillage blade. Pressure gauges were used to measure the pressure drop across the motor, and a tachometer was connected to the motor shaft to measure the angular velocity. The motor operated at 452 r/min throughout the experiment. A camera was used to observe the two pressure guages and the tachometer simultaneously. The observed pressure drop across the motor was the attribute which was analyzed to compare the torque and power required to rotate the blade at the different angular velocities.

RESULTS AND DISCUSSION

The data on pressure drop across the motor were used to calculate the torque and power required to operate the tillage blade at each angular velocity relative to the torque and power required at free roll angular velocity of the blade, i.e., the torque and power required at free roll angular velocity were each considered as one unit. This approach was taken because the actual torque and power would vary if the blade was operated under conditions different from those encountered in this experiment; however, the relative requirements among the different velocities would not be expected to vary.

Since the angular velocity of the motor was constant, the flow rate of oil through the motor was constant and the following ratios could be used to calculate the torque and power required to operate the tillage blade at each angular velocity relative to the requirements at free roll angular velocity

$$\frac{T}{T_f} = \frac{\Delta p}{\Delta p_f} \frac{S_f}{S} \quad \ldots \quad [5]$$

$$\frac{P}{P_f} = \frac{T}{T_f} \frac{S}{S_f} \quad \ldots \quad [6]$$

where

T = torque required to operate the blade at any angular velocity

T_f = torque required to operate the blade at free roll angular velocity

P = power required to operate the blade at any angular velocity

P_f = power required to operate the blade at free roll angular velocity

Δp = pressure drop across the motor at any angular velocity

Δp_f = pressure drop across the motor at free roll angular velocity

S = speed ratio between the motor and the blade at any angular velocity

S_f = speed ratio between the motor and the blade at free roll angular velocity

The results are plotted on Fig. 3, where the abscissa is the angular velocity of the blade divided by its free roll angular velocity; and the ordinate is the torque or power required to operate the blade at any angular velocity

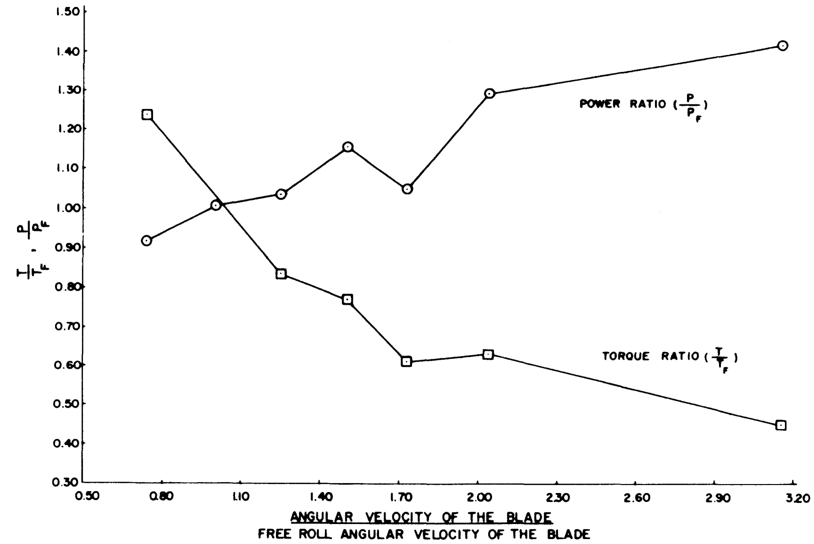

FIG. 3 Measured torque (T) and power (P) vs. angular velocity for a tillage blade rotating opposite to direction of travel. The abscissa is normalized by the free roll angular velocity of the blade and the ordinates are normalized by the respective values of torque (T_f) or power (P_f) which correspond to this angular velocity.

divided by the torque or power required to operate the blade at free roll angular velocity. The torque ratio decreases as the ratio of blade velocity increases; i.e., less torque is required as the tangential velocity of the cutting edges on the blade increases relative to ground speed. On the other hand, the power ratio increases as the ratio of blade velocity increases; i.e., more power has to be supplied as the tangential velocity of the cutting edges on the blade increases relative to ground speed. There is about a 50 percent increase in power between a tangential velocity of 75 percent of ground speed and a tangential velocity of three times ground speed.

Table 1 gives the mean values of the torque and power ratios for different ratios of the angular velocity divided by free roll angular velocity. The power ratio is significantly lower when the tangential velocity of the cutting edges on the blade is 75 percent of ground speed than when this velocity is above 125 percent of ground speed. On the basis of these data the powered tillage blade should be operated so that the ratio of the tangential velocity of the cutting edges on the blade divided by the ground speed should be as low as possible as long as the proper tillage action is obtained.

CONCLUSIONS

A powered tillage blade affords the opportunity to control the relative velocity between the cutting edges on the blade and the soil. This cannot be accomplished with a passive rolling coulter. Rotating a powered tillage blade in a direction opposite to the direction of travel along the ground results in a higher velocity of the cutting edges relative to the soil at a lower angular velocity of the blade than when the blade is rotated in the same direction as ground travel. The ratio of the tangential velocity of the cutting edges on the blade divided by the ground speed should be as low as possible as long as a proper tillage action is obtained.

The teeth on a powered tillage blade should be shaped so that each cutting edge moves through the soil without interference from other parts of the blade. The clearance angles on the leading and trailing faces of the tooth are related to the ratio of the angular velocity of the blade divided by the free roll angular velocity of the blade, the diameter of the blade, the number of teeth on the blade, and the tillage depth.

TABLE 1. TORQUE AND POWER RATIOS FOR THE DIFFERENT RATIOS OF ANGULAR VELOCITY DIVIDED BY FREE ROLL ANGULAR VELOCITY OF THE BLADE

Velocity ratio	Torque ratio	Power ratio
0.74	1.23(c)	0.91(f)
1.00	1.00(d)	1.00(fg)
1.24	0.83(c)	1.03(g)
1.50	0.77(c)	1.15(h)
1.72	0.61(b)	1.04(g)
2.03	0.63(b)	1.29(i)
3.14	0.45(a)	1.41(j)

*Values identified by a common letter are not significantly different at the 99 percent probability level.

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