Study on Working Process of No-tillage Disc Coulter

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**Abstract.** Disc coulter is a widely used stubble-cutting component in no-tillage seeder which is very important to conservational tillage. An understanding of working process of disc coulter is necessary for developing no-tillage seeder with high quality and reliability. By force analysis, the condition that maize stalk on soil surface was cut off and not pushed forward was derived and the minimum diameter of disc coulter was determined. The change of sliding cutting angle of cutting edge in the working process was analyzed, and the influence of coulter slip on the sliding cutting angle and velocity of any point on cutting edge was studied. This study provided valuable information for the design and application of disc coulter and no-tillage seeder.

**Introduction**

Compared with traditional tillage, conservational tillage can effectively prevent soil from wind erosion, resist spring drought, increase crop yield, and save cost [1]. No-tillage seeder is a very important implement for conservational tillage [2]. In northeast China, ridge culture is the primary planting mode for maize production. Because the soil in this region is covered by a small amount of stalks and much hard stubble, no-tillage seeder must have good stubble-cutting ability. Stubble-cutting device is one of the key components for no-tillage seeder. Two kinds of commonly used stubble-cutting device consist of power-driven device and passive one. Power-driven device can smash stubble and create good seedbed, but also lead to much soil disturbance, higher power consumption and blade wear [3]. One kind of widely used passive device is disc coulter which can easily cut through stubble under the soil surface by rolling without digging stubble out of the soil, consumes less energy, and only causes slight soil disturbance. Therefore, disc coulter is suitable for application in northeast China [4]. However, there are few studies on working process of disc coulter. This paper analyzed the working process of no-tillage disc coulter and has significance on improving the quality and reliability of no-tillage seeder.

**Diameter Determination of Disc Coulter**

Forces exerted on stalk on the soil surface are shown in Fig.1 when the stalk gravity is ignored. \(N_1\) is the support force and \(F_1\) is the friction force on stalk produced by soil. \(N_2\) and \(F_2\) are the normal pressure and friction force separately acted by the disc coulter. The letter \(\alpha\) is the angle between \(N_2\) and vertical direction and \(h\) is the cutting depth of disc coulter.

![Figure 1. Forces on stalk on the soil surface.](image-url)
According to force equilibrium condition, the following expression is put forward:

\[ N_1 = N_2 \cos \alpha + F_2 \sin \alpha. \]  

(1)

To assure the stalk on the soil surface is cut off rather than push forward, the condition is required:

\[ F_1 + F_2 \cos \alpha \geq N_2 \sin \alpha. \]  

(2)

From Eq. 1 with Eq. 2, we can derive:

\[ \alpha \leq \phi_1 + \phi_2, \]  

(3)

in which \( \phi_1 \) is the friction angle between stalk and soil surface, \( \phi_2 \) is the friction angle between stalk and disc coulter. Combined with the geometric relations demonstrated in Fig. 1, Eq. 3 can be described:

\[ \arccos \left(1 - \frac{2h + d}{D}\right) \leq \phi_1 + \phi_2, \]  

(4)

where \( d \) is stalk diameter and \( D \) is coulter diameter.

Generally, the stalk diameter varied very little, so \( d \) can be treated as constant. When the coulter diameter keeps constant, increasing cutting depth leads to increasing \( \alpha \). To meet the requirement of Eq. 4, \( h \) should be as small as possible. However, the stubble under the soil surface can’t be cut off if \( h \) is too small. On the contrast, if \( h \) is too large, the stalk on the soil surface is push forward and can easily cause block of no-tillage seeder. Therefore, the cutting depth \( h \) is appropriate as long as the stubble can be sliced off. When \( h \) keeps constant, the larger the coulter diameter \( D \) is, the smaller \( \alpha \) is, and the more likely Eq. 4 is reached. As a result, increasing the coulter diameter is favorable for cutting stalk on the soil surface.

In Shenyang City and ZhangWu County in Liaoning province, the average diameter of maize stalk is 31 mm, the average stubble depth in maximum diameter is 78 mm [5]. Hence, the cutting depth of disc coulter is determined 80mm. The friction angle between maize stalk and steel material is 23°–33° [6]. Because no-tillage seeder is mainly used in arid area where the soil moisture is about 6%, the average friction angle between stalk and soil surface is considered 30°. By Eq. 4, we can calculate that the coulter diameter should be more than 350 mm. However, with the limit of seeder structure and frame height, the commonly used coulter diameter is 430–460 mm.

For notch disc coulter, the notches on the circumference of coulter can cut off stalk or press it into soil, the stalk cannot move along soil surface. Therefore, at the same condition, the diameter of notch disc coulter is less than one of ordinary disc coulter.

**Change of Sliding Cutting Angle in Working Process**

During working process, the movement direction of cutting edge of disc coulter has large influence on cutting resistance. When the direction is aligned with the normal of cutting edge, the cutting resistance is relatively large. However, when the direction deviates from the normal, the cutting method is defined sliding cutting in which the resistance is relatively small. The angle between the velocity vector and the normal of any point on the cutting edge is named sliding cutting angle. Generally, the larger the sliding cutting angle is, the smaller the cutting resistance and the consumed power are.

The movement of any point on the cutting edge is composed of displacement with seeder and rotation around the coulter shaft. When the slip of coulter is neglected, the coulter movement is pure rolling during which the instantaneous centre of velocity is the contact point of coulter with furrow bottom. As shown in Fig. 2, \( M \) represents a point on the cutting edge of coulter. The velocity of \( M \) can be resolved along the tangent and normal direction separately, and the angle \( \tau \) between \( v \) and \( v_n \) is the sliding cutting angle. Because \( P \) is the instantaneous centre of velocity, the velocity direction of \( M \) is perpendicular to line PM. The \( \tau \) can be expressed according to Fig. 2:

\[ \tau = \arccos \left(1 - \frac{h_m}{R}\right)/2, \]  

where \( h_m \) is the distance from \( M \) to furrow bottom, \( R \) is the coulter radius.
From Eq.5, it can be concluded that the sliding cutting angle of a point on the cutting edge gradually decreases with the reduction of the distance to furrow bottom. When the point just contacts the soil surface, the sliding cutting angle is the maximum. At the same cutting depth, the more the radius of coulter is, the less the sliding cutting angle is. Too small sliding cutting angle is disadvantageous for coulter to go into soil and reduce resistance. Therefore, the coulter radius should be smaller when the condition permits it.

However, the slip of disc coulter is unavoidable in real working process. The slip rate is affected by structure parameters of coulter, soil properties, the unit working speed, and so on. Hence, the real sliding cutting angle is also influenced by these factors and is different from the theoretical one. When the coulter rolls with slip, the contact point of coulter with furrow bottom is no more the instantaneous centre of velocity, but the point Q is, as shown in Fig.3.

The real sliding cutting angle $\tau'$ of M is put forward according to Fig.3:

$$\tau' = \alpha_m - \theta,$$

where $\alpha_m$ is the angle between the coulter radius OM and the line OQ, $\theta$ is the angle between the line MQ and the horizontal line through point M.

Comparison of Eq.5 with Eq.6 results in the following relationship:

$$\tau' < \tau.$$

This means that the slip of coulter makes the real sliding cutting angle smaller than the theoretical one. The more the slip amount is, the less the angle is and the more the resistance is. Compared with plain disc coulter, wave disc coulter is difficult to slip because of the close contact between waves and soil. Consequently, wave disc coulter has more strong sliding cutting effects and better stubble-cutting ability than plain one.

**Velocity Analysis of Disc Coulter**

When the disc coulter works in pure rolling, the following equation is acquired according to Fig.2:
\[
v = v_u \sqrt{\frac{2h_m}{R}},
\]

(8)

where \( v \) is the velocity of M without consideration of slip, \( v_u \) is the forward velocity of unit.

Based on Eq. 8, in order to assure the cutting velocity, the coulter radius cannot be too large. On the precondition of good seeding quality, increasing the working speed of unit is favor of cutting stubble.

When the slip of disc coulter is considered, the following equation is concluded according to Fig.3:

\[
v' = v_u \sqrt{\frac{2h_m}{R + l} + \left( \frac{l}{R + l} \right)^2},
\]

(9)

where \( v' \) is the velocity of M with consideration of slip, \( l \) is the distance from the contact point of coulter with furrow bottom to the instantaneous centre of velocity.

It is assumed that the slip rate of disc coulter is \( \delta \). By calculation and comparison, we can conclude that \( v > v' \) when \( h_m > R\delta/2 \). This means that the influence of slip rate on the velocity of any point on cutting edge of disc coulter is related with the location of the point. When the distance from the point to furrow bottom is more than \( R\delta/2 \), the slip of coulter decreases the velocity of point and is disadvantageous to cutting stubble. When the distance is less than \( R\delta/2 \), the slip of coulter increases the velocity and is favor of cutting stubble. Because the amount of \( R\delta/2 \) is very small, in most of the working process, the slip of coulter causes adverse effects on cutting velocity. Therefore, the slip of coulter should be minimized when possible.

**Summary**

The cutting depth of disc coulter merely needs to assure cutting off the stubble under the soil surface. Increasing the coulter diameter is advantageous to slice the stalk on the field. In northeast China, the diameter of no-tillage disc coulter should be no less than 350 mm. When the cutting depth is same, the larger the diameter is, the smaller the sliding cutting angle is, the more adversely the coulter penetrates into soil and the resistance decreases. The slip of coulter is disadvantageous to the cutting velocity and should be minimized as much as possible.

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**References**


