Design of Seed Rope Guiding Opener Based on DEM

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Abstract. Rice seed rope planting has the advantages of water saving, energy saving and it can precisely control the rate and hill space of seeds, fertilizer and herbicide or pesticide, and simplify the sowing process as well. To solve the problem of ditching and rope laying the influence of cutting edge curve of trench opener on trench resistance is studied in this paper. Three kinds of furrow opener curves are put forward: exponential, parabola and circular. The mechanical model of the seeder was established and simulation analysis of furrow opener based on discrete element method, therefore, the edge curve equation of the soil cutting and seed rope guiding device was optimized. The simulation test results show that the exponential opener has the minimum working resistance 6.71 N; and the parabola opener has a higher working resistance 7.87 N; the circle opener has the highest resistance 9.59 N. This study may provide the basis for design of the rice seed rope planter.

Keyboards: Seed Rope Planter, Rice Direct Seeding, Furrow Openers, EDEM

1. Introduction

Seed rope planting technology (also called as seed tape direct sowing) was first put forward by McComb (1913) to solve the issue of uniquely sized seeds of vegetables, flowers, and other plants which is hard to sowing with a same seeder in 1913 [1]. Seed rope sowing technology positions seeds and fertilizer in a tape of some suitable material and twists into a seed rope. The seed rope is planted into field with a planter at seeding season. Some machines were developed to produce seed rope and its planting (Sanford, 1918; Fischer, 1937; Schindler, 1948; Foster, 1972; Henrik, 2006; Benjamin, 2010). In some family gardens in Europe, toilet paper or newspaper slip is used as the material to make seed rope. Seed rope sowing gradually became popular in Asian countries in the 21st century. Ohta (1999; 2001) designed a paddy tape seeder, which guides the seed rope on the paddy and pressed with the vane wheel assembled in the back of the seeder [2-4]. In 2005, Lerink and Wondergen (2005) developed a trailed tape seeder. Deppermann et al. (2011) developed another trailed tape seeder with four rod copying apparatus. In 2012, a Japanese researcher Motohashi (2012) developed a walking tape seeder with one row, which is driven by a battery. The seeder speed can be changed by a change-over speed gear. This machine was very flexible when it was working [5-8].
Furrow opener is one of the most important parts of the seeder. At present, there are more researches on openers. Jia et al. (2020) based on the efficient and low resistance penetration structure of the dog-badger canine tooth surface, proposed an optimal design method of furrow opener based on the bionics principle to solve the problem that he resistance of the core-share furrow opener is too large under high speed operation. Morrison Jr. et al. (1978) design a new apparatus for opening furrows in soil. This apparatus consists of an opening mechanism, a closing mechanism, an automatic seed planting mechanism, an automatic seedling planting mechanism, a driving means, a towing means, and the salient component parts necessary to make them function. Sun (2020) designed nine kinds of singular convex hull, nine kinds of singular wedge and nine kinds of mixed convex hull and wedge structural biomimetic disc furrow opener and the furrowing process with the soil simulated by finite element method [9-12]. In order to solve problems of imprecise positioning of fertilizer and low utilization rate in traditional fertilizer application of potato planter, Yang (2019) designed a combined ditching device of layered fertilizer application for deep and shallow layer at the same time of sowing.

However, furrow opener of seed rope planter should include two functions: trench opening and rope guiding. There are few researches reported about this kind of furrow opener. Therefore, a kind of rope guiding opener of rice seed rope planter based on discrete element method [13].

2. Design of Cutting Edge of the SCSRGM Based on DEM
A soil cutting and seed rope guiding mechanism (SCSRGM) was designed in this study to cut the soil and guide seed rope into the groove. Technical requirements for this mechanism are as follows: 1) keep the depth of groove at 3 cm; 2) no soil layer mixing [14]. The key factors affecting soil cutting drag and furrowing quality are penetration angle, cutting curve of opener, and separate soil angle. Blunt angle was employed in the mechanism to meet the requirement of soil cutting and guiding rope. Gu (2013) designed the cutting edge equations of a furrow opener as exponential function, and conducted a series of experiments to investigate the traction resistance with variable cutting angles [15]. He drew the conclusion that it would be a minimum when the cutting angle was 35° ~ 55°.

2.1 Geometric Model
Experiment was conducted with the test variables of various cutting curve types: exponent, parabola and circle, to explore the curve with the smallest resistance. The models of the three curves were established in coordinate, which were shown in Figure 2. The cutting angles of point A and B are θA and θB, respectively. lAC is the height of cutting edge of SCSRGM. Curve AB is the cutting edge. The tilt angles of tangents in point A and B are αA, αB, respectively. The cutting edge equations are as follows: the exponential function \( y = (e^{\cot(\theta_A)} - \cot(\theta_A) - b) x \), quadratic function \( y = ax^2 + bx \), and circle \( x^2 + (y-r)^2 = r^2 \).

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![Diagram](image1)

![Diagram](image2)

a. exponential  
b. parabola
The conclusion stated by Xun (1979) and Pang (1982) showed that the machine could perform the cutting action only when $\theta B > \Phi$ (frictional angle). It can be observed from Figure 2 that point B is the top of cutting curve, $\theta B$ is the starting cutting angle. Thereby the cutting angles of other points in cutting curve are all smaller than $\theta B$. The frictional angle of the soil before sowing is generally 23°; hence, $\theta B$=23°. The height of the furrow opener cutting edge is $l_{AC}$=100mm and $\theta A$=45° because the suitable depth for the buried seed rope is 20~30cm. Therefore, the derivative values of A and B are $k_A$=$\tan 45°$ =1 and $k_B$=$\tan 23°$ =0.424. Kostritsyn’s (1981) research results showed that the cutting resistance is minimum when the wedge angle close to 45°, hence the value of $\eta$ was designed as 45° (Figure 2 d). For the exponential edge curves (Figure 2 a), substitute $\theta A$ and $\theta B$ into exponential equation and the equation can be obtained as $y = e^{0.01356x}$, and $x_A$ = 317.00, $x_B$ = 380.11, $l_{BC}$ = 63 mm after rounding [16-18].

For the parabola edge curves (Figure 2b), vertex of a parabola was kept coincided with origin of coordinate. Set up point A($x_A$, $y_A$), point B($x_B$, $y_A$+$l_{AC}$). The parabola equation could be worked out by the following equations:

\[
\begin{align*}
    f'(x_A) &= \tan \alpha_A \\
    f'(x_B) &= \tan \alpha_B \\
    f(x_B) - f(x_A) &= l_{AC}
\end{align*}
\]  

Namely: $y=0.0114x^2$, $x_A$=43.86, $x_B$=103.33, $l_{BC}$=60mm after rounding.

For the circle edge curves, cutting curve equation can be changed to

\[h(x) = \sqrt{r^2 - x^2} + r, \quad x > 0\]  

And circle equation could be worked out by the following equations:

\[
\begin{align*}
    h'(x_A) &= \tan \alpha_A \\
    h'(x_B) &= \tan \alpha_B \\
    r \cdot \sin \alpha_A - r \cdot \sin \alpha_B &= l_{AC}
\end{align*}
\]  

Namely: $r$=316, $x_A$=223.45, $x_B$=290.88, $l_{BC}$=67mm after rounding.

### 2.2 Simulation and Analysis of the Cutting Edge Curve

The process of soil cutting includes the contact between soil particles and the opener and the contact between soil particles. There was a bonding force between moisture in the soil for the soil consist matters of solid, liquid and gas state. Henth, Hertz-Mindlin bonded model was selected in this simulation (Pan et al., 2016). Three models of soil samples whose particles had different sizes and
shapes were established: 1) single spherical particles having a diameter of 2 mm; 2) double spherical particles having a radius of 1.5 mm and a combined diameter of 4 mm; 3) three spherical particles having a length of 4 mm that make up an equilateral triangle [19-20].

In order to simplify calculations, we omitted connection parts with framework and used only the cutting edge part and imported the 3D model into the EDEM software. The simulation time was set as 5 s and the forward speed was 1 m/s, and the parameters of the particles are listed in Table 1.

Table 1. Simulation parameters

| Parameter                             | Value   | Parameter                             | Value   |
|---------------------------------------|---------|---------------------------------------|---------|
| Poisson’s rate of soil                | 0.38    | Shear modulus of opener, MPa          | 10      |
| Shear modulus of soil, MPa            | 1       | Opener density, kg/m$^3$               | 7800    |
| Soil density, kg/m$^3$                | 1263    | Dynamic friction coefficient between soil and opener | 0.483 |
| Dynamic friction coefficient between soil | 0.15 | Static friction coefficient between soil and opener | 0.5 |
| Static friction coefficient between soil | 0.532 | Rolling friction coefficient between soil and opener | 0.32 |
| Rolling friction coefficient between soil | 0.25 | Working velocity, m/s                 | 0.5    |
| Poisson’s rate of opener              | 0.3     | Simulation time, s                    | 21     |

The resistances of the three types of curves were chosen for the interval between 3 and 4s, and the plotted curves are shown in Figure 2.
According to Figure 2, the resistance of the three types of SCSRGM fluctuated around its fixed value over time. The average resistance of exponential one is 6.71 N, the quadratic function is 7.87 N, and the circular one is 9.59 N. Therefore, the exponential curve was employed on the planter because it had the lowest resistance in the same working conditions.

3. Conclusions

To realize the rice seed rope planting, a kind of SCSRGM was put forward in this research and analyzed the resistance of three different cutting curve. The main conclusions are as follows:

1) The soil cutting model of the SCSRGM was established based on discrete element method (DEM) theory.
2) The effect of the cutting curve of SCSRGM on the resistance was qualitatively analyzed. And the SCSRGM with exponential cutting curve is of the least resistance.
3) The model of rope guiding opener was determined.

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