Optimization Design on Deep-Fertilization Fertilizer Amount Adjusting Mechanism for Paddy Field

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Abstract. In order to solve the deliquesced fertilizer adheres to fertilizer conveying pipe, and leads to fertilizer conveying pipe blocked, a kind of fertilizer amount adjusting mechanism of deep-fertilization machinery for paddy field was designed. This adjusting mechanism was taken as research object, the distance between hinge axis and the center of blade connection seat, the distance between hinge axis and sliding limited post axis, the rotation angular velocity of cam ring and the angular velocity of blade rotating around hinge axis were taken as objective function, the diameter of fertilizer through-hole, the number of blades and the changing range of curvature radius of guide chute were taken as constraint conditions, the aided design and analysis software for fertilizer amount adjusting mechanism was programmed by VB software, through which kinematics optimization was carried out for fertilizer amount adjusting mechanism. The obtained optimal parameter ranges are: the radius of inner ring of cam is 30mm, the number of blade is 6, the distance between the hinge axis and the center of blade connection seat is 47.5mm, the distance between hinge axis and sliding limited post axis is 12.5mm, the rotation angular velocity of cam ring is 25-35r/min, the angular velocity of blade rotating around hinge axis is 30-35r/min. According to optimization results, the fertilizer amount adjusting mechanism was simulated by Pro/E software, the simulation results were validated by experiment. The results show that the adjustable range of diameter of fertilizer through-hole for fertilizer amount adjusting mechanism is 9-56mm, the sliding limited post of blade and the guiding chute of cam ring have good sliding performance, and the designed fertilizer amount adjusting mechanism can satisfy the expected design requirements.

Keywords: fertilizer applicator, fertilizer amount, adjustment, simulation, mechanism, optimization.

1 Introduction

Fertilizer is easily deliquescent chemical product, after moisture absorption, fertilizer has low flow ability, high adhesive ability, often adheres to fertilizer box and conveying fertilizer pipe, which results in technical issues, such as fertilization amount reduce, fertilization quality decline, or even conveying fertilizer pipe blockage, and cannot continue to operate, which reduce the operation efficiency of the equipment [1].

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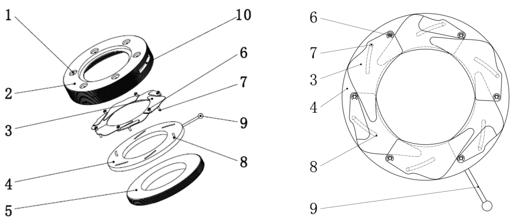
In order to solve the above problems, in recent years, the structure of configuration helical screw blades in fertilizer box and conveying fertilizer pipe emerges, but when operating, a large amount of deliquescent fertilizer still adheres to helical screw blades, the dredge effect is not ideal. Aiming at the existing technical problems, deep-fertilization mechanism for paddy fields was developed, which uses spiral wire instead of the helical screw blade, in this mechanism the traditional outer-fluted roller fertilizer distributor has been unable to matching, therefore, it is imminent to design a new fertilizer amount adjusting mechanism. In order to facilitate the adjustment of the amount of fertilizer, and the installment of spiral wire for deep-fertilization mechanism, a kind of fertilizer amount adjusting mechanism was designed, and its main parameters were optimized. Fertilizer amount adjusting mechanism was analyzed using kinematics theory, its mathematical model was developed, human-computer interaction simulation software was developed by VB software, which was used to obtain optimization parameters, structure design and simulation for fertilizer amount adjusting mechanism were carried out by Pro/E software, thus the movement of fertilizer amount adjusting mechanism was simulated [2-3], the simulation results were validated by experiment.

2 Structure and Operation Principle

The structure of fertilizer amount adjusting mechanism is shown in figure 1. The hole 1 of hinge axis is set on the upper surface of blade connection seat 2, the lower side portion of the hinge axis 6 is plugged in the adjacent blade 3, annular assembly is composed by blade 3, the upper side portion of hinged axis 6 is plugged in hole 1 of hinge axis of the blade connection seat 2, annular assembly composed by blade 3 is mounted on the inner of blade connection seat 2, sliding limited post 7 is fixed on the lower side of blade 3, the cam ring 4, which has a guide chute 8, is fixed on the lower part of blade 3,sliding limited post 7 is plugged in the guide chute 8, the locked ring 5 is assembled in the lower side of blade connection seat 2 by thread, which is located in the lower part of cam ring 4. The handle 9 is inserted in slots 10 of blade connection seat, the inner part of handle 9 is connected to cam ring 4.



1. hole of hinge axis 2. blade connection seat 3. blade 4. cam ring 5. locked ring 6. hinge axis 7. sliding limited post 8. guiding chute 9. Handle 10. Notch of the connection seat

Fig. 1. Structure drawing of fertilizer amount adjusting mechanism

When operating, the upper side of fertilizer amount adjusting mechanism was connected to fertilizer box; the lower side was connected to fertilization pipe, non-helical part of the longitudinal spiral wire passed through the center of fertilizer through-hole of fertilizer amount adjusting mechanism. When adjusting the amount of fertilizer, the handle 9 was moved in the slots 10 of blade connection seat, which drove cam ring 4 to rotate, under the control of guide chute 8, sliding limited post 7 made radial arc movement in the guide chute 8, the blade 3 moved around the hinge axis 6, the opening size of center hole was adjusted, which was composed by blade 3, the amount of fertilizer application was adjusted.

3 Mathematical Models

When fertilizer amount adjusting mechanism operating, the blade connection seat was fixed, cam ring was drove by adjusting handle, which realized the adjustment of the amount of fertilizer application. Handle and cam ring were fixed, the adjustment of the amount of fertilizer application can also be realized by rotating the blade connection seat, the latter method was used to develop mathematical model, as shown in figure 2. xoy is fixed reference system, $x'oy'$ is moving reference system, and the origin of coordinate system is coincide. M is the pivot point of sliding limited post, the relative motion is fixed axis rotating around hinge axis hole of blade connection seat, translational motion is the blade connection seat rotating around cam ring. The relationship of absolute, relative and translational motion was established by coordinate transformation relation (1) [4-5].

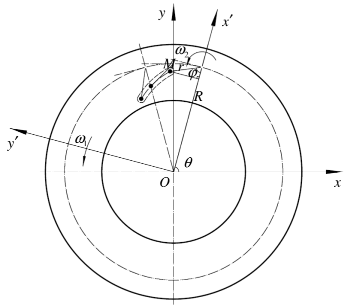


Fig. 2. Movement analysis diagram of fertilizer amount adjusting mechanism

$$\begin{cases} x = x_{O'} + x'\cos\theta - y'\sin\theta \\ y = y_{O'} + x'\sin\theta - y'\cos\theta \end{cases} \tag{1}$$

Where x and y are absolute motion coordinates of points, $x_{O'}$ and $y_{O'}$ are coordinate origin of moving reference system, x' and y' are relative motion coordinates of points, θ is rotation angle from x axis to x' axis, taking the counterclockwise direction as positive, relative movement equation of point M is shown as follow:

$$\begin{cases} x' = R - r\cos\omega_2 t \\ y' = r\sin\omega_2 t \end{cases} \tag{2}$$

R is the distance between hinge axis and the center of blade connection seat, unit: mm; ω_2 is the angular speed of blade rotating around hinge axis, unit: r / s; r is the distance between hinge axis and the axis of sliding limited post, unit: mm; t is time, unit: s. The equation of transport motion is shown as follow:

$$x_{O'} = x_O = 0\,,\quad y_{O'} = y_O = 0\,,\quad \theta = \omega_1 t$$

The equation of absolute motion of point M was obtained by equation (1) and (2), which is shown as follow. ω_1 is the rotation angular velocity of cam ring, unit: r / s.

$$\begin{cases} x = (R - r\cos\omega_2 t)\cos\omega_1 t - r\sin\omega_2 t\sin\omega_1 t \\ y = (R - r\cos\omega_2 t)\sin\omega_1 t - r\sin\omega_2 t\cos\omega_1 t \end{cases} \tag{3}$$

4 Parameters Optimization

4.1 Objective Function and Constraint Conditions

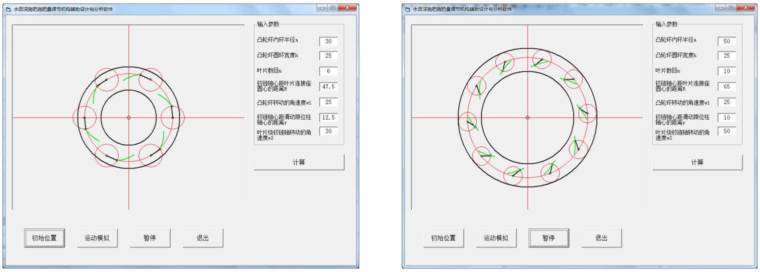
In order to satisfy the fertilizer requirement of rice in different periods, the structure of fertilizer amount adjusting mechanism has the following requirements: (1) 30mm $\le$ the diameter of the fertilizer through-hole $\le$ 80mm; (2) the number of blade is greater than or equal to 6; (3) the guide chute of cam ring is smooth, curvature radius is greater than or equal to 15mm ; (4) the distance between hinge axis and the center of blade connection seat is greater than the diameter of fertilizer through-hole. In this case, taking lightweight of the fertilizer amount adjusting mechanism as target, thus the flexibility of adjustment was improved. The objective functions of fertilizer amount adjusting mechanism are the distance between hinge axis and the center of blade connection seat (R), the distance between hinge axis and the sliding limited post axis (r), the rotation angular velocity of cam ring (ω_1) and the angular velocity of blade rotating around hinge axis (ω_2).

The constraint conditions and objective functions are multi-variable nonlinear function, it is difficult to solve global optimal solution using traditional optimization methods, therefore, based on mathematical models and objective functions, on the premise of satisfy the constraint conditions, human-computer interaction simulation software was developed to optimize parameters by VB software [6].

4.2 Human-Computer Interaction Simulation Software

The input parameters of software include a , h , n , R , r , ω_1 and ω_2 , a is the radius of inner ring of cam ring, h is the width of cam ring, n is the number of blades. According to the variation of system parameters, software can output calculation parameters in real-time, and display the trajectory, meanwhile the absolute motion of the blade sliding limited post can also be simulated, as shown in figure 3.

When using this software, firstly enter a set of parameters based on experience, the computer calculates results, displays trajectory and simulates moving trajectory in real-time. Then based on these results, with people's experience and logical thinking to determine whether this set of parameters are good or not [7-14].



(a) Initial position (b) Motion process

Fig. 3. Optimization interface of visible human-computer interaction

4.3 Analysis of the Influence of Variables on Results

As shown in simulation software:

(1) The rotation angular velocity of cam ring (ω_1) affects the length of guide chute, which increases with the increase of ω_1 .

(2) The angular velocity of blades rotating around hinge axis (ω_2) affects the changing rate of the area of adjusting fertilizer through-hole, which increases with the increase of ω_2 .

(3) k is the ratio of ω_1 and ω_2 , which influences curvature radius of the guide chute, curvature radius of the guide chute increase with the increase of k .

(4) The distance between hinge axis and the center of the blade connection seat (R) affects the mounting position of blade, the mounting position increases with the increase of R .

(5) The distance between hinge axis and the center of the blade connection seat (R),the distance between hinge axis and the sliding limited post axis(r) and the number of blades(n) can determine parts of blade size, the profile of blade can be determined in three-dimensional software.

4.4 Optimization Results

The optimization results which satisfy the movement requirements were obtained by software, as shown in table 1.

Table 1. Optimization results

a /mm	h /mm	n	R /mm	ω_1 /r·min^{-1}	r /mm	ω_2 /r·min^{-1}
30	25	6	47.5	25~35	12.5	30~35

5 Structure Design and Simulation

Parameters optimization, trajectory simulation and structure schematic of the fertilizer amount adjusting mechanism were realized by human-computer interaction simulation software, which was developed by VB software, but the blade, the movement of cam ring and the inspection of interference problems for fertilizer amount adjusting mechanism need to be realized by three-dimensional solid modeling and simulation software. A set of optimized parameters were selected, which were a = 30mm, h = 25mm, n = 6, ω_1 = 25r/min, ω_2 = 30r/min, R = 47.5 and r =12.5 mm, fertilizer amount adjusting mechanism was designed by Pro / E, its structure simulation diagram is shown in figure 4.

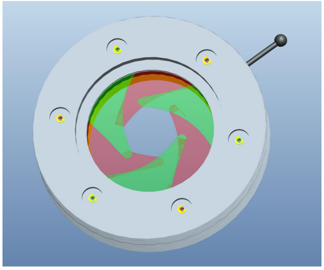


Fig. 4. Structure simulation diagram of fertilizer amount adjusting mechanism

Kinematics simulation was carried out for fertilizer amount adjusting mechanism by Pro / E, the profile of blade was modified, the blade assembly had no gap in the rotation process. The range of the diameter of fertilizer through-hole was adjusted from 7 mm to 56mm, as shown in figure 5. Interference test was carried out by Pro / E, the test results show that the moving process of the designed fertilizer amount adjustable mechanism has no interference, the sliding performance of the blade sliding limited post and the guide chute of cam ring is good, the designed fertilizer amount adjustable mechanism can meet the design requirements.

(a) Maximum adjustment value (b) Minimum adjustment value

Fig. 5. Adjustable range of fertilizer amount adjusting mechanism in simulation

6 Experimental Results and Analysis

Fertilizer amount adjusting mechanism was processed, and then the experiment was carried out. To turn the adjustment handle, the size of the diameter of fertilizer through-hole can be adjusted. The maximum diameter of fertilizer through-hole was 56mm, as shown in figure 6a. The minimum diameter of fertilizer through-hole was 9mm, as shown in figure 6b. The maximum value of the diameter of fertilizer through-hole was the same as the simulation results. the minimum value of the diameter of fertilizer through-hole was 2mm greater than the simulation results, A gap of 1mm in width between the two blades emerged in the process of adjusting the diameter of fertilizer through-hole smaller, which mainly due to the processing accuracy of the blade hinge axis and the position and verticality of the sliding limited post with the blade didn't satisfy the design accuracy requirements. In order to ensure that no gap appears between blades in the process of through-hole diameter changing, on the premise of without changing any other design parameters and improving the design accuracy, the number of blades can be increased by one.

(a) Maximum adjustment value (b) Minimum adjustment value

Fig. 6. Adjustable range of fertilizer amount adjusting mechanism in experiment

7 Conclusions

(1) Aided design and analysis software for fertilizer amount adjusting mechanism was programmed by VB software, kinematics optimization was carried out using this software, the optimization results show that the radius of inner ring of cam is 30 mm, the number of blades is 6, the distance between hinge axis and the center of blade connection seat is 47.5mm, the distance between hinge axis and the axis of sliding limited post is 12.5mm,the angular velocity of cam ring is 25-35r/min, the angular velocity of blade rotating around hinge axis is 30-35r/min.

(2) According to kinematic optimization results, fertilizer amount adjusting mechanism was designed by Pro / E software, kinematics simulation was carried out for fertilizer amount adjusting mechanism. The simulation results show that the adjustable range of diameter of fertilizer through-hole is 7-56mm for fertilizer amount adjusting mechanism, the sliding performance of the blade sliding limited post and the guide chute of cam ring is good, the designed fertilizer amount adjusting mechanism can meet the design requirements.

(3) Experimental results show that the adjustable range of diameter of fertilizer through-hole is 9-56mm for fertilizer amount adjusting mechanism, which satisfies the design requirements, a gap of 1mm in width between the two blades emerged in the process of adjusting the diameter of fertilizer through-hole smaller, which mainly due to the processing accuracy didn't satisfy the design accuracy requirements. In order to ensure that no gap appears between the blades in the process of adjusting the diameter of fertilizer through-hole, the processing accuracy can be improved or the number of blades can be increased by one.

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