Design and Simulation Analysis of Seedling Picking Mechanism of Pot Seedling Transplanter

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Abstract: Aiming at the problems of complicated structure, difficult processing and high cost of transplanting mechanism of pot seedling transplanting machine, this paper develops a kind of crank and rocker type transplanting mechanism. The mechanism consists of transplanting arm, eccentric wheel, connecting rod and cylindrical cam seedling clamp. This paper analyzes the working mechanism of the seedling picking mechanism, and establishes the geometric relations among the components by selecting the appropriate parameters of the seedling picking and releasing points of the crank and rocker mechanism. A set of optimal solutions are solved iteratively by using the software of Matlab. Meanwhile, the cam mechanism used to control the opening and closing of the seedling clamp is designed by using the geometric characteristics of the seedling clamp and the periodic characteristics of the seedling clamp, and the results of Matlab are modeled in SolidWorks and imported into Adams for virtual simulation analysis. The analysis results showed that the seedling clamp could reach the pre-set position to pick and release seedlings smoothly through the movement of the seedling picking mechanism, which verified the correctness of the mathematical model of the seedling picking mechanism.

1. Introduction
Mechanized planting is the weakness of the rice mechanized production process [1]. At present, mechanical rice planting is mainly divided into two categories: direct seeding and transplanting. Direct seeding has a series of problems such as long growth cycle, slow growth rate, low rate of seedling formation and serious damage of grass [2-3]. Transplanting can be divided into three ways: blanket seedling, half pot seedling and pot seedling transplantation. In the process of planting, seedlings will be torn off the blanket seedlings by seedling claws and transplanted to the field, which is easy to cause damage to the seedlings' roots and result in slow seedling growth, thereby to affect its growth and development, and ultimately to cause yield reduction [4]. Pot seedling transplantation has obvious advantages, which can not only save seeds, but also reduce seedling injury, and slow seedling growth. Early and effective seedling distribution can greatly improve rice yield [5-6]. The key technology of pot seedling transplanter is seedling picking mechanism. For the existing seedling picking mechanism, there are some shortcomings such as complex structure and trajectory and high cost [7]. The great speed of the tip of the rotating seedling picking mechanism damages the seedlings and affects the growth of seedlings. Tensile strength of single or multiple seedlings is much greater than that of the extraction force of seedlings in the pot [8], and it is a feasible design scheme to pick seedlings by clamping the stalk of seedlings. The seedling picking mechanism of crank and rocker is widely used [9]. In view of the existing problems, it is particularly important to develop a clamp-and-pick seedling picking mechanism.

With reverse designing, and under the premise of reaching the requirement of picking seedlings, the
paper solved the movement track of seedling clamp by selecting the point of picking and releasing seedlings, which can simplify the structure of the seedling picking mechanism and reduce the speed of picking and releasing seedlings.

The seedling was taken out of the pot tray and dropped into the opened mud ditch through the conveying pipe of seedling by reciprocating swing transplanting arm. It is the better transplanting effect when the angle is not less than $130^\circ$ that between the seedling and the horizontal plane and that between the bus bar of the conveying pipe of seedling and the horizontal plane $^{[10]}$. Modeling and analyzing the seedling picking mechanism by SolidWorks and Adams, the paper solved the rod length by selecting trajectory of the mechanism, to find the value of the length of the rod that meets the requirements.

2. Working principle of seedling picking mechanism

As shown in Figure 1, the eccentric wheel 7 rotates at a constant speed and transfers the power to the transplanting arm 2 through the connecting rod 3, and two identical sprockets are built in the reciprocating swing transplanting arm 2. Through the chain 4, the lower sprocket 5 transmits the power to the cylindrical cam 15 fixed on the seedling clamping shaft 1. There is a seedling clamp 11 with ball 14 meshing with the cam15 on both sides of the cam 15. The cam 15 driven by the seedling clamping shaft 1 overcomes the resistance of the springs 9, 13, and 17 to control the opening of the seedling clamp 11. In the process of opening and closing seedling clamp 11, the upper and lower rubber rollers 16 at the end of the seedling clamp roll on the seedling clamping shaft 1 with the seedling clamp 11 to limit the seedling clamp 11. The spring 17 set in the seedling clamping shaft 1 to prevent the side swing of the clamp 11. The spring 9 and spring 13 at the ends controls the closing process of the seedling clamp 11 and completes the action of seedling picking and sending. The picking mechanism transplants the seedlings by putting the seedlings into the conveying pipe of seedling and dropping them into the opened mud ditch.

As shown in Figure 2, the seedlings clamped by seedling clamp is pulled out of the pot seedling hole, and moved to the top of the conveying pipe by the seedling clamp, finally put into the conveying pipe of seedling.

3. Design of seedling picking mechanism

3.1. Crank and rocker mechanism

Figure 3 is a schematic diagram of crank and rocker mechanism. According to the position of the picking and releasing seedling points, the mechanism is designed to meet the requirements of various motion rules and trajectories. It is one of the three requirements of connecting rod design that mechanism satisfies the predetermined trajectory $^{[11,12]}$.

Taking the center of crank rotation as the origin point in the plane rectangular coordinate system, the point of seedling picking and releasing are respectively used as the starting point and the end point to
delimit seedling picking trajectory. As shown in the Figure 3, in the plane rectangular coordinate system, point B is the coordinate origin, and AB is the frame, and BC is the crank, and CD is the connecting rod, and AE is the rocker and EF is the seedling clamp. The lengths are \(d, a, b, c+e, f\), respectively. The polar angle of crank and rocker mechanism is set to be 10°, and the minimum transmission angle is 45°. The seedling picking and releasing point is determined by the two endpoints of the planned trajectory, their coordinates are (266, 208) and (193, 231), respectively. The position, length and swing angle of crank and rocker mechanism are determined by seedling picking point \(N\) and seedling releasing point \(M\). It can be seen from the analysis that the length of the frame is 160 mm and the swing angle is 18.68°.

![Figure 3. Working principle diagram of the crank and rocker mechanism](image)

It can be obtained by using the law of cosines in \(\Delta BD_2A\), \(\Delta D_1BA\), \(\Delta C_3AD_3\) and \(\Delta C_3D_3A\).

\[
(b - a)^2 = d^2 + c^2 - 2cd \cdot \cos(\alpha) \\
(b + a)^2 = c^2 + d^2 - 2cd \cdot \cos(\alpha + \phi) \\
(d - a)^2 = b^2 + e^2 - 2be \cdot \cos(\gamma_{\text{min}}) \\
(b + a)^2 + (b - a)^2 - 2(b + a) \cdot (b - a) \cdot \cos(\theta) = (2c \cdot \sin(\frac{\phi}{2}))^2 \\
(e + c) \cdot \sin\left(\frac{\pi \cdot \alpha}{180}\right) + f \cdot \cos\left(\frac{\pi \cdot \alpha}{180}\right) = 231 \\
160 + f \cdot \sin\left(\frac{\pi \cdot \alpha}{180}\right) - (e + c) \cdot \cos\left(\frac{\pi \cdot \alpha}{180}\right) = 193
\]

The value of the swing angle, the polar angle, the minimum transmission angle and the rack length are taken into the above equations to solve the results by Matlab solver. The initial value of the given calculation is [20 170 145 45 35 160]. The solution results are shown in Figure 4.

![Figure 4. Diagram of solution result](image)

The results show that it approaches zero after six iterations. The calculation results are [21.697 189.759 167.697 61.656 19.941 138.715], and the calculation results are rounded to 22, 190, 168, 62, 20 and 139, respectively.
3.2. Cam model of seedling picking mechanism

The cam mechanism is simple and compact, which can meet complex motion requirements. The contour curve of cylindrical cam is studied by plane curve, and the cam is designed by the geometric characteristics of seedling clamp. The diagram of seedling clamp is shown in Figure 5.

![Diagram of opening and closing of seedling clamp](image)

The point \( O \) is the rotation center of the seedling clamp. The rod \( a \) and \( b \) are the length of front and back section of the seedling clamp respectively. The point \( P \) is the contact point between the seedling clamp and the seedling on the seedling clamp. The distance between the back ends is \( l_1 \) and the angle is \( \delta \) when the seedling clamp is closed, and the relationship is as follows.

\[
\delta = \arccos\left(\frac{2b^2 - l_1^2}{2b^2}\right)
\]

The distance between two back ends is \( l_1 \) and the angle is \( \varepsilon \) between two back seedling clamps when the seedling clamp is opened.

\[
\varepsilon = \arccos\left(\frac{2b^2 - l_1^2}{2b^2}\right)
\]

The rotation angle of the point \( P \) relative to the center of rotation \( O \) is

\[
\theta = \frac{\varepsilon - \delta}{2}
\]

The distance from \( P \) to the center of rotation \( O \)

\[
l_{op} = a \cdot \cos\left(\frac{\delta}{2}\right) = \frac{1}{2} a \cdot \sqrt{4 - \frac{l_1^2}{b^2}}
\]

The distance between \( P \) points of the seedling clamp is

\[
l = 2l_{op} \cdot \sin \theta
\]

The relationship between \( l_1 \) and \( l_1, l, a \) and \( b \) can be established by the upper formulas, and \( l_2 \) is to be solved. The distance between the two ends of the cam’s near pause and far pause are \( l_1 \) and \( l_2 \), respectively. The spacing between adjacent seedling combs is 20 mm, the distance between the endpoint of the seedling clamps is 16 mm when the seedling clamp is opened. and the pushing of cam is \( \frac{2(l_1 - l_2)}{2} \).

The crank and the cylindrical cam have the same speed 1r/s. The swing angle of the seedling clamp should not be too large to keep the cam in contact with the balls at both ends of the seedling clamp. The time of the seedling picking stroke is more than the seedling sending stroke, and the closing process of seedling clamp is short.
As shown in Figure 6, the work cycle of the seedling picking mechanism includes two parts: the seedling sending stroke (near pause and pushing, the clamp in closed state) and the seedling picking stroke (returning and far pause, the clamp in opened state).

4. Simulation and result analysis of seedling picking mechanism

4.1. Simulation analysis of crank and rocker mechanism

Taking the crank rotation center as the coordinate origin, the crank and rocker mechanism is modeled in SolidWorks. Then the 3D model is converted into Parasolid format by data exchange and imported into Adams/view, as shown in Figure 8. Constraints (fixed pair, rotating pair) are added in the corresponding position of each component of the model, and the center of rotation of the crank is set a rotational drive $360^\circ/s$. When the termination time and the number of simulation steps are set to 2s and 360 steps respectively, the displacement curve of seedling clamp’s terminal F was obtained through simulation and post-processing.

Figure 8 is a trajectory diagram of the endpoint of the seedling clamp. Taking the coordinates of the two ends (192.71, 231.51) and (266.03, 208.38) on the endpoint motion trajectory curve, it can be picked and released at the previous point, which proves that the design of the picking mechanism is reasonable.
According to the clamp speed curve shown in Figure 9, the speeds of the reciprocating stroke of the clamp are inconsistent. The interval between the yellow and green lines means the seedling picking stroke which is slow, and the interval between the blue and yellow lines means the seedling sending stroke which is fast to reduce the delivery time. The speed of the clamp is too fast, which leads to a high rate of seedling hurt. According to Figure 9, the damage of the seedlings can be reduced when the speed of the seedling picking point is zero, and the effect of the instantaneous speed of seedling clamp on the seedling vertical degree can be reduced when the speed of seedling releasing point is zero. The initial speed of the seedlings before release has an effect on the movement of the seedlings, so the design of the seedling picking mechanism meets the requirements.

4.2. simulation analysis of Seedling clamp
The 3D model of seedling clamp is saved as paransolid file format and imported into Adams. Constraints, forces and drives are added to the appropriate locations, as shown in the Figure 10.

4.2.1. Simulation analysis

Figure 10. The simulation model of seedling clamp

Figure 11 shows the movement trajectory of the seedling clamp endpoint after simulation and post-processing. The maximum distance of opening and closing of seedling clamp is 16 mm (releasing seedlings), and the minimum distance is 0 (picking seedlings), which meets the requirements of clamping seedlings. Figure 12 is the displacement time curve of the endpoint of the seedling clamp, the seedling clamp can pick and release seedlings in the corresponding location according to the cam profile, which meets the requirements.

5. Conclusion
(1) This paper sets the trajectory by picking and releasing points, and establishes the mathematical relationship between the components of the seedling picking mechanism. A set of data that meets the length requirements are obtained by Matlab. At the same time, a cam mechanism is designed to cooperate with the seedling clamp, which meets the clamping requirements. The rod length was modeled in SolidWorks and virtual simulation analysis was performed through Adams. Therefore, it is verified that the design of the rod length is reasonable, and the seedling clamp can be picked and released normally.

(2) The mechanism’s zero speed at the seedling picking and releasing points can avoid the problem that the speed is too fast or can not be accurately picked during the seedling picking process. In addition, the seedlings can be transplanted smoothly by adjusting the inclination angle of the planting
table and formulating a suitable conveying pipe of seedling.

(3) 3D modeling and simulation analysis are used to shorten the design cycle and the cycle times of the trial production prototype.

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