Design of picking seedling device for plug seedling transplanter

R Y Ge¹,*, B B Kong² and J L Wu²

¹ School of Mechanical Engineering, University of Jinan, Jinan, 250022, China
² School of Mechatronics Engineering, Qilu Institute of Technology, Jinan, 250200, China

E-mail: me_gery@ujn.edu.cn

Abstract. Plug seedlings are the main way of modern seedling cultivation in China. Aiming at the problems of low efficiency, high labor intensity and poor work quality for manual transplanting or semi-automatic transplanting of plug seedlings, a stable and efficient seedling picking device is designed for the automatic transplanting machine. It is based on the gear-cam-link composite mechanism to realize the seedling trajectory in accordance with the agronomic requirements. The mathematical model of the seedling picking device is established, and the theoretical profile equation of the cam groove and the actual picking trajectory equation are deduced. The 3D model and the virtual prototype model of the picking seedling device are constructed, and the simulation trajectory is obtained, using SolidWorks and ADAMS software. The simulation results show that the simulation working trajectory has good consistency with the theoretical trajectory.

1. Introduction

It is a kind of effective way to cultivate seedlings using plug trays in greenhouse and then transplant outside into the field, which has become the main planting method for crops such as corn, cotton, tobacco, vegetables, and medicinal materials [1]. With the development of agricultural mechanization, the agronomic process of transplanting is gradually realized by transplanting machines. From the degree of automation, transplanting machines can be divided into manual transplanting machines, semi-automatic transplanting machines and fully automatic transplanting machines. At present, a variety of transplanting machines have been developed in China, but most of them are semi-automatic transplanting machines, that is, the planting work is completed by mechanical devices, and the seedling picking work is still performed manually, resulting in the poor seedling picking speed, which not only increases labor and costs, but also leaks seedlings due to human fatigue, so the transplanting efficiency of the whole machine is relatively low [2]. The research and development of automatic transplanting machine is the key to promote the mechanization of planting. As the core working part of the automatic transplanting machine, the seedling picking device determines the efficiency and quality of transplanting. Therefore, independent research and development of the automatic transplanting machine seedling picking device is a great significance to improve the mechanization level of planting in China. For this reason, a new type of automatic seedling picking device of the plug seedling transplanting machine is innovatively designed to solve the problems of complex structure,
high manufacturing cost and poor performance of the current automatic seedling transplanting device for automatic transplanting machine, and improve the speed and quality of transplanting operations.

2. Scheme Design of Seedling Picking Device

According to the agronomic requirements for transplanting plug seedlings, the automatic seedling picking device of the plug seedling transplanting machine is used to replace manpower to take the seedlings from the plugs and transfer them to the seedling cup according to a specific track, and then the plug seedlings are carried out by the planting mechanism. Planting, that is, the seedling picking device must meet special trajectory requirements. For example, the movement direction of seedlings should be perpendicular to the placement plane of plug as much as possible, and the seedlings should be placed vertically into the seedling receiving cup.

In order to achieve the requirements of seedling trajectory and attitude, domestic and foreign scholars have proposed a variety of seedling retrieval mechanisms, such as combined non-circular gear planetary seedling retrieval mechanism [3], planetary gear-link mechanism [4], etc. The linkage mechanism is widely used to achieve reciprocating movement and swing, but its motion law depends on the length of the component, and it cannot accurately achieve any given motion law; although the cam-link mechanism can accurately achieve any given motion law and Track, but the serial combination makes the overall size of the mechanism too large. Based on the double-crank mechanism that realizes a specific trajectory, and in order to increase the flexibility and dexterity of the trajectory design of the linkage mechanism, the length of the intermediate connecting rod of the double-crank mechanism is variable, thereby designing a gear-cam type connecting rod parallel combination mechanism to achieve the required work trajectory.

![Figure 1. The schematic diagram of the automatic seedling picking device of the plug seedling transplanting machine.](image)

Figure 1 shows the transmission diagram of the automatic seedling picking device of the plug seedling transplanting machine, which mainly controls the formation of the trajectory through the compound motion of the cam-type connecting rod, and through gear transmission, the degree of freedom of the whole transmission system is 1. Its working principle is: the seedling picking mechanism is fixed on the transplanting test platform through the bearing seat, the driving shaft drives the driving gear to rotate, and the driven gear meshing with it rotates; the driving gear and the driven gear are respectively fixedly connected with the driving roller and the driven rollers that constitute a driving crank and a driven crank. One end of the cam connecting rod with a cam groove is fixedly connected with the driving roller, and the other end is meshed with the driven roller to form a cam mechanism. Therefore, under the combined action of the combined motion of the gear-cam linkage mechanism, a predetermined working track can be obtained; the cam linkage is equivalent to a linkage with variable rod length, and the working path can be adjusted flexibly by optimizing the theoretical profile of the cam groove. When the driving gear is in the initial position, the seedling grabber is located at point C and completes the seedling picking action; when the driving gear rotates 180° anticlockwise from the initial position, the seedling picking claw mechanism starts to move along the CDE track and completes the seedling throwing at point E; when the driving gear continues to rotate...
from 180 ° to 360 ° counterclockwise, the tip track of the seedling claw mechanism returns to point C along the EFC straight-line trajectory to pick up seedlings again. The periodic movements of picking up, holding, throwing and returning were completed.

3. Mathematical Model of Seedling Picking Device

As shown in figure 2(a), the mechanism diagram of the automatic seedling picking device of the plug seedling transplanting machine is firstly made; figure 2(b) is the working track, in which EFC is the known straight-line return track, and CDE is the seedling taking track to be solved. As shown in figure 2(c), the moving rectangular coordinate system OXY is established with point o as the center of the circle, point o coincides with point A on the cam type connecting rod, and the x-axis coincides with the rod length L; the fixed rectangular coordinate system OXY is established with O as the center, and the center point O1 of the driving gear coincides with the O point of the fixed rectangular coordinate system OXY, that is, O2O1O is a double crank mechanism with variable rod length. The right-hand coordinate system is adopted, and the counter clockwise rotation direction is the positive direction. For the fixed coordinate system and the moving coordinate system, the X-axis and x-axis are taken as the starting edges.

Figure 2. Mathematical model of seedling picking device.

Let the OX direction be the initial edge of the cam connecting rod rotation, and the rotation angle of the cam connecting rod from the initial position is \( \phi_1 \), and other corresponding parameters are shown in Figure 2 (c).

3.1. The Cam Groove Theoretical Profile Equation

As shown in Figure 2(b), the working trajectory is divided into the desired working trajectory CDE and the known working trajectory EFC, namely the upper half of the working trajectory and the lower half of the working trajectory, the seedling picking device should be based on the lower half of the working trajectory (EFC) to get the theoretical contour curve equation in the cam-type connecting rod. Suppose that the trajectory equation of the working track EFC of the tip point P of the seedling in the lower half is as follows:

\[
Y_p = F(X_p) \quad (1)
\]
The angle $\theta$ between the $x$ axis of the moving rectangular coordinate system and the $X$ axis of the fixed rectangular coordinate system is as follows:

$$\theta = \arctan \left( \frac{Y_p - r \sin \phi}{X_p - r \cos \phi} \right)$$

(2)

The coordinates of point $P$ are $(X_p, Y_p)$ and point $A$ are $(r \cos \phi, r \sin \phi)$, that is, the length of rod length $L$, the relationship between point $P$ and angle $\phi$ is as follows:

$$(X_p - r \cos \phi)^2 + (Y_p - r \sin \phi)^2 = L^2$$

(3)

Suppose the relationship between angle $\phi_2$ and angle $\phi_1$ is as follows:

$$\phi_2 = \pi - \phi_1$$

(4)

The position coordinates of point $B$ in $OXY$ is as follows:

$$\begin{cases} X_B = -C + r_2 \cos \phi_1 \\ Y_B = r_2 \sin \phi_2 \end{cases}$$

(5)

The coordinate transformation relationship between the moving rectangular coordinate system $oxy$ and the fixed rectangular coordinate system $OXY$ is as follows:

$$\begin{cases} X = X \cos \theta + Y \sin \theta - r \cos(\phi_1 - \theta) \\ Y = -X \sin \theta + Y \cos \theta - r \sin(\phi_1 - \theta) \end{cases}$$

(6)

By introducing equation (1), equation (2), equation (3), equation (4) and equation (5) into equation (6), the theoretical contour curve equation can be obtained in cam connecting rod, that is, the displacement equation of point $B$ at $oxy$:

$$\begin{cases} X_{B1} = -(C + r_2 \cos \phi_1) \cos \theta + r_2 \sin \phi_1 \sin \theta - r \cos(\phi_1 - \theta) \\ Y_{B1} = -(C + r_2 \cos \phi_1) \sin \theta + r_2 \sin \phi_1 \cos \theta - r \sin(\phi_1 - \theta) \end{cases}$$

(7)

According to equation (7), the coordinate points $(x_{B1}, y_{B1})$ of theoretical contour curve of cam groove in cam type connecting rod can be obtained.

**Working Track Equation**

The trajectory equation of theoretical contour curve of cam groove with point $B$ is as follows:

$$\begin{cases} x_B = f(x) \\ y_B = f(y) \end{cases}$$

(8)

Coordinate position of point $B$ in $OXY$ coordinate system:

$$\begin{cases} X_B = -C + r_2 \cos \phi_2 \\ Y_B = r_2 \sin \phi_1 \end{cases}$$

(9)

The coordinate transformation relationship between the fixed rectangular coordinate system $OXY$ and the moving rectangular coordinate system $oxy$ is as follows:

$$\begin{cases} X = x \cos \theta - y \sin \theta + r_1 \cos \phi_1 \\ Y = x \sin \theta + y \cos \theta + r_1 \sin \phi_1 \end{cases}$$

(10)
From equation (8), equation (9) and equation (10), the displacement equation of $CDE$ in the upper half of the trajectory can be obtained, this is, the displacement equation of $P(X_P, Y_P)$ is as follows:

\[
\begin{align*}
X_P &= L \cos \theta + r \cos \phi_i \\
Y_P &= L \sin \theta + r \sin \phi_i
\end{align*}
\]

(11)

4. 3D Modeling and kinematic simulation of seedling picking device

The 3D solid model of all the parts of the seedling device is completed and assembled in SolidWorks, as shown in figure 3. The 3D solid model is imported into ADAMS, and the virtual prototype of the device is established, as shown in figure 4. Setting the speed of the driving shaft 120 rad/s, the kinematic simulation is performed. As shown in figure 5(a), the theoretical working trajectory of the end point of seedling claw is calculated using MATLAB software according to equation (11), and the simulation working trajectory of that in ADAMS is demonstrated in figure 5(b). It can be seen from Figure 5 that the simulation trajectory curve is consistent with theoretical motion trajectory basically, which verifies that the designed structural parameters can meet the working trajectory required by the automatic seedling picking device of the plug seedling transplanter.

5. Conclusions

An innovative automatic seedling picking device of the plug seedling transplanting machine is designed to take place of the action and posture of the manual seedling picking and seedling throwing. The kinematic model is established to realize the working trajectory including seedling picking, seedling holding, seedling throwing and return. The structural parameters are determined and the 3D modeling of the seedling picking device is finished with SolidWorks software. After the model is
simplified, a virtual prototype based on ADAMS is built. The motion simulation verifies the consistency between the theoretical trajectory and simulation trajectory.

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