Design and analysis of planting mechanism for a self-propelled transplanting machine

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Abstract: In order to solve the problems such as missing planting, burying seedlings and pouring seedlings of the current transplanter, a planting mechanism was designed and its function was analyzed theoretically in the paper. Firstly, the three-dimensional model of the transplanting mechanism was established; secondly, the mathematical model of the end movement trajectory of the transplanting mechanism was established and calculated using Matlab; finally, the motion simulation of the planting mechanism was carried based on ADAMS. The simulation results show that the velocity of the end of the planting mechanism is as same as the theoretical calculation. Therefore, the planting time and the seedling taking time were obtained in order to increase the planter’s movement stability and the rationality of structure.

1. Introduction

The planting mechanism is the core part of the pot seedling transplanting machine, and its working process is to imitate the process of planting pot seedlings into the hole by hand[1].

At present, transplanting machine can be divided into clamping type, flexible disc type, planetary gear type, multi-link type, guide seedling tube type,[2-5] etc. Clamping, flexible disc and guide seedling tube transplanter have three steps to complete the transplanting which are ditch opening, seedling falling and soil covering and are mostly used for filmless transplanting. The transplanters above have many problems such as inverted seedling or buried seedling.

In order to improve the transplanting quality of the transplanters, many scholars had done many works to optimize the planting mechanism. Yin Daqing[6] designed a planting mechanism with a kind of high speed variable posture grafting duck mouth which average qualified rate of planting was 99.8% and average qualified rate of planting depth were 99.2%. Hu Jianping[7] put forward a kind of duck-mouth planting mechanism using a planetary gear system with constant speed gear. The duck-mouth was fixed on the planetary gear to meet the requirements of multi-distance transplanting. Zhang Kaixing[8] proposed a five-bar planting mechanism which could meet the planting requirements.

In view of the poor verticality of pot seedlings in the transplanting process of duck-mouth transplanting machine and other problems such as inverted seedlings and buried seedlings, a new duck-mouth planting mechanism was designed in this paper based on the multi-wheel mechanism designed by the our research group.

2. Design of planting mechanism

The planting mechanism designed in this paper is shown in Figure 1, which is mainly composed of duckbill transplanter, active planetary wheel, driven planetary wheel, eccentric shaft, connecting piece and so on. When the duck-mouthed planter distributed on planetary wheel moved to the pick-up position,
the bowl seedling was sent to the seedling location at the same time. So the bowl seedling will be entered the duck-mouthed planter. Then the duckbilled planter moved to planting position with pot seedling. The duckbill transplanter was inserted into the soil and opened. A hole was be made under the action of the spring driven by the cam and the pot seedling falls into the hole just made above. The duckbill transplanter rotated to complete the planting process. Multi-link transplanting machine and planetary gear transplanting machine rely on the plante's own drilling for seeding, multi-link transplanting machine transplanting prone to inverted seedling problems. Planetary gear motion is stable, easy to achieve high-speed transplanting.

Figure 1 Planting mechanism

3. Motion Analysis of Transplanting Process

3.1. Theoretical calculation of transplanting process
The rectangular coordinate system \(XOY\) was established taking the upper axis of the eccentric axis as the origin point \(O\), the horizontal right direction as the positive direction of \(X\) axis and the vertical upward direction as the positive direction of \(Y\) axis, which was shown in Figure 2.

Figure 2 Analysis of Planter Motion

Based on the rectangular coordinate system above, the relative coordinates of the end of duckbill transplanter was established as follow:

\[
X = D_1 \cdot \sin \varphi_1 + D_2 \cdot \sin \varphi_2
\]  
(1)

\[
Y = D_1 \cdot \cos \varphi_1 + D_2 \cdot \cos \varphi_2
\]  
(2)

And the \(X\) and \(Y\) were differentiated based on the position coordinate relation of duckbill transplanter obtained above.
The equations above could be simplified as follows:

\[ dX = \frac{\partial x}{\partial \varphi_1} d\varphi_1 + \frac{\partial x}{\partial \varphi_2} d\varphi_2 \]  

(3)

\[ dY = \frac{\partial y}{\partial \varphi_1} d\varphi_1 + \frac{\partial y}{\partial \varphi_2} d\varphi_2 \]  

(4)

The equations above could be simplified as follows:

\[
\begin{bmatrix}
    \frac{\partial x}{\partial \varphi_1} & \frac{\partial x}{\partial \varphi_2} \\
    \frac{\partial y}{\partial \varphi_1} & \frac{\partial y}{\partial \varphi_2}
\end{bmatrix}
\begin{bmatrix}
    d\varphi_1 \\
    d\varphi_2
\end{bmatrix}
\]  

(5)

Where,

\[ J = \begin{bmatrix}
    \frac{\partial x}{\partial \varphi_1} & \frac{\partial x}{\partial \varphi_2} \\
    \frac{\partial y}{\partial \varphi_1} & \frac{\partial y}{\partial \varphi_2}
\end{bmatrix} \]  

(6)

So the equations could also be gotten as below,

\[
\begin{bmatrix}
    dX \\
    dY
\end{bmatrix} = J
\begin{bmatrix}
    d\varphi_1 \\
    d\varphi_2
\end{bmatrix}
\]  

(7)

The Jacobian matrix \( J \) could be rewritten as below:

\[
J = \begin{bmatrix}
    D_1 \cos \varphi_1 + D_2 \cos \varphi_2 & D_2 \cos \varphi_2 \\
    -D_1 \sin \varphi_1 - D_2 \sin \varphi_2 & -D_2 \sin \varphi_2
\end{bmatrix}
\]  

(8)

So the linear velocity of the end of the duckbill transplanter could be rewritten as below.

\[ V = J \dot{\varphi}_1 + J \dot{\varphi}_2 \]  

(9)

The expressions \( J_1 \) and \( J_2 \) are vectors of the first and second columns of Jacobian matrix \( J \). Finally, the end velocity of the duckbill transplanter could be written as below.

\[
\begin{bmatrix}
    V_x \\
    V_y
\end{bmatrix} = J
\begin{bmatrix}
    \dot{\varphi}_1 \\
    \dot{\varphi}_2
\end{bmatrix}
\]  

(10)

Due to the particularity of the planting mechanism in this paper, \( \varphi_1 \) and \( \varphi_2 \) were supplementary angle, and the rotational angular velocities of the two angles were opposite number. Therefore, supposing that the angular velocity provided by the driving motor was set to \( \delta \), the final formula was as follow:

\[
\begin{bmatrix}
    V_x \\
    V_y
\end{bmatrix} = \begin{bmatrix}
    \partial D_1 \cos \varphi_1 \\
    -\partial D_1 \sin \varphi_1
\end{bmatrix}
\]  

(11)

The speed at the end of the duckbill planter was only related to the radius of the driving and the driven wheel and the angle of its position \( \varphi_1 \). The above formulas were imported into MATLAB and the velocity curves in \( X \) and \( Y \) directions at the end of the duckbill transplanter could be obtained as shown.
in Figure 3. The planting time and seedling picking time can also be obtained by the speed at the end of the duckbill planter.

![Velocity curve at the top of duck bill](image)

**Figure 3** Velocity curve at the top of duck bill

### 3.2. Kinematic characteristics analysis

Analyses of the overall mechanism of the planter using ADAMS could directly find out the rationality of the structure and its motion performance. Firstly, the three-dimensional model of the whole mechanism of the planter was imported into ADAMS, and the gravity was added in the ADAMS working environment (as shown in table 1). Then, binding force and driving force were added to the planter model. The calculation was done after preparation work completion. The end of one duckbill planter was selected as the target point in ADAMS to capture the velocity changing during post-processing. The output speed in the $X$ and $Y$ directions of the target point were selected to generate the speed curve (shown in Figure 4).

| Constraints and driving speed | Component 1                  | Component 2                  |
|------------------------------|------------------------------|------------------------------|
| Fixed pair 1                 | Eccentric shaft              | Ground                       |
| Rotating join 1              | Six planting apparatus       | Driving wheel                |
| Rotating join 2              | Six planting apparatus       | Engaged wheel                |
| Rotating join 3              | Driving wheel                | Eccentric shaft              |
| Rotating join 4              | Engaged wheel                | Eccentric shaft              |
| Driving speed 1              | Rotating join 3              | 10r/min                      |

![Output speed in the $X$ and $Y$ directions of the target point](image)

**Figure 4** Output speed in the $X$ and $Y$ directions of the target point

The simulation results show that the end speed of the seeder was the same as the theoretical calculation results.
3.3. Analysis of planting time

The angle of the duck bill planter from the time which touched the ground to the time which left
the ground was called the planting angle or the planting time. The rotating angle of the duck bill planter
from the beginning of the duck bill planter which contacted the seedlings to the seedlings completely
into the duck bill planter was called the seedling angle or the seedling time.

As shown in Figure 5, this position of the planter was the beginning of planting process. When the
soil entry point started to touch the ground, the planting process began. As shown in Figure 6, when the
end of the planter started to leave the ground, it is indicated that the planting process was completed.

Figure 5 Start of planting    Figure 6. End of planting

The rectangular coordinate system $XOY$ was established with the axis of the lower side of the
eccentric shaft as the origin $O$, the horizontal left direction as the positive direction of $X$ axis, and the
vertical upward direction as the positive direction of $Y$ axis, which was shown in Figure 5. The planting
angle $\alpha$ was shown in Figure 6. The distance from the origin $O$ to the installation hole $C$ was $R$, and the
distance from the installation hole to the end of the planter was $L$. So the planting angle was gotten as
below.

$$\alpha = \arccos \left( \frac{(OA)^2 + (OB)^2 - (BC)^2}{2OA \cdot OB} \right)$$  \hspace{1cm} (12)

Where,

$$OA = OB = \sqrt{R^2 + L^2 - 2RL \cos \left( \frac{\pi}{2} - \theta \right)} = \sqrt{R^2 + L^2 - 2RL \cos \theta}$$  \hspace{1cm} (13)

$BC$ is the displacement of the end of the planter in the $X$ direction, which was denoted by $x$,

$$x = \int_{t_1}^{t_2} V_x \, dt$$  \hspace{1cm} (14)

$t_1$ is the start time of planting and $t_2$ is the end time of planting.

If $R=150$mm, $L=90$mm, so the planting angle $\alpha$ could be rewritten as below.

$$\alpha = \arccos \left( \frac{x}{2 \sqrt{L \cdot x - L^2 + R^2}} \right) = \arctan \left( \frac{\int_{t_1}^{t_2} V_x \, dt}{ \frac{1}{2} \left[ \int_{t_1}^{t_2} V_x \, dt + 14400 \right] } \right)$$  \hspace{1cm} (15)

The planting angle is related to the radius of the main and driven wheels and the position angle $\varphi_1$ at
the beginning of planting. It can be seen from Figure 4 that: when the output speed was 10 r/min, (1) in
0 seconds the planter began to touch the ground; (2) in 0 to 1.5 seconds, the planter began to open the hole; (3) 1.5 to 1.8 seconds was the main time of transplanting. At this stage, the duck mouth would be opened and the pot seedling would be released; (4) between 1.8 and 3.2 seconds, the planter continues to work to prepare for subsequent wheel cover’s working. The planter reached the lowest point in 1.6 seconds, at this time, the pot seedling has been completely thrown out. When time approached 3.2 seconds, the planter left the ground and the planting ended. All the time for planting was beyond 3 seconds which would give the planter enough time to throw out the pot seedling.

4. Conclusion
A duck bill planter composed of planetary wheel, planter and eccentric wheel was designed. The structure and working principle of the duck-billed planter were introduced. And the velocity at the end of the duck bill planter was obtained by theoretical calculation with MATLAB.

The planting mechanism’s functions were simulated based on ADAMS. And the simulation result showed that the end speed of the planter was the same as the theoretical calculation. And the planting time were over 3 seconds when the planting mechanism output speed was 10 r/min.

When the output speed was constant, the planting angle is related to the radius of the main and driven wheels and the position angle \( \Phi \) at the beginning of planting.

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