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Design of planting mechanism for rapid return transplanter

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Abstract Large-scale crop planting uses transplanting machines to transplant seedlings. The planting mechanism of transplanting machines is the last step of the transplanting machine seedlings. In the production practice, the planting mechanism often causes the seedlings to be turned over and logging, which affects the survival rate of the crops. In response to this problem, the mathematical model of the planting mechanism which combined with the digital design method was established. SolidWorks2017 was used to design a rod-type plant with rapid return characteristics. The rationality of the planting mechanism was tested using ANSYS 17.0. A quick-return transplanter planting mechanism with reasonable motion characteristics and reliable work performance was obtained.

1. Introduction

At present, transplanting machines are widely used in the planting process of crops, including corn in food crops, various vegetables in cash crops, etc. In order to improve the survival rate, various seedlings are transplanted into the fields using transplanting machines [1-4]. The planting mechanism of the transplanting machine is an important link in the transplanting process. The planting mechanism on the existing transplanting machine often has the situation that the seedlings are turned over and fall, which leads to the roots of the seedlings to expose and die and has directly impact on the quality of planting [5-7]. The occurrence of this kind of situation is mostly caused by the unreasonable design of the planting mechanism. The planting mechanism does not meet the requirements of “zero-speed seedling” and “low-acceleration seedling” when seedlings are planted [8-9], the seedlings flip due to its own speed and acceleration when they are falling down. The multi-rod planting mechanism is widely used in semi-automatic transplanters because of its simple structure and cost-effective.

2. The structure and working principle of the transplanting plant

2.1. Structural design

He planting mechanism is fixed on the tractor, so it has the speed of the tractor in traveling direction when throwing seedlings. The planting mechanism itself generates acceleration, and the movement process of the duckbill device from the seedling to the seedling is also accelerated with the movement of the planting mechanism. If the speed and acceleration of the duckbill device of the planting mechanism are too large, the seedlings will be turned over and fall down. Therefore, the design of the planting mechanism should meet the principle of low speed and low acceleration of the duckbill seedlings [10].

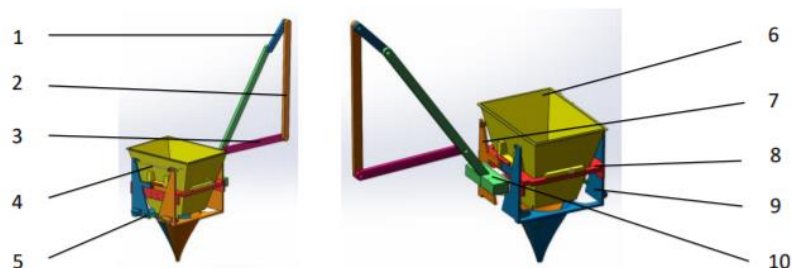
The crank rocker mechanism in the four-bar mechanism has a rapid return characteristic [11], and the working stroke speed and acceleration of the crank rocker mechanism are lower than the return



stroke. Therefore, applying the crank rocker mechanism to the planting mechanism can decrease the speed and acceleration of the process of seedling throwing and reduce the probability of the seedlings turning over and lodging. moreover, the application also make the mechanism quickly leave the working soil during the return journey to avoid the fall of the seedling. On this basis, Solidworks 2017 is used to draw a three-dimensional model of the planting mechanism of the quick-return transplanter, as shown in 'Figure 1'. The quick-return transplanting planting mechanism is composed of a crank-link mechanism and a planter. The crank-link mechanism is composed of a frame, a crank, a rocker and a connecting rod, and the planter is composed of a duckbill device I, a duckbill device II, a spring, a brake line, a seedling bucket and a support frame.

2.2. Working principle

A decription of the working principle of the rapid-return transplanter planting mechanism is given with reference to 'Figure 1'. The entire planting mechanism relies on the fixed connection of the frame and the tractor. The crank rotates at a constant speed to drive the rocker to swing the rocker. The lower end of the swing bar is fixed with a planter, and the planter moves with the end of the rocker. Because the reciprocating stroke of the end of the rocker is different, it means the working stroke speed and acceleration of the rocker end are low, while the return speed acceleration is high ,and therefore the plant has a quick return characteristic during the working process, meanwhile, the planter is relatively stable from the seedling to the seedling,so The seedlings are not easy to turn over and fall down.and it also quickly leave the soil when returning, avoiding the fall of the seedlings. At the beginning of the operation, the duckbills I and II remain closed, and the seedlings can be used to pick up the fallen seedlings, and the duckbills are then sent to the soil by means of a crank rocker mechanism. When the lower end of the planter moves to the lowest point, the external force pulls the brake line, and the lower ends of the duckbills I and II are opened, and the seedlings fall into the soil. As the tractor travels ,The entire working process continues to circulate, the seedlings are orderly planted in the working soil.



1 crank. 2 rack. 3 connecting rod. 4 brake line. 5 spring. 6 picking up the bucket. 7 duckbill I. 8 support frame. 9 duckbill II. 10 rocker.

Figure 1. Overall structure of the planting mechanism of the rapid return transplanter.

3. Theoretical analysis of the motion characteristics of the planting mechanism of the quick-return transplanter

3.1. Theoretical model

In order to facilitate the analysis of the motion characteristics of the planting mechanism, a structural diagram of the planting mechanism is established, as shown in 'Figure 2'. For racks \overline{AD} , the crank is indicated by \overline{AB} , the rocker is indicated by \overline{BC} , and the connecting rod is indicated by \overline{CD} .

3.2. Mathematical model

$$v_R = \omega_1 l_{AR} \quad (1)$$

$$v_B = \omega_2 l_{BF} \quad (2)$$

$$v_T = \frac{\omega_1 l_{AB} l_{FT}}{l_{BF}} \quad (3)$$

 ω_2 —the angular velocity of the rod AB, rad/s.
$$v_{B1} = v_{B2} = \omega_1 l_{AB} = \omega_2 l_{BF} \quad (4)$$

Calculate the angular velocity of the rocker

$$\omega_2 = \omega_1 \frac{l_{AB}}{l_{BF}} \quad (5)$$

$$\alpha_2 = \omega_1 \frac{l_{BF} \frac{dl_{AB}}{dt} - l_{AB} \frac{dl_{BF}}{dt}}{l_{BF}^2} \quad (6)$$
$$\alpha_2 = -\omega_1 \frac{dl_{BF}}{dt} \frac{l_{AB}}{l_{BF}^2} \quad (7)$$
$$a_T^t = \alpha_2 l_{BT} \quad (8)$$

$$a_T^n = \frac{(v_T \cos \theta)^2}{l_{BT}} \quad (9)$$

$$\alpha_B = \frac{v_B^2}{l_{AB}} \quad (10)$$

$$a_T = a_B + a_{AB}^n + a_T^t \quad (11)$$

a_B —the acceleration of point B, m/s²;

a_T —the acceleration of point T, m/s^2 .

4. Kinematics simulation of planting mechanism of rapid return transplanter

4.1. Motion trajectory analysis

The analysis of the trajectory of the planter take the lower end of the duckbill as analytical point, as shown in 'Figure 3'. The left half of the trajectory represents the working stroke, and the right half of the trajectory represents the return stroke. It can be directly seen that the trajectory has the characteristics of large working stroke and small return stroke, which can ensure stable work during seedling and quickly recover the planter after the seedling is completed.

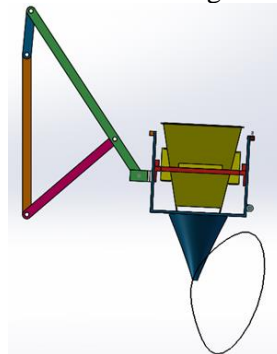
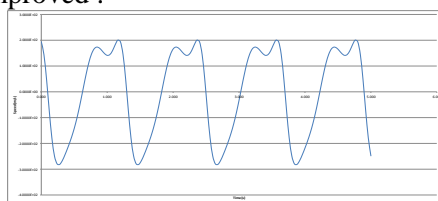


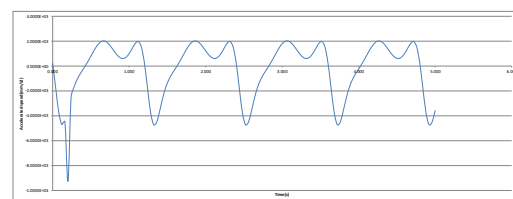
Figure 3. The working track of the lower end of the duckbill.

4.2. Speed and acceleration analysis

The lower end point of the planting duckbill can indicate the movement characteristics when the seedlings are detached from the planting mechanism. Therefore, the speed and the acceleration of the horizontal direction of the lower end of the duckbill are selected as the research object. According to the current working speed of most transplanters, the crank speed is set to 30r/min. The velocity and acceleration characteristics of the lower end of the duckbill are shown in 'Figure 4'. When the platypus opener is opened, the horizontal speed of the break point of the slap beak is about 100mm/s, and the horizontal acceleration is close to 0, so the planting mechanism can better satisfy the requirements of "zero speed seedling" and "low acceleration". So the quality of seedling transplanting have improved .



(a) speed



(b) acceleration

Figure 4. Speed and acceleration diagram of the lower end of the duckbill.

5. Dynamic simulation of planting mechanism of quick-return transplanter

5.1. Crank strength check.

The crank provides power to the entire planting mechanism and is highly stressed. Static analysis of its structure is completed with ANSYS 17.0. Its stress and strain cloud diagrams are shown in 'Figure 5'. The maximum stress is 1.6955MPa, the maximum strain is 0.0030744mm. And the deformation of the material is negligible. so the structural strength of the crank is acceptable.

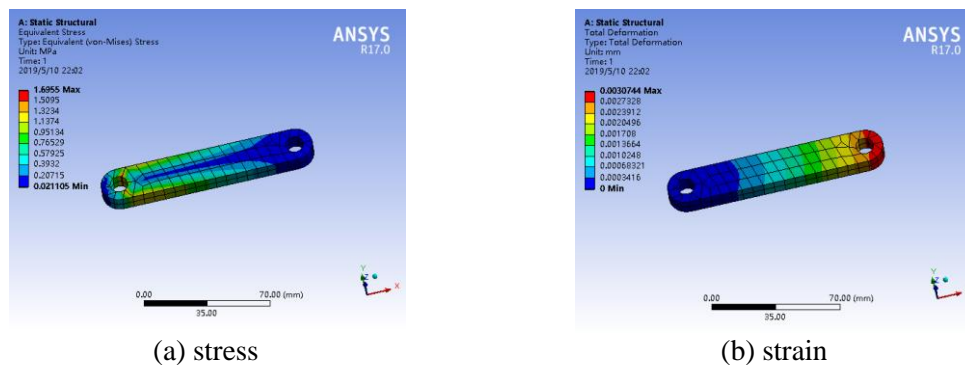


Figure 5. Schematic diagram of the static structure analysis of the crank.

5.2. Modal analysis of the support frame

The 3D model of the support frame was drawn with SolidWorks2017, and the conversion format was imported into ANSYS 17.0. The modal analysis function in ANSYS Workbench was used for processing. Because considering the overall weight of the planting mechanism. Fix the hole connected to the rocker in the support frame model, apply the 5N pre-tightening force on the upper surface of the support frame to simulate the weight of the connecting part of the support frame, divide the mesh, and obtain the sixth-order mode of the support frame, as shown in Table1. When the tractor engine is working, the vibration frequency of the tractor engine is generally low. The support frame does not resonate with the engine, and the structure of the planting mechanism does not be destroyed due to resonance.

Table 1. Sixth-order modal frequency distribution table of the support frame.

Mode	Frequency[Hz]
1.	66.261
2.	143.62
3.	218.77
4.	443.96
5.	695.99
6.	724.34

6. Conclusion

According to the analysis of the mathematical model and the kinematics analysis of the model using Motion in SolidWorks2017, a rapid-return transplanter planting mechanism with reasonable motion characteristics was designed. This planting mechanism can meet the requirements of some crop seedlings transplanting. It can effectively decrease the rate of seedling lodging and increase the survival rate of seedlings. Static design analysis and modal analysis were carried out on the designed planting mechanism with ANSYS 17.0. The overall working performance of the planting parts was verified to ensure that the strength of the planting mechanism meets the requirements ,the structural characteristics are reasonable and it is not easy to fatigue and damage. This design can be reliably applied to the cultivation of crops such as corn and vegetables, improving work efficiency and further reducing the production cost of these crops.

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