Design and simulation analysis of a transplanting mechanism for rice transplanter

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Abstract. In order to improve the performance of rice transplanter, we have designed a new transplanting mechanism of rice transplanter. To verify its feasibility, 3D simulation model was performed by using SolidWorks software. As vibration characteristic is the key index that affects the performance of transplanter, the ANSYS software was used to analyze the vibration modal of the designed structure. From analysis, the natural frequency and the first 20 modes of the designed mechanism were obtained, which provided a theoretical basis for the design of transplanting mechanism and improved the performance of transplanting machine.

1. Introduction

With the development of mechanization and modern agriculture, transplanting operation has long been transformed from traditional artificial rice transplanting to mechanical rice transplanting. As the deepening of agricultural mechanization, more requirements have been put forward for the operation of the rice transplanter, which more efficiency, precision and reliability rice transplanter are needed. The core component of the rice transplanter, which determines the performance of the rice transplanter, “Transplanting Mechanism” has a direct impact on the quality, reliability, and efficiency of the rice transplanter. Therefore, most of the research on the rice transplanter is also focused on the “transplanting mechanism”\cite{1}. Up to now, this kind of transplanting mechanism mainly can be classified into two categories. One is a traditional transplanting mechanism and the other is a high-speed transplanting mechanism. The traditional transplanting mechanism is represented by a crank rocker mechanism; the high-speed transplanting mechanism is represented by an elliptic gear planetary system mechanism and eccentric gear planetary mechanism\cite{2}. The common point of the two is that the planting arm drives the picking pin to complete the comprehensive operation of the picking and transplanting. When designing, it is necessary to comprehensively consider the picking action, the transplanting action, and the swinging action. There are many limitations and it is difficult to satisfy the comprehensive parameters. Through research and analysis, these two mechanism have their own advantages and disadvantages. The structure of the crank rocker plug and insert mechanism is simple, low in cost and high in reliability, but connecting rod motion inertia when motion is bigger, and high-speed transplanting cannot be achieved. At the same time, there are problems such as the seedlings are torn, the seedlings are poorly erected, and serious soil hanging belt and large holes of rice seedlings. High-speed transplanting mechanism can realize high-speed transplanting, but relatively high manufacturing accuracy, cost is higher, the planting trajectory is messy. The kinematic characteristics of the take-off site were poor, and the tearing method was adopted when transplanting, which also caused greater damage to the seedlings \cite{3}. After analysing and researching, this paper optimizes and improves the transplanting mechanism and designs a new type of transplanting mechanism.
2. Design and 3d modeling of transplanting mechanism

2.1. Design of transplanting mechanism

After research and discussion, the picking needle in the traditional transplanting mechanism (as shown in Figure 2.1) shoulder both picking and planting movements, which is always mutually restrictive of ensuring the picking and planting in the optimal state.

For instance, while ensuring the erectness of the seedlings at the time of picking and avoiding tearing the seedlings, it is impossible to assure the size and depth of acupoints when transplanting. If the size and depth of seedlings are to be optimized during transplanting, it will not guarantee the picking action parameter track[4]. An interpolation method is proposed to overcome these problems simultaneously of adding a picking robot arm to the transplanting mechanism, which is named picking arm. One can complete the taking-seeding action alone, instead of the needle’s taking and inserting. The picking robot arm is placed above the planting arm and the moving box structure middle chain box, and adopts the crank rocker mechanism. The crank is the active part and rotates at a constant speed, the rocker swings for the follower, and the connecting rod does plane compound movement. At the same time improve the transplanting mechanism, increase the transmission device of the picking arm[5-6]. After the optimization, the increased picking robot arm is used to complete picking and placing operation, and the picking needle only completes the inserting action, so that the planting mechanism reduces the constraints of picking angle, picking amount, picking height, the tilting of the picking arm and etc, which allows the planting arm to optimize the parameters with greater degrees of freedom.

2.2. Structure Diagram and 3D Modeling of Robot Arms

After the design idea was put forward, the structure diagram was drawn on the designed picking robot arm (as shown in Fig. 1.2) and three-dimensional structure modeling was performed using SolidWorks software (as shown in Fig. 1.3) to prepare for the later structural simulation and optimization.
3. Simulation Analysis of Robot Arms

3.1. Simulation basis and principle

The accuracy of the arm picking is an important indicator to measure the effectiveness and performance of its work. Whether it can take the seeding accurately and does not cause tear damage to the seedlings during the picking process is the key to the success or failure of the pick arm design. In the process of design, accurate picking of the pick-up arm has been achieved. However, whether this structural design and the cooperation of other components is reasonable, and whether the mechanism can work accurately in the continuous transplanting operation requires corresponding verification and optimization. Especially in the transplanting operation, it will inevitably cause bumps and vibrations of the transplanter. If the picking arm has a high vibration, the accuracy of the picking will be affected, and even the picking cannot be achieved\cite{7}. Therefore, it is necessary to study the vibration characteristics of the take-up arm to provide a theoretical basis for the design and optimization of the take-up arm, so as to make the design more rational. Because it is relatively complicated to obtain the vibration mode through the analytical method, the finite element method is used to analyze the vibration mode, which can make the solution process more simple and convenient. The basic principle of the solution is as follows:

The free vibration equation of the finite element model is:

\[ M \ddot{x} + Kx = 0 \] (1)

Type of \( M \) - total mass matrix of finite element model for transplanting mechanism

\( K \) - total stiffness matrix of the finite element model of a transplanting mechanism

\( X \) - modal shape displacement vectors of the model

The solution of equation (1) is:

\[ \delta = \delta_0 \sin (\omega t + \phi) \] (2)

Bring equation (2) into equation (1), condition for obtaining a non-zero solution is that the value of its determinant coefficient is 0, that is:

\[ |K - \omega^2 M| = 0 \] (3)

Type of \( \omega \) - natural frequency of free vibration of the transplanting mechanism

Solving formula (3) can get the eigenvalues of the equations and the corresponding eigenvectors, that is, mode frequency and mode mode mode\cite{8-9}.

3.2. Establishing a finite element model for taking arm

The 3d model of rice picking arm constructed by SolidWorks is stored as Parasolid(*.X-t) file and imported into ANSYS software. In order to improve the speed and quality of ANSYS meshing and reduce calculation errors, the arm model for arm acquisition is simplified. The main component of the arm is its main arm. The vibration of the main arm determines the vibration of the arm. Therefore, the main arm is simulated and analyzed. After the model is imported, the properties of the model are defined in ANSYS. The elastic modulus is 210GPa, Poisson's ratio 0.3, mass density 7800 kg/m³, the results after meshing are shown in Figure 3.1:
3.3. Modal Analysis
When the external excitation source and the natural frequency of the component are the same or similar when the rice transplanter is working, it will cause severe vibration of the arm mechanism, so that the movement path of the retrieval arm will deviate from the movement trajectory, which will seriously affect the accuracy of picking up seedlings and transplanting efficiency. More seriously cannot work normally. Through the simulation analysis, we get the first 20th frequency mode, the first 20th natural frequency (as shown in Figure 3.2), and the oscillating mode shape (shown in Figure3.3-Figure 3.8):
After analysis, it was found that the first 20 modes could be classified according to the mode characteristics: the 5th and 6th mode vibration modes were the vibrations of the lower part of the main boom; the 7th and 8th mode vibration modes have larger vibrations in the upper part of the main arm ;The 11th and 14th modes of the mode shape are relatively violent for the entire main boom. And the 14th-order mode vibration has the largest vibration, even the main arm has undergone severe distortion.
4. Conclusion

Through the research and analysis of the transplanting mechanism of the rice transplanter, the original transplanting mechanism was redesigned and the picking robot arm was added. In order to verify the feasibility of the designed mechanism, a three-dimensional simulation modeling of the organization was conducted, which verified the feasibility of the mechanism. What is more, a modal simulation analysis was performed to obtain the vibration characteristics of the designed mechanism. The result of the modal analysis shows that: When the frequency of the external excitation source is close to the natural frequencies of the 8th, 11th, and 14th modes, the resonance displacement is large, and the resonance frequency generated when the natural frequency of the 14th mode is close to the maximum. So during the design process, it should be far away from these three frequencies to avoid resonance and cause structural failure.

In order to overcome the influence of its periodic external excitation vibration source on the picking arm and improve the working efficiency and planting quality of the rice transplanter, we can reduce or alleviate vibration by the following methods during the design process:

1) Reasonable structural design can reduce the resonance phenomenon; changing the material of the pick-up arm and appropriately increasing the section size can increase its natural frequency and keep its natural frequency away from the external excitation frequency.

2) By changing the stiffness of crank and rocker, the energy of external excitation can be absorbed to reduce vibration. [10].

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