Design and Analysis of Multifunctional Spinach Tillage and Planting Machine

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Abstract. Due to the lack of integrated mechanized farm equipment for spinach cultivation in the current market, this paper studies a multifunctional spinach cultivation machine, which applies modular and multifunctional design, through the design of four functional structures, so that it can adapt to different soil conditions and crop planting needs. The structural reliability and use stability of the agricultural machine are verified through the design calculation of torque, the role of institutional bearing force and finite element static load analysis. After a large number of experiments and practical applications, it is verified that this agricultural machinery has certain practical applicability, thus alleviating the market gap of spinach planting integrated agricultural machinery and equipment to a certain extent.

Keywords: spinach seeds; Multifunctional Agricultural Machines; finite element analysis

1 Introduction

Since the release of the State Council's *Guiding Opinions on Accelerating Agricultural Mechanization and the Transformation and Upgrading of Agricultural Machinery and Equipment Industry* [1], the development of agricultural mechanization has been widely emphasized. As agricultural productivity improves, farmers' incomes increase and the purchasing power of agricultural machinery increases [2]. In the context of sustainable development, examining the impact of agricultural mechanization services on the technical efficiency of food production is of great practical significance for the formulation of policies to safeguard food production capacity [3]. The research and development and application of agricultural machinery provide new solutions for field operations [4]. Due to the high nutritional value of spinach, short planting cycle, adaptability, high economic value, ecological benefits and other advantages, the planting of spinach has become the choice of many farmers, but the planting of spinach is labor-intensive, the sowing requirements are high, and there is an urgent need for a spinach planting machine to alleviate the pressure of sowing. However, the research related to multi-functional small-scale high-efficiency spinach tillage and planting machines has not been reported in the relevant research.

In this paper, a multifunctional spinach cultivator is studied, which applies modular and multifunctional design to adapt to different soil conditions and crop planting needs by designing the wheel part expansion structure, soil loosening structure, crank rocker mechanism and seeding structure. The structural reliability and use stability of the agricultural machine are verified through design calculations including the torque required by the wheel motor, the crank rocker mechanism to withstand the force action and finite element static load analysis. To a certain extent, the research and development of this efficient and labor-saving spinach crop seeding integrated machine is of great significance for improving spinach production efficiency and reducing costs. The overall three-dimensional diagram is shown in Figure 1. Abbreviated main components are noted in the figure.

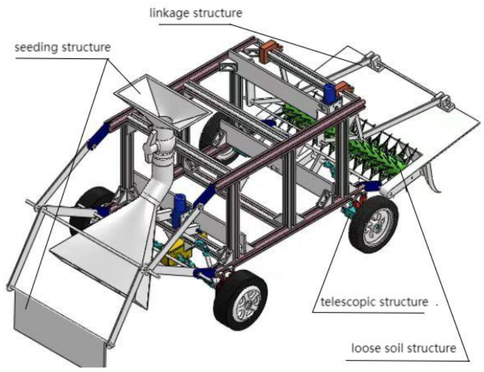

Fig. 1. Overall three-dimensional diagram.

Fig. 2. Spinach planter available.

2 Functional Design

The most important feature of this agricultural machine is its multifunctionality and integration. This undoubtedly increases the difficulty of the mechanical design, so it is necessary to choose reasonable structural dimensions to fulfill its functions. Due to textual limitations, this study focuses on the most difficult part of the design process.

At present, the common spinach harvester in China is shown in Figure 2, which is mainly driven by human power, with a single structural function, and it is designed to support only the sowing of spinach seeds. The designed integrated spinach cultivator disperses multiple functions on four main modules: Wheel telescopic structure, Loose soil structure, Crank rocker mechanism, and Seeding structure.

2.1 Wheel Telescopic Structure Design

The core function of the front wheel structure of this device is to efficiently and smoothly transfer the power generated by the electric motor to the front wheels of the agricultural machine, thereby driving the agricultural machine forward. The key components include the motor, universal joint coupling, rotating shaft, etc., which work together to ensure the driving stability and transmission efficiency of the agricultural machine in various terrain conditions.

The motor serves as the power source of the whole transmission system, driving the agricultural machinery. The universal joint coupling allows a certain angular deviation between the two connected shafts while transmitting power, thus making the power transmission more flexible and adapting to the various angular changes generated when the agricultural machine is traveling on uneven ground. This design effectively reduces the stress on the drive shaft caused by the undulation of the ground, and improves the smoothness of the traveling of the agricultural machine and the durability of the drive system. In addition, the rotor shaft is an important component connecting the universal joint coupling and the front wheels, which is responsible for transferring power from the universal joint coupling to the front wheels. The design of the rotor shaft needs to take into account the strength, rigidity and corrosion resistance in order to adapt to the working conditions of the agricultural machinery in various harsh environments.

In practical application, this front wheel structure design can significantly improve the driving performance and operating efficiency of agricultural machinery. When the agricultural machine operates in the field, the ground conditions are often complex and variable, and this design enables the agricultural machine to better adapt to the undulations and unevenness of the ground, reducing the impact and vibration caused by the terrain changes, thus protecting the key components of the agricultural machine and prolonging its service life, as shown in Figure 3.

2.2 Loose Soil Structure Design

The front side of the loosening teeth has an edge to reduce resistance and divide the land into ditch-long parts, the rollers at the back rotate to break up the hard stones in the loosened land, and the loosening machine operates not only to loosen the deep soil, but also not to disturb the soil layer [5]. The loosening depth is adjusted by changing the height of the ground wheel, and the maximum loosening depth is about 15 centimeters. This improves the physical and chemical properties of the soil, which is conducive to water storage and moisture conservation, and the deep loosening of low-lying land can accelerate the infiltration of surface water, which is an effective measure to exclude excessive moisture from the cultivated layer of the cultivated land [6].

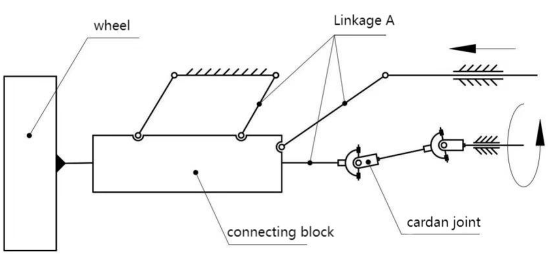

Fig. 3. Wheel telescopic structure.

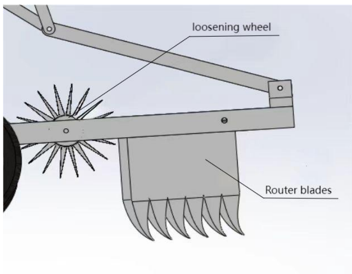

Fig. 4. Loose soil structure.

Loosening the soil can break the soil block, so that the gap between the soil particles increases, which is conducive to the penetration and distribution of air, water and nutrients in the soil, and improve the permeability, permeability and water retention of the soil, thus improving the soil structure and providing a more suitable soil environment for crop growth. The loose soil structure is shown in Figure 4.

2.3 Crank Rocker Mechanism Design

The crank, connecting rod, rocker and other rods will convert the rotary motion of the motor into the reciprocating swing of the rocker arm, so that the shank does a circular motion (rotary motion), the connecting rod does the rocking motion, the rocker does the reciprocating motion, and the frame plays a role in fixing the crank and the rocker, to realize the lifting and lowering function of the loosening machine.

During lifting and lowering, the swinging amplitude and speed of the rocker can be changed by adjusting the positional relationship between the crank and the connecting rod, thus realizing that the working parts operate in different depths of soil. This design enables the loosening machine to adapt to different soil conditions and crop planting needs, improving the applicability and flexibility of the machine. Figure 5 shows the crank rocker mechanism, where A, B, C, and D are the rockers that make up the structure. Among them, the role of Linkage A is to transmit power, the role of Linkage B is to limit, and the role of Linkage C and D is to transmit power and support the Router blades and Loosening wheel. The structural sketch is shown in Figure 5.

2.4 Seeding Structure Design

The concept of the seeding structure is to achieve precise seeding and efficient seed utilization. The seeding structure consists of two main parts, the upper and lower parts, which work together to ensure that the seeding process is carried out smoothly.

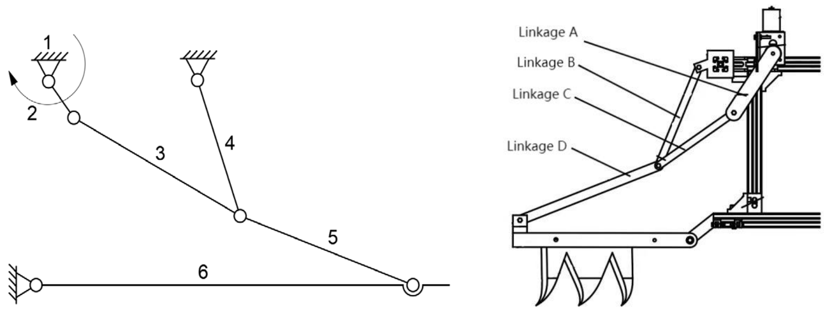

Fig. 5. Crank rocker mechanism structure.

The upper part is the seed storage slot of the sowing structure, which is a specially designed container for the seeds to be sown. The capacity and structure of the storage box are adapted to the size and needs of the sowing to accommodate different types of crop seeds and sowing areas. The design of the storage box usually takes into account sealing and moisture resistance to ensure that the seed remains in optimal condition during storage and is protected from the external environment.

The lower part (valves and conduits) contains the working mechanism of the seeding structure, including the rotary switch and knob. When the sowing operation starts, the sowing structure is activated by turning the switch knob, which triggers the movement of the seeds in the storage box through the conduit system at the bottom. The conduit system consists of five tubes that ensure an even distribution of the seeds.

The furrowing mechanism is responsible for plowing five parallel furrows in the land to provide a suitable sowing environment for the seeds. As the seeds leak through the conduit, they are evenly sprinkled across these furrows. This design ensures that the spacing and depth between the seeds remain consistent, which is conducive to seed germination and growth. And housing is used as a protective case.

The entire sowing process is automated, greatly improving the efficiency and accuracy of sowing. In this way, farmers can sow a larger area of land in a shorter period of time, while reducing labor costs and labor intensity. In addition, uniform sowing also helps in balanced crop growth and improves crop yield and quality. The structure is shown in Figure 6.

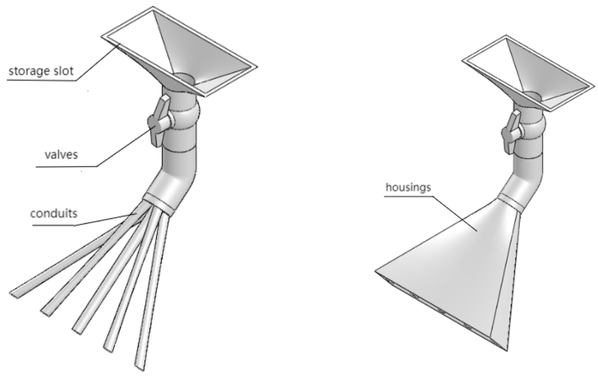

Fig. 6. Sowing structure.

3 Design and Calculation

3.1 Calculation of the Amount of Torque Required for Wheel Motors

The agricultural machine in this project uses two active and two driven wheels to power the movement of the machine. Wheel motor torque is too small will cause the machinery to get stuck in the mud and not be able to move, so the wheel motor torque for the design of agricultural machinery is critical. To establish a simplified model of the agricultural machinery, as shown in Figure 7. The mass of the agricultural machinery is m, determined to be about 50 kg (fully loaded state), the vehicle accelerated to a steady speed acceleration is a, and then the traction force is:

$$F = mg\mu + ma \tag{1}$$

where μ is the coefficient of friction between the wheels and the plowed land, which can be obtained by reviewing the literature, acceleration can be measured as $3m/s^2$. Bringing in the data, the moment M is:

$$M_e = 4.1 \text{ N/m} \tag{2}$$

Therefore, the torque of the adopted motor only needs to be greater than 4.1 N/m to realize the operation of the agricultural machine during normal work in the field, which is in line with the theoretical calculation.

3.2 Degree of Freedom Analysis

Degree of freedom calculation:

$$F_n = 3n - 2P_L - P_H = 3\times5 - 2\times7 - 0 = 1 \tag{3}$$

It can be concluded that the mechanism requires only the prime mover to obtain a uniquely determined trajectory.

3.3 Finite Element Static Load Analysis

The main deformation-prone parts of this agricultural machine design are the axle bracket and crank rod, which are related to the safety and operational feasibility of the whole equipment. This section mainly analyzes their stresses and displacements. As shown in Table 1.

Table 1. Material properties.

Causality	Numerical value
Modulus of elasticity	3500 MPa
Bending modulus	100-150 MPa
Densities	1.25-1.28 g/cm^3
Tensile strength	40-60 MPa
Yield strength	130 Mpa

The surface degrees of freedom of the fixed position of the backrest axle bracket and the connecting crank rod are limited. The backrest plate under maximum load conditions is analyzed, that is, the stresses and deformations of the bedplate under full load are simulated and analyzed. The load and clamping are shown in Figures 7 and 8.

The stress and displacement of the crank rod is shown in Figure 9, and the stress and displacement deformation of the axle bracket is shown in Figure 10. From the stress and displacement plots, it can be seen that the maximum values occur around the axle bracket with the connecting rod. The main data analyzed can be clearly seen from the results of the example calculation. The output displacements of the parts shown have been exaggerated to represent the direction and extent of material deformation, as the degree of elastic deformation of the material is so small that it is difficult to differentiate in the model.

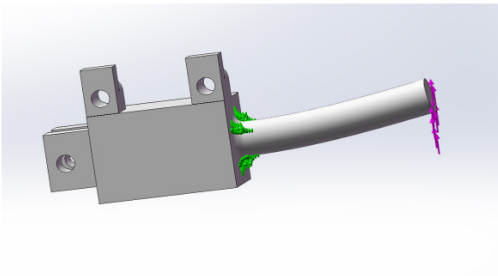

Fig. 7. Rotating shaft load and clamping.

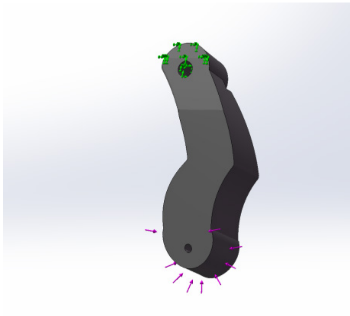

Fig. 8. Load and clamping of fin slider.

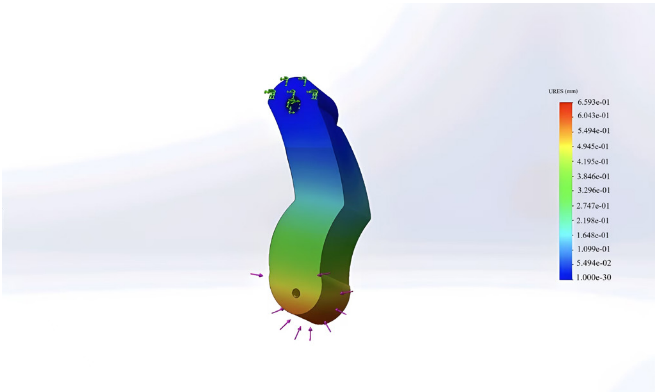

Fig. 9. Rotating shaft output stress.

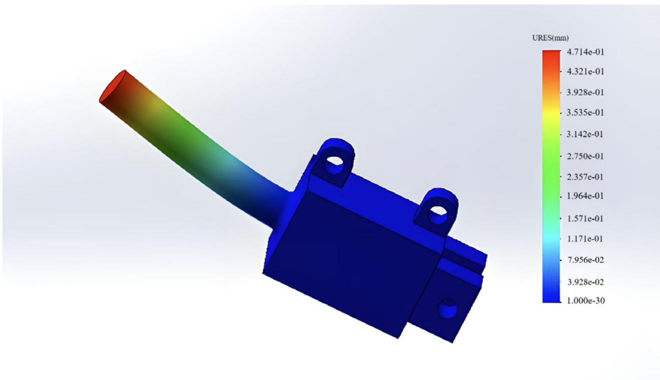

Fig. 10. Output stress of fin bone slider.

The above static load analysis leads to a reasonable degree of structural design of the device. The choice of materials and dimensions for each critical part complied with the loading conditions at three times the impact coefficient, and there were no problems of fracture and severe plastic deformation in each part.

4 Conclusion

Through calculation and analysis, the design of the multifunctional spinach plowing and planting machine was completed, and actual production and a large number of experiments were carried out. The test results show that the function and use stability of the multifunctional spinach tiller meet the expected requirements. The structure is reliable with high performance and environmental adaptability.

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