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Structural design and kinetic analysis of precise seed planter for tray seedling

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Abstract. As the most advanced vegetable cultivation technology adopted all over the world, tray seedling is the key link of vegetables to increase crop yield and economic benefit. As the key to the whole production process, the precision of tray seedlings is directly related to the survival rate of seeds. Combining the small scale of the domestic vegetable tray seedling industry, low level of mechanization, and low profit of sowing equipment, a tray seedling precision seeder is proposed in this paper and ADAMS software is used to carry out dynamic analysis on the main stressed parts. The results showed possible problems in the design of this type of mechanism, and possible causes were analyzed, the structure of the precision planter was optimized based on the results, and the motion performance of the seeder was improved, which is of great significance for the realization of precision seeding in an automated assembly line.

Key words: Tray seedling; Sowing equipment; Structural design; Dynamics analysis; ADMAS

1. Introduction

With the adjustment of rural economic structure and cultivation means and the reform of agricultural supply-side structure, seedling cultivation technology has stepped into a rapid development stage [1]. So far, more than 60% of vegetables, flowers, and some crops in China have been grown using seedling cultivation technology [2]. Vegetable seedlings are scientifically treated vegetable seeds, sown in a specific environment suitable for seed germination and growth, and grown to robust seedlings suitable for transplanting and planting after a certain period of intensive cultivation care [3]. The small size seeds (average diameter less than 3 mm) are in an extremely important position in China's planting industry, where leafy vegetables like spinach and kale have been widely used for factory seedlings due to the advantages of regular seed shape and high market demand. The main seedling methods include the hole tray seedling, the container seedling, and the hydroponic seedling, and the hole tray seedling is the mostly applied method [4]. It has been shown that tray seedling technology is beneficial to improve the seedling rate, shorten the maturation time of vegetables, and significantly increase the economic returns of the vegetable growing industry.

Human or semi-mechanized planting methods are mainly used in traditional hole tray sowing, which can bring problems such as low production efficiency, heavy production, and management costs, and high seed loss. It has become a problem that restricts the development of industrialization and popularization of seedling technology in the hole tray [5]. And tray seedling as the top priority of modern seedlings, the performance of the seeder is directly related to the quality of cultivated seedlings [6]. Perforated plastic hole trays are usually adopted as seedling containers in this technology; seeds are grown into semi-formed or formed seedlings in hole trays through an automated assembly line consisting of multiple processes such as soil mulching, scraping, hole pressing, precision sowing, and irrigation [7]. Compared with traditional agricultural seedling cultivation methods, it has significant advantages such as labor saving, energy loss reduction, "one hole, one seed, improved seedling efficiency", suitable for large quantities, long-distance transportation, and mechanized transplanting cultivation, etc. It is a seedling technology that should be vigorously promoted and popularized in the process of promoting agricultural modernization in China.

Blackmore (USA), Hamilton (UK), MOSA (Italy), Visser (Netherlands), and Helper (Korea Daedong Machinery & Electric Co) [8] are all well-known foreign manufacturers and brands of precise seed planters for tray seedlings. In recent years, the Dutch company VISSER has produced the Eco-routine cylinder seeder with dual-use rollers; the American company Blackmore has produced the Cylinder roller precision seeder with a unique four-option roller, which can enables precise seeding of different sizes of hole trays and different seeds without replacement.

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2. Model for precision tray seeder

The whole machine structure consists of an integrated frame, a hole tray limit conveyor belt, an intermittent hole pressing device, a roller type pressure point device, and a reseeding device. Among them, the hole tray limit conveyor belt mainly consists of a conveyor belt assembly, hole limiters, and a tensioning device; the roller type pressure point device mainly consists of a seeding roller, an auxiliary suction device, and an auxiliary pounding device; the reseeding device mainly consists of a seeding rotary disc, a sealed chamber, an electromagnetic excitation seed tray, and a drive servo. SolidWorks model of the whole machine is shown in Figure 1.

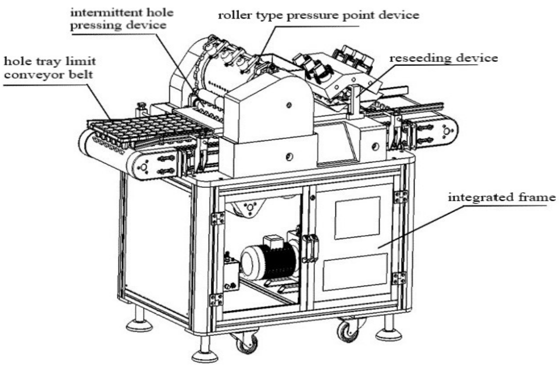


Figure 1. SolidWorks model of the whole machine

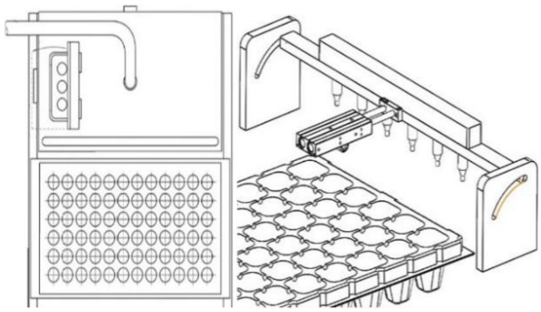
The working principle is to divide the piles of seeds into single seeds and sow them quickly into each hole of the hole tray with a 72-hole standard with equal row spacing and the same depth through the cooperation of each mechanical part. Based on this, the hole tray is quickly detected for missing seeds, and the seeds are reseeded by "one-to-one" spot sowing, thus completing the whole seeding process and realizing high-precision sowing.
The 72-hole trays enter continuously from one end of the planter (the previous station) and are automatically separated by the same distance by the hole tray limit conveyor and the intermittent hole pressing device, so that they enter the hole pressing and seeding station periodically; then, the seed holes with the same depth are pressed on the hole trays; then, the seeds are pre-planted and the missed empty holes are detected in real-time; finally, the seeds are reseeded by "one-to-one" spots according to the detection results, thus completing the whole workflow.

3. Structural design of main components

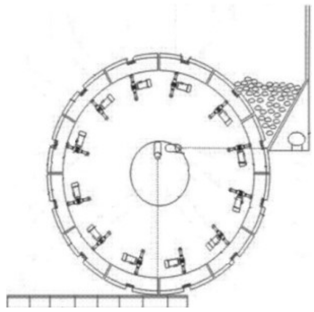
3.1 Selection and the basis of seeder

The seeder is a kind of seeding device that separates and picks up the seeds quantitatively stored in the seed box and drops them precisely into the corresponding seed bed under the premise of avoiding damage to the seeds. The seeder used in this paper has to be able to continuously and efficiently complete "one seed in one hole" sowing while ensuring high production efficiency and a high seeding pass rate.

Currently, there are two major categories of seeders at home and abroad, which are air-suction and magnetic-suction seeders. The working principle of the magnetic-suction seeder is to coat the seeds with magnetic powder before seeding. When seeds of different sizes are sown, only the current needs to be adjusted to control the magnetic force for seed suction, thus eliminating the trouble of replacing rollers. The advantages are not outstanding for leafy vegetable seeds, and the quality of seed coating will directly affect the working performance of the seeder, and at the same time, it will increase the production cost. Therefore, in this paper, we choose to use the lower-cost and more stable performance of the air-suction seeder.
According to the design style of the seeder, it is mainly divided into three types: the plate-type, the needle type, and the roller type. Types of seeders is shown in Figure 2.



(a) Plate-type (b) Needle-type



(c) Roller-type

Figure 2. Types of seeders

(1) The working mode of the plate-type seeder is to make the negative pressure inside the seeding plate whose size matches with the hole tray by vacuum pump, so that the seeds are adsorbed in the small holes evenly arranged on the bottom surface of the seeding plate, and then the seeding plate is moved to the top of the hole tray and aligned with it, and then finally disconnect the air source so that the seeds fall into the hole [9]. This type of seeder is simple in structure and low in cost, but has problems such as very low sowing accuracy and large size of the equipment [10].
(2) The working mode of needle-type seeder is that when the suction nozzle is above the seeding tray, the vacuum pump makes the suction nozzle tube form a negative pressure to adsorb the seeds in the seed box; then the suction nozzle moves above the hole tray under the push of the pendulum cylinder, cutting off the air circuit, so that the seeds fall down to the hole tray [10]. This type of

seeder is can sow one row of seeds at a time, and the needles can be changed according to the size of the seeds. It can realize precise sowing of single seed and high sowing efficiency. However, the suction nozzle is thin and long, and it is easy to be clogged by impurities in a long time working, which will seriously affect the sowing efficiency and it is time-consuming to clean it [11]. Secondly, due to the intermittent reciprocating motion of the suction nozzle, it is necessary to overcome its own inertia force when working, which leads to the working efficiency of this type of seeder will not be too high.

(3) The working mode of the roller-type seeder is to connect the vacuum pump on the inside of the roller, dividing the roller into negative pressure seed suction area, positive pressure seed discharge area and positive pressure hole clearing area, and the position of each fan-shaped area is fixed. The vacuum generator makes the negative pressure suction zone produce negative pressure, which adsorbs the seeds from the seed box, and when the roller moves to the holy tray, the positive pressure seed discharge zone passes into the positive pressure, the seeds fall into the hole tray [6]. This type of seeder can realize continuous work, and the air pressure in the three working areas is basically constant, without the inertia delay of the above two types of seeder that frequently pass through the air source, so the work efficiency is very high. At the same time, there are some problems, for different sizes of seeds, it is necessary to replace the rollers of the corresponding sizes and reassemble them, time-consuming [13].

In summary, the needle-type seeder has the highest seed rowing accuracy and qualified rate among the three, it cannot meet the production requirements of high speed and continuous work for a long time; while the roller-type seeder has the highest working efficiency and reliability among the three, however, it also has its problems of large size and high cost. Therefore, this paper is based on the working principle of the roller-type seeder, and reduces the size of the equipment as the pre-discharge device of this machine.

3.2 Hole detection device

The seeding qualification rate of the pre-planting device is ensured by the monitoring of the hole detection device located directly in front of the roller, which works through a photoelectric sensor installed in front of the roller to receive the infrared irradiation from the internal beam of the roller. If a light signal of a certain intensity is received, it means that the sucking hole has not sucked the seed or the seed has been vibrated down by the whacking mechanism, then it is judged to be a missed hole and the information about the location of the hole is transmitted to the supplementary seeding device; if no light signal is received or the received light signal is not strong enough, it means that the hole has sucked the seed and the sensor does not do the signal transmission. The principle of the cavity detection device is shown in Figure 3.

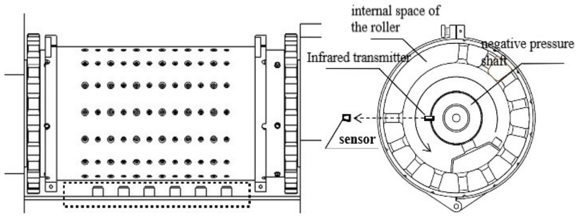


Figure 3. The principle of the cavity detection device

3.3 Reseeding devices

The principle of the seeder is shown in Figure 4.A positive pressure chamber and a negative pressure chamber are built through the welded-together spacer, and a servo controls the rotary motion of the seeding rotor inside the seeder, so that the suction holes on the seeding rotor pass through the negative pressure and positive pressure zones in turn, thus realizing the process from the suction of the seeding tray to the seeding discharge along the drop hole. The process is similar to the roller seeder, but the difference is that the device is smaller and a set of spot-sowing devices corresponds to a certain hole in each row of the hole tray, which is very flexible. At the same time, it takes less time to complete sowing, with 120° of rotation of the tiller, and can relatively match the sowing efficiency of the roller pre-planters.

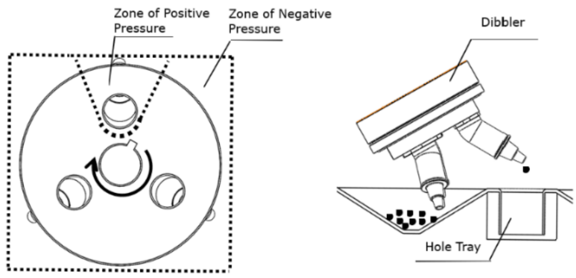


Figure 4. The principle of the seeder

4. Kinetic analysis of ADAMS software

The 3D model drawing of the mechanical drive part of the seeder was imported from SolidWorks software. The model drawing on the ADAMS software interface is shown in Figure 5.

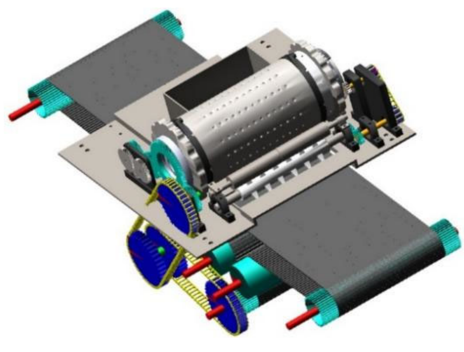


Figure 5. Import the 3D model into the ADAMS software

4.1 Adding motion subs and drives

Firstly, the fixed subsets of the chassis and seeding roller, the long thin rod instead of the drive motor, and the rotating subsets were added; secondly, the gear transmission and chain transmission of the traditional part of the machine were drawn by the "Adams Machinery" module in ADAMS software.

The seeder is assumed to be operated normally at a speed of 1000 trays/h, and the speed of the drive roller n is 33 r/min from the transmission ratio.

$$n = \frac{33r}{min} = 0.55r/s \quad (1)$$

$$\omega = 2\pi n = 1.1\pi rad/s \quad (2)$$

$$1.1\pi \times \frac{180}{\pi} = 198°/s \quad (3)$$

The input speed is set to -198 °/s by the formula above (the drive function with a negative sign is set according to the actual sowing process direction), the simulation time t=10.8 s (3 cycles for the expected efficiency), and the simulation step=108.

4.2 ADAMS simulation post-processing

After performing the simulation, data such as displacement, velocity, acceleration, force, and moment of the moving sub can be obtained and various data curves can be generated. The post-processing module ADAMS/Post processor is usually used for the production of image work such as curve plotting and animation recording. Since the precision tray seeder has many components and the seed rower roller is very important in the whole automated seeding workflow, the different parameters of the components, seed rower roller, and roller drive gear, are focused on in this paper.

The velocity and acceleration parameters of the seeder roller are analyzed, and its velocity and acceleration curves in the X-axis direction are shown in Figure 6, and the curves in the Y-axis direction are shown in Figure 7.

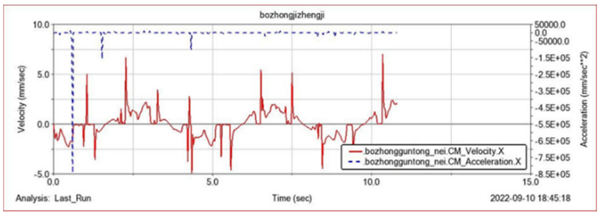


Figure 6. The velocity and acceleration curves of the X-axis direction of the seed-metering roller

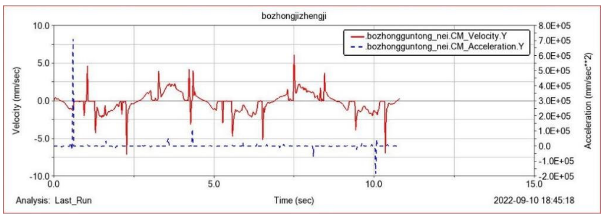


Figure 7. The velocity and acceleration curves of the Y-axis direction of the seed-metering roller

From Figures 6 and 7, it can be seen that the acceleration curves of the seeder roller in the X and Y directions are relatively smooth overall, but a "sharp point" appears at 0.6 s with the same size but in the opposite direction. The reason for this is that during the simulation, the active chain drive was not set on the tensioning wheel, and the chain was shaking violently, so the seed releaser roller did not operate simultaneously. At the same time, the speed curve in the X and Y axes is not smooth, but the trend still corresponds with the design requirements. Overall, the simulation results reveal the shortcomings in the speed transmission process and point out a direction for subsequent structural optimization.

The roller drive gear is analyzed using force and moment parameters, and its force as well as moment curves, as shown in Figure 8 and 9.

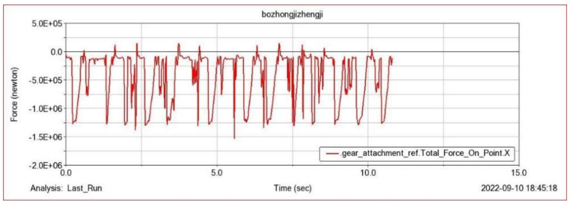


Figure 8. The force curve of the roller drive gear

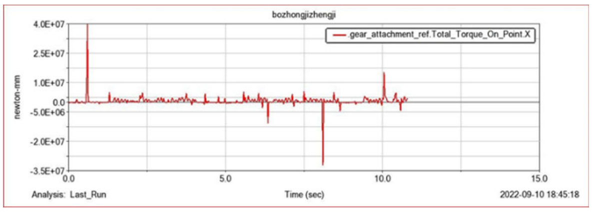


Figure 9. The torque curve of the roller drive gear

From the torque curve of the roller drive gear, it can be seen that there is a "sharp point" at 0.6 s and 8.1 s during the simulation process, which indicates that there is still a deficiency in the design of force transmission, resulting in a sudden change in both the chain shaking and the force of the gear when starting. The life of the equipment will be greatly reduced if it is put into use. The simulation results in the ideal state and the deficiencies found are of the great value of reference and significance for the improvement and optimization of the structure of the precision seeder in the future.

5. Conclusion

In this paper, a comparative analysis of the research process of domestic and foreign precision tray seeder was conducted, with a conclusion that domestic seeding machines have lower efficiency, high labor cost, and insufficient innovation capacity; subsequently, a complete set of lightweight and functional precision tray seeder was designed concerning the working mode of more mature foreign seedling seeding lines, combined with the domestic production scale and market demand. And based on this, the program was modeled on the equal scale by SolidWorks software; the dynamics of the relevant seeding parts were analyzed using ADAMS software, and the following conclusions were drawn.

(1) The working principle of this design is to quickly divide the piles of seeds into single seeds by mutual

collaboration between the mechanisms and sow them into each hole of the standard hole tray with equal row spacing and depth. Based on the principle of mechanical seal, a roller-type pre-planting device is designed with high productivity and the suction hole in it is not easily blocked; based on the new idea of "automatic replanting", a "one-to-one" reseeding spotting device with high speed and reliability is designed. Each device is designed to achieve precise sowing and a very high level of success.

(2) ADAMS software was used to simulate and analyze the dynamics of the key components of the seeder, to find out some shortcomings in the design process of this type of mechanism, analyze the possible causes, optimize the structure of the precision seeder, improve the motion performance of the precision seeder, and realize the precise seed sowing in the automated assembly line, which is of great significance.

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