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Structural Design and Three-dimensional Modeling of a Hand-propelled Seedling Weeder

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ABSTRACT: *Most vegetables are grown in solar greenhouse, and inter-ridge weeding has become a difficult problem in the process of planting management. The traditional artificial weeding is time-consuming and laborious, and the use of herbicides is easy to produce pesticide residues, affecting the quality of vegetables. In order to develop green and healthy vegetable industry, a hand-propelled seedling weeder is designed. In this paper, the bionic design and experimental study of the weeding blade are carried out, and the results show that the bionic blade has better cutting performance and faster cutting speed. Through the structural design and calculation of the hook-and-loosen wheels, it is concluded that the addition of hollow wheel hub and welding blade can greatly improve the efficiency of weeding. In order to further optimize the overall structure of the weeder, the three dimensional modeling design of each component is carried out,and the whole machine is digitally assembled. The weeder has great significance in increasing yield, protecting crop health, improving production efficiency and optimizing soil structure.*

Keywords: *Weeder, Hand-propelled, Bionic blade, Three-dimensional modeling design*

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I. INTRODUCTION

weeder is a kind of mechanical equipment, mainly used for mowing lawns and grassland, widely used in gardens, agriculture, sports fields and other fields. With the enlargement of landscape market and agricultural market space, the market scale of weeder is increasing steadily. According to the relevant data, in 2018 the market size of weeders reached about 8 billion, the market size is increasing year by year. From the perspective of market application,the landscape market and the agricultural market are the two areas with the largest market demand for weeders. In recent years, the market demand of weeder in landscape market has kept a rapid growth, and its market scale has exceeded the market demand of agricultural market[1].

At present, according to the way of travel weeder is divided into intelligent semi-automatic towing type, after implementation type, mount type, tractor suspension type.According to power, it is divided into human animal drive, engine drive, electric drive and solar drive.According to the form of the knife, it is divided into hob type , rotary knife type, side hanging type and swinging knife type[2-3].Aiming at the difficulty of weed removal in solar greenhouse, a hand-propelled seedling weeder is designed . In this paper, the blade of the weeder was bionic designed and experimentally studied, and The structure design and calculation were carried out on the hook-and-loosen wheels. In order to further optimize the overall structure of the weeder, the three dimensional modeling design of each component is carried out,and the whole machine is digitally assembled. The utility model has the advantages of simple structure, small occupation area and convenient operation, and is a more practical weeder.

II. Design Concept of the Weeder

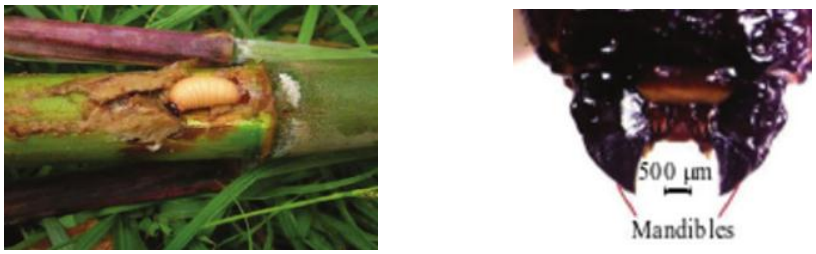
In solar greenhouses, weeds are the main competitors in the growing process of vegetables, they will rob vegetables of nutrients, water and sunlight resources, and may spread diseases and pests. In traditional agriculture, the main methods of weeding are manual weeding and spraying herbicides. However, manual weeding is time-consuming and laborious. Spraying herbicides will result in pesticide residues on fruits and vegetables, which will cause harm to human body. Therefore, a hand-propelled seedling weeder has been designed. A pair of walking wheels were installed under the weeder. Through the handle, people can control the weeder forward and turn. In the process of walking, the front blade is driven by a motor to make a high-speed rotary motion, first clearing the higher weeds. On the rear side of the weeder, a pair of hook-and-loosen wheels were installed. They are driven by the motor to achieve rotation, so as to hook out the roots of weeds, in order to achieve the purpose of weeding, and play the role of turning the soil and loosening the soil. The application of the weeder can not only reduce the occurrence of diseases and insect pests, improve the health degree of vegetable growth, but also optimize the soil structure and improve the soil aeration, and other issues.

III. Overall Structural Design of the Weeder

The hand-propelled seedling weeder is a kind of mechanical equipment specially used for weeding. It is composed of frame, hook-and-loosen wheels, weeding blade and drive part, which is easy to maintain. The operator controls the movement and working depth of the machine through the control system, and flexibly adjusts the working mode. The machine is strong and durable, and can operate stably in different terrain and working environment. It is mainly suitable for small-scale farmland, orchards and gardens.

3.1 Design of bionic blade

The study showed that the larvae of the bamboo weevil can eat the stronger bamboo. It was found that the larvae can eat the tender bamboo by their teeth as shown in Figure 1. When the larvae eat the bamboo, the mandible moves like a sickle, the tip of the tooth grabs and pierces the surface, then the internal cutting edge of the tooth cuts into it. In addition, the back profile of the tooth is a convex arc, which can greatly reduce the friction resistance between the mandible and the bamboo, and the cutting state is similar to the actual tool, which is suitable for the bionic blade prototype[4-6].



(a) Surface of bamboo after eaten by larva (b) Mandibles

Fig. 1 Bamboo weevil larvae and their teeth[7]

Therefore, the geometric shape of mandible of bamboo weevil larvae is selected for blade bionic design in this paper. In order to improve the efficiency of weeding, a zigzag shape is designed on the blade to increase the effective working length of the blade. The blade design and object are shown in Figure 2.

(a) Bionic blade design (b) Original blade (c) Bionic blade

Fig. 2 Design and object drawing of bionic blade

In order to make a more direct comparison between the cutting performance of the bionic blade and the traditional blade, the cutting experiments were carried out with the bionic blade and the traditional blade respectively. The cutting effect is shown in Figure 3 and Figure 4.

(a) Traditional blade cutting (b) Bionic blade cutting

Fig. 3 Experiment on cutting carrots

(a) Traditional blade cutting (b) Bionic blade cutting

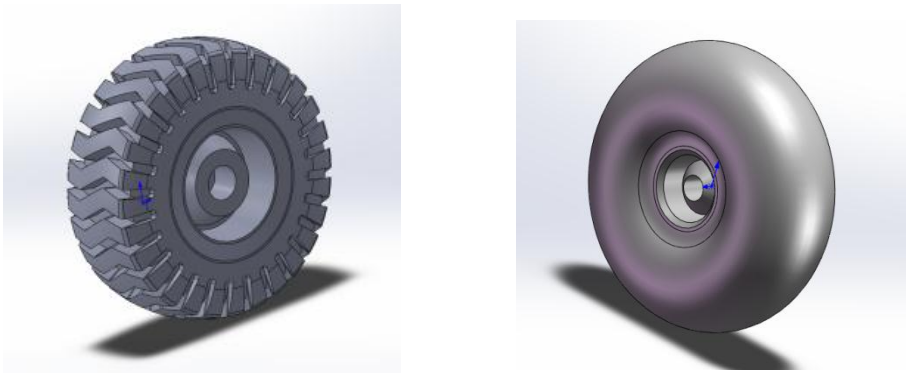
Fig. 4 Experiment on cutting bush

According to the blade surface, the edge of the bionic blade cutting object is more flat, more destructive, and cutting time is shorter. Therefore, the cutting force of the bionic blade is better than that of the traditional blade.

3.2 Design of the hook-and-loosen wheel

The hook-and-loosen wheels pull weeds out of the soil and helps loosen the soil. Therefore, it is necessary to select the suitable size of the hook-and-loosen wheels according to the design size and weight of the actual machine to ensure the stability and high efficiency of the machine, and considering that the weeder can be used under different terrain. Therefore, it is necessary to ensure that the structural design of the tire can adapt to different ground friction.

The weeding efficiency of cylindrical wheel and spherical wheel was compared and analyzed in order to make the wheel adapt to different ground. Suppose that a cylindrical Tyre and a spherical Tyre are shown in Figure 5.Their radius and heights are 10 cm and 20 cm, respectively.



(a) Cylindrical wheels (b) Ball wheel

Fig. 5 Comparison of the shape of the wheels

(1) cylindrical wheel

Volume: $V\ cylinder = \pi r^2 h = 3.14 \times 10^2 \times 20 = 2000\pi cm^3$（1）

Surface area: A cylinder $= 2\pi rh + 2\pi r^2 = 2\pi 10 \times 20 + 2\pi 10^2 = 600\pi cm^2$（2）

(2) ball wheel

Volume: $V\ sphere = \frac{4}{3} * \pi r^3 = \frac{4}{3} \times \pi 10^3 = 4188.79\pi cm^3$（3）

Surface area: A sphere $= \frac{4}{3} * \pi r^2 = \frac{4}{3} \times \pi \times 10^2 = 1256.64\pi cm^2$（4）

(3) Comparative analysis

By calculation, the cylindrical tire has a smaller surface area, while the spherical tire has a larger surface area. This means that at the same volume, cylindrical tire are better suited to reduce friction and puncture risk while maintaining better stability and durability. And in order to let the hook-and-loosen wheels can pull out the root of the grass and play the role of loosing soil, the toothed blades are installed by welding on the wheel. Therefore, the structure of the hook-and-loosen wheel designed in this paper is shown in Figure 6.

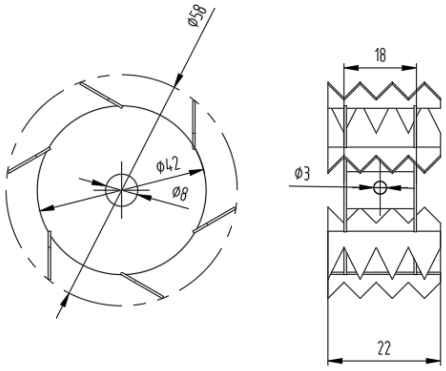


Fig. 6 Design drawing of the hook-and-loosen wheel

3.3 Selection of drive system

Because the hand-propelled seedling weeder belongs to small equipment, the small motor is chose as a driver.

3.3.1 Selection of blade motor for the hand-propelled seedling weeder

The rotating speed of the blade of the hand-propelled seedling weeder is an important technical parameter, because it directly affects the working efficiency and performance of the weeder. Generally, as the cutting speed increases, the cutting force also increases. This is because an increase in cutting speed leads to an increase in the frequency of tool contacting with the work-piece, thus increasing the cutting force. In addition, the increase of cutting speed may lead to the increase of cutting temperature, and then affect the size of the cutting force. However, too high cutting speed will make the temperature of the cutting area increase, make the hardness of the cutting area reduce, the cutting material become soft and lead to lower quality, tool wear and other problems. Through market research, the blade speed peak values of the main herbicides are 8000r/min, 10000r/min and 12000r/min. In order to avoid the problems caused by excessive cutting speed, the driving blade motor speed is 8000r/min.

3.3.2 Selection of the hook-and-loosen wheel motor

As a result of the hook-and-loosen wheel need to match people's walking speed. Therefore, the calculation is as follows:

(1) the length of adult walk per minute

According to the investigation, The average stride length of adults is 0.8 m and the average gait speed of adults is 100 steps per minute.

So, the length of adult walk per minute:

$$0.8 \times 100 = 80\mathrm{m/min} \quad (5)$$

(2) the driving distance of the hook-and-loosen wheel

The diameter of the wheel is: $\mathrm{d} = 150\mathrm{mm}$

$$\mathrm{C} = \pi\mathrm{d} = \pi \times 150 \approx 471\mathrm{mm} \approx 0.47\mathrm{m} \quad (6)$$

Because using a hand-propelled seedling weeder, it is not considered normal walking speed, walking speed is about one-third of normal walking speed, about 26.7 m/min. Therefore, the running distance should be between 25-50m/min. The rotating speed of the machine is 100r/min.

So, the driving distance of the hook-and-loosen wheel:

$$\mathrm{d} = 0.47 \times 100 = 47\mathrm{m/min} \quad (7)$$

After testing, this driving distance is more in line with the speed of people using the hand-propelled seedling weeder.

3.4 Determination of shaft size and material

In this paper, the force is analyzed and calculated on the hook-and-loosen wheels according to the formula of material mechanics. According to the materials purchased, the torque is 5.

According to the torque and the force, $\mathrm{t} = \frac{\mathrm{tp}}{\mathrm{Ip}}$, the diameter of the fixed shaft is 2 cm.

After the diameter of the shaft is determined, the material is determined by calculating the shear stress, which is influenced by many factors such as component materials, loading conditions and design requirements. Generally speaking, in engineering design, it is necessary to calculate and determine the appropriate value of torsional shear stress to ensure the safety and reliability of components[8].

The shear stress is calculated as follows:

(1) Polar moment of inertia of a circular axis Ip

$$\mathrm{Ip} = \frac{\pi\mathrm{D}^4}{32} = \pi \times \frac{0.024}{32} \approx 1.57 \times 10^{-8}\mathrm{m}^4 \quad (8)$$

(2) Torsional cross-section coefficient of a circular shaft Wt

$$Wt = \frac{\frac{Ip}{D}}{2} = \frac{\frac{1.57\times10^{-8}}{0.02}}{2} = 1.57 \times 10^{-6} \text{（9）}$$

(3) Shear stress at the interface t

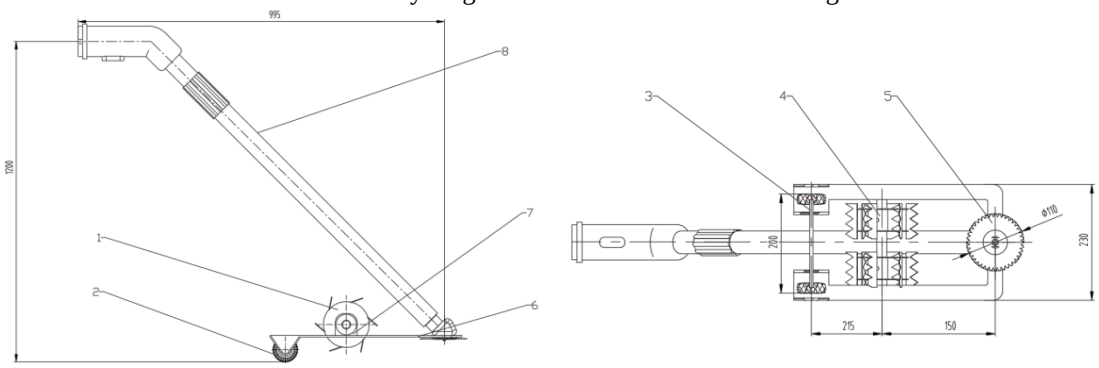
$$\mathrm{t} = \frac{\mathrm{T}}{\mathrm{Wt}} = \frac{5}{1.57\times10^{-6}} \approx 3.18\mathrm{MPa} \text{（10）}$$

From the calculation, the material of the shaft is carbon steel. Because carbon steel has good strength and rigidity, suitable for shafts subjected to moderate stresses and loads. And carbon steel is relatively economical.

IV. Digital Design of the Weeder

4.1 Two-dimensional engineering drawing design

Through the previous design calculation, the assembly diagram is drawn in CAD. It can more intuitively express the assembly relationship of the product, the working principle, the transmission route, the main structural shape of the parts and the size data and technical requirements required for assembly, inspection and installation. The two-dimensional assembly diagram of the weeder is shown in Figure 7.



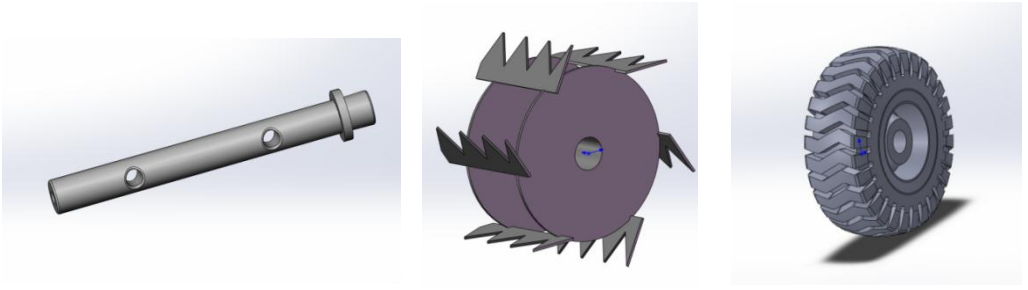
(a) Main view (b) Upward view

1. Hook-and-loosen wheel, 2. Shock-absorbing walking wheel, 3. Axle, 4.Driving shaft, 5. Bionic blade, 6. Supporting plate, 7. Supporting frame, 8. Handle rod

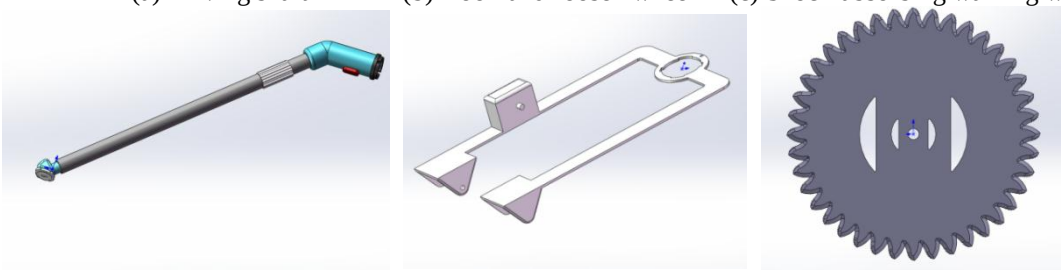
Fig. 7 Two-dimensional assembly diagram of the weeder

4.2 Three-dimensional modeling design of each component of the weeder

After mastering the whole structure, motion and transmission structure of the weeder, the main parts of the weeder are designed in three dimensions by Solidworks, as shown in Figure 8.



(a) Driving shaft (b) Hook-and-loosen wheel (c) Shock-absorbing walking wheel



(d) Handle rod (e) Supporting plate (f) Bionic blade

Fig. 8 Three dimensional modeling of each component of the weeder

4.3 Overall modeling design of the weeder

In this paper, the digital assembly of the mechanism of the weeder increases the three-dimensional feeling of the whole machine, and more intuitively expresses the structure, shape and operation of the product inside and outside. The overall three-dimensional modeling of the weeder is shown in Figure 9. A motor is installed on the head of the handle rod and directly drives the bionic blade to work. A control system is installed at the end of the handle rod. The width of the supporting plate is designed in reference to the width between small crops. The supporting plate is mounted on the head of the handle rod, positioned with a groove and secured with three screws. The driving shaft and motor are mounted on a supporting plate. Two hook-and-loosen wheels are fixed to the driving shaft by means of two pins. After the power is energized, the motor drives the hook-and-loosen wheels to rotate through the drive shaft.

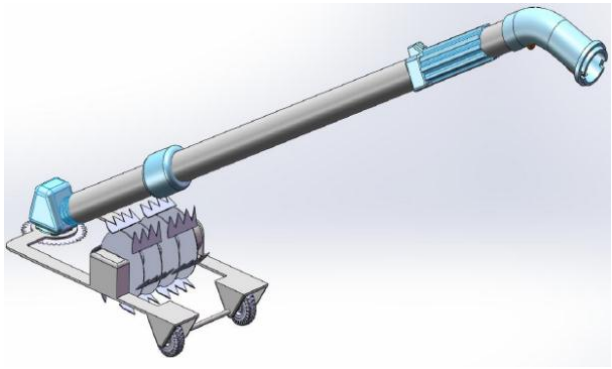


Fig. 9 Overall three-dimensional modeling

V. Conclusion

With the acceleration of agricultural modernization and urbanization, there is an increasing demand for efficient and labor-saving agricultural machinery equipment. As an efficient farming equipment, the hand-propelled seedling weeder can complete the two requirements of weeding and soil loosening at the same time, which greatly reduces manpower and material resources, and has great market potential.. In this paper, the bionic design and experimental study of the weeding blade are carried out, and the results show that the bionic blade has better cutting performance and faster cutting speed. Through the structural design and calculation of the hook-and-loosen wheels, it is concluded that the addition of hollow wheel hub and welding blade can greatly improve the efficiency of weeding. In order to further optimize the overall structure of the weeder, the three dimensional modeling design of each component is carried out, and the whole machine is digitally assembled.. The hand-pushed seedling weeder is smaller than the ordinary small-scale weeder in the market, and greatly increases the weeding efficiency between the small-scale seedling ridges. With the advancement of agricultural modernization and technological innovation, the hand-pushed seedling weeder is expected to play a greater role in the field of farmland management.

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