Design of 1SGL-240 type sugarcane deep-soiling soil preparation machine

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Abstract—Aiming at the problems of low efficiency and high energy consumption in the process of sugarcane planting, as well as the problems of soil compaction and hardening caused by tractor repeatedly entering the field and rolling sugarcane field, this paper designed a kind of combined soil preparation machine with reasonable structure and conforming to the continuous planting conditions of sugarcane field in China by optimizing the combination of key components. The tractor drives the machine into the field once, which can complete the processes of deep loosening, loosening the head of sugarcane, ridging and soil preparation. In this paper, the overall mechanism of the machine, subsoiling parts, pulling wheel, ridging mechanism and other key components are designed and analyzed, and the performance of the machine is evaluated through field test. The results showed that: the process of soil entry and subsoiling was stable, the rate of pulling out sugarcane head reached 91.2%, and all properties met the requirements of sugarcane field.

1. INTRODUCTION
Sugarcane, as one of the main economic crops, is also an important sugar crop. Its planting area accounts for more than 85% of China's perennial sugar crops. In China, at present, sugarcane planting is basically continuous years, with the following patterns: first, planting for one year, Ratoon for 1-2 years, then ploughing and replanting; second, ploughing and replanting after one year of new planting[1-2]. In recent years, affected by the rising labor costs and the impact of international sugar prices, the planting efficiency of sugarcane is getting lower and lower. Therefore, in order to improve the efficiency of sugarcane production and planting, in addition to reducing production costs and breeding excellent varieties, the implementation of the whole mechanization operation is a key factor. In the process of sugarcane production mechanization, the most basic work is to plough and prepare the soil. The
traditional method is to use a high-power tractor to drive the plow or heavy harrow to plough, then use the rotary tiller to level the soil for 1-2 times, and finally use the ditcher to open the deep ditch. This method not only has low efficiency and high energy consumption, but also has to roll sugarcane field many times[3-4]. In addition, high-power tractor drives plow for ploughing, which is inconsistent with the implementation of conservation tillage technology in China.

2. DESIGN PRINCIPLES OF MACHINES AND TOOLS

According to the agronomic characteristics of continuous planting of sugarcane in China and the traditional planting characteristics of "turning, raking and pressing" for many years, tractors are required to drive machines and tools into the ground for operation many times when planting sugarcane, resulting in soil compaction and hardening. Sugarcane is a kind of ridge crop. This traditional farming method makes the soil water and soil conservation capacity obviously insufficient, and soil erosion is also very serious. However, after mechanized subsoiling, the topsoil of sugarcane field is not disordered and the amount of soil moving is small, which can effectively improve the permeability and permeability of soil. In this paper, through the optimization of key components and design a reasonable structure, in line with China's sugarcane planting situation for many years. The tractor drives the machines and tools into the field at one time, which can complete the deep loosening, integral and furrow building operations, and realize the processes of deep loosening, cane head loosening, ridge building and land preparation in continuous cropping sugarcane fields. This method can greatly improve the efficiency of land preparation and reduce the operation cost. At the same time, sugarcane can be replaced by ridge and furrow to solve the serious problem of diseases and insect pests caused by sugarcane planting in the same position year after year.

3. STRUCTURE AND WORKING PRINCIPLE OF THE WHOLE MACHINE

1SGL-240 type sugarcane deep-loosening soil preparation machine is mainly composed of frame, opposite subsoiling plough group, hydraulic pump, pulling wheel, ridging board, etc., as shown in Fig. 1. The machine is suspended at the back of the tractor through three-point standard. With the tractor moving forward, the opposite subsoiling plough group (composed of two deep subsoiling ploughs on the left and right) implements deep loosening and breaking of sugarcane roots; the pulling wheel is powered by the hydraulic cylinder of the tractor and driven by the hydraulic pump on the pulling wheel axle, which rotates anticlockwise along the forward direction of the tractor to complete the loosening and breaking of sugarcane head In this way, it can prevent the sprouting of sugarcane head in the next year and affect the production of newly planted sugarcane in the next year; at the same time, the ridge building mechanism on both sides of the plucking wheel is installed to build the ridge for the deep loosening and the uprooting of sugarcane head. After the completion of the ridge construction, we can apply chemical fertilizer and plant sugarcane in the ridge and furrow to realize the shifting planting of sugarcane. The design parameters of machine foundation are shown in Table 1.

Figure 1. The structure of 1SGL-240 type sugarcane subsoiling and soil preparation machine
TABLE I. MAIN PARAMETERS OF THE MACHINE

| Parameter                                      | Parameters               |
|------------------------------------------------|--------------------------|
| Overall dimension (L / w / h, mm)             | 2600×1350×1250           |
| Supporting power (kw)                         | 88.3~102.9               |
| Working width (CM)                            | 240                      |
| Number of opposite subsoiling ploughs         | 2                        |
| Number of loosening wheels                    | 2                        |
| Number of loosening wheels                    | 3 (Two rows of long teeth and one row of short teeth) |
| Subsoiling depth (CM)                         | ≥35cm                    |
| Maximum turning radius (CM) of loose gear teeth | 180                   |
| Speed of loosening wheel (R / min)            | 160                      |
| Pure working hour productivity (hm2 / h)      | 0.90                     |
| Stability coefficient of subsoiling depth (%)  | 85.0                     |
| Fuel consumption per unit area (kg / hm2)     | ≤35                      |

4. DESIGN OF KEY PARTS OF PROTOTYPE

4.1 Subsoiling plough formation

Subsoiling plough group is one of the key components of subsoiling and soil preparation machine. It is mainly composed of two opposite subsoiling ploughs, as shown in Fig. 2 and Fig. 3. The subsoiling plough is composed of a subsoiling plough column and a subsoiling plough cutter. The plows of the two subsoiling ploughs are respectively installed on the subsoiling plough posts. When the machine is working, the opposite subsoiling plough group mainly completes the deep loosening of sugarcane ridge and the ploughing of sugarcane root. The opposite subsoiling plough group can adjust the opposite distance of two subsoiling ploughs according to the row spacing of sugarcane planting, and the adjustment range is 0.6m-1.4m, so as to meet the needs of farmers planting different sugarcane row spacing. The subsoiling plough shall have sufficient strength, rigidity and wear resistance [2]. According to GB / T 14225.2-93, the subsoiling plough column shall be made of Q345 with a thickness of 25 mm, and the subsoiling plough shall be made of 65 Mn and heat treatment, and the hardness shall be hrc48-56.

In order to realize the full subsoiling of the original sugarcane ridge and cutting off the sugarcane root system, the plow blade of the subsoiling plough is composed of a sharp upper plow and a lower plough with a good edge. The upper and lower plough forms a wing shaped "L-shaped" structure, which does not disturb the soil layer or turn the soil during operation. The upper plow is designed as a hollow Mitsubishi column with a mounting handle. The upper plow is installed on the subsoiling plough column through the mounting handle. One of the side cutters is processed into a sharp blade. The blade length can be designed as 25-40cm according to the height of sugarcane ridge row. The lower plough is composed of a main plough and a secondary plough, which is installed under the plough post of subsoiling. The main plow is designed to be asymmetric "V" structure composed of two parts: cutting plow and installing cutter board. The cutting plough is processed with sharp blade, and the mounting cutter board is installed on the deep loosening plough column through countersunk screw. When installing, install the cutter plate at an angle of about 14 ° with the ground, and the side is buried into the soil. The auxiliary plow blade is designed to be 20cm long and 4em wide. It is installed on the subsoiling plough column in parallel with the mounting plate of the main plow blade through the countersunk screw. The top edge of the auxiliary plow blade is 5cm higher than that of the main plow blade, which can reduce the soil penetration resistance.
4.2 Pulling loose whee

4.2.1 The structure design of pulling loose whee
The loosening wheel device includes hydraulic driving mechanism, transmission shaft, loosening wheel and gear tooth, as shown in Fig. 4. The center of the puller is equipped with a transmission shaft which provides power from the tractor hydraulic cylinder, and the puller teeth are evenly distributed on the outer wall of the puller. During the operation, the hydraulic drive mechanism drives the transmission shaft to rotate, and the drive shaft drives the loosening wheel and the gear teeth on the outer wall of the puller to rotate, so as to loosen and destroy the sugarcane head. The diameter and width of the puller are designed to be 20cm and 30cm respectively. Three rows of loose teeth are evenly distributed and welded on the wheel. There are four teeth in each row. The outer two rows of loose teeth are long teeth, and the middle row is short teeth. The long teeth are 45cm long and 15cm longer than the short teeth. The installation of long teeth and short teeth forms a 45° angle.

4.2.2 The structural design of tooth profile for pulling loose whee
In the design of the gear tooth, firstly, according to the planting row spacing and seed metering mode of sugarcane, the lowest energy consumption is selected; secondly, the reasonable driving system components are matched according to the operation requirements, and then the reasonable structural size of the puller is designed. In the process of tooth design, we should pay more attention to the shape of the tooth to ensure the minimum resistance when pulling out the sugarcane head; and how to arrange the tooth to ensure better loosening of the sugarcane head. Only the design of low energy consumption and reasonable layout of the loose teeth can improve the work quality and efficiency and reduce the
power consumption. The shape of the tooth directly affects the energy consumption, the degree of loosening and the speed of tooth wear. The force and strength of the tooth will directly affect the service life of the whole machine, so it is necessary to analyze, design and select the tooth profile.

In the design process of the whole machine, three kinds of tooth profile structures, depressiform, cylindrical pointed and cylindrical circular, are analyzed and compared, as shown in Fig. 5. The test results show that the energy consumption and pullout rate of sugarcane head with cylindrical tip structure are better than those of the other two tooth profiles. Therefore, the cylindrical tip type is selected for the design of the pultrusion gear of the prototype.

![Figure 4. The structure design of pulling loose wheel](image)

(a) Depressiform  (b) Cylindrical point  (c) cylindrical circular

Figure 5. Tooth structure

4.3 Design of ridging mechanism

The ridging mechanism is composed of left and right ridging plates. As shown in Fig. 6, it is installed behind the opposite subsoiling plough group. The two ridging plates are respectively installed on both sides of the loosening wheel, and are installed in an "eight" shape structure in the opposite direction. The distance between the two groups of ridge building plates gradually increases along the direction of the sugarcane subsoiling and soil preparation device. The ridge building mechanism mainly completes the deep loosening operation of the deep loosening plough group and the sugarcane ridge row after the top of sugarcane is pulled by the pulling wheel.

During the operation of machines and tools, the soil after the subsoiling part and the pulling wheel will be further piled and squeezed by the ridging mechanism based on the original loose soil ridge to maintain the original ridge structure. In this way, the soil in the ridging area mainly comes from the original ridge soil, and part of it comes from the deeply loosened soil at the bottom of the original ditch. The installation angle of the left and right ridging plates is designed to be adjusted in the range of 0-10°. This design mainly considers the depth and width of the new planting ditch, the shape of the newly built ridge and the agronomic needs of sugarcane planting. When the machine is working, the installation angle of the ridging board is generally set at 45° and the length, height and thickness of the left and right ridging boards are designed to be 60cm, 50cm and 1cm respectively.
4.4 Machine frame

4.4.1 Frame structure design

The frame is the key component of the subsoiling and soil preparation machine. According to the configuration of subsoiling and soil preparation machine, sugarcane planting row spacing agronomy and machine working performance, the machine adopts rectangular frame with strong anti bending and twisting ability, as shown in Fig. 7. The frame is welded by three-point suspension frame, front cross beam, rear cross beam, middle longitudinal beam and end plate. The front crossbeam structure adopts 120mm × 80mm × 8mm channel steel, the rear crossbeam structure adopts 80mm × 80mm × 8mm channel steel, the longitudinal beam structure adopts 50mm × 100mm × 8mm channel steel, and the end plate thickness is 12mm. The steel material of the whole frame is Q235 low carbon structural steel. The whole frame has the characteristics of simple structure, convenient manufacturing and processing. The subsoiling plough group and ridging board are installed on the frame by anti impact bolts. In this way, if the subsoiling plough encounters hard objects, the anti impact bolts will be cut off, so that the subsoiler will not be seriously damaged, and the transmission mechanism of machines and tractors will be protected at the same time.
4.4.2 The stress analysis of frame

Under the joint action of several loads, such as subsoiling plough group, loosening device and ridging board, the frame bears various excitation loads under working state. When the frequency of various excitation is close to a certain natural frequency of the frame, it will cause strong vibration and even resonance, and the frame is prone to fatigue damage [5-6]. Therefore, it is of great significance to analyze and study the dynamic and static characteristics of the frame structure to improve the reliability and subsoiling effect of the sugarcane subsoiling machine.

In the process of frame design, the virtual prototype is mainly established in UG software environment. Based on the finite element analysis method, the dynamic and static characteristics of the frame are analyzed by using ANSYS Workbench engineering simulation technology integration platform[7-8]. The results are as follows:

4.4.2.1 Under the bending condition, the maximum deformation displacement is 0.1237mm and the maximum bending stress is 14.46MPa. Under torsion condition, the maximum deformation displacement is 0.87mm and the maximum torsional stress is 143.6MPa. The bending stress and torsion stress are less than the allowable stress, which shows that the design of sugarcane subsoiling and soil preparation machine frame meets the strength requirements and the design is reasonable.

4.4.2.2 The natural frequencies of the first six modes of the frame are 69.834 ~ 134.284 Hz. By comparing with the random vibration of the subsoiling plough group and the pulling wheel, the possibility of resonance in the working process of the sugarcane subsoiling and soil preparation machine is very small, the dynamic characteristics are good, and the design is reasonable.

5. RESULTS AND ANALYSIS

A new round of sugarcane planting was prepared after sugarcane harvest. The field performance test was carried out under the conditions of soil moisture content of 30.1% and mechanized crushing rate of sugarcane leaves of more than 92% in southern sugarcane region. After testing, the test results of 1SGL-240 subsoiling and soil preparation machine are shown in Table 2. The results showed that: the process of soil penetration and subsoiling was stable, and the rate of sugarcane head plucking reached 91.2%, and all properties met the requirements of sugarcane field.

Figure 8. Frame structure of sugarcane subsoiling and soil preparation machine
TABLE II. SUMMARY OF TEST ITEMS

| Test items                              | Unit | Quality index | Test results |
|-----------------------------------------|------|---------------|--------------|
| Average subsoiling depth                | cm   | ≥35cm         | 38           |
| Stability coefficient of subsoiling depth| %    | ≥85           | 90.6         |
| Top plucking rate of sugarcane          | %    | ≥88           | 91.2         |
| Pure working hour productivity          | hm²/h| ≥0.90         | 0.98         |
| Fuel consumption                        | kg/hm²| ≤35           | 23.68        |

6. CONCLUSION

This paper is based on the 1sl series subsoiler designed in the early stage, aiming at the problems of low efficiency and high energy consumption in the process of sugarcane planting, as well as the problems of soil compaction and hardening caused by the tractor repeatedly entering the field to roll the sugarcane field. The machine can realize deep loosening, loosening the head of sugarcane, ridge building, soil preparation and other processes, realize the shifting planting of sugarcane by changing ridges and furrows, reduce the times of tractor near the ground cultivation, and solve the serious problems of diseases and insect pests caused by sugarcane planting in the same position year after year.

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