The Design of Negative-Pressure Precision Millet Seed-Metering Device

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Abstract — In order to solve the millet sowing labour, improve the accuracy of sowing and seeding efficiency, reduce the leakage sowing rate, this paper presents a negative pressure precision millet seed-metering device with adjustable disc gap. Each set of seeding device is composed of two discs, can adjust the gap to meet the requirements of different seed amount. The millet seed-metering according to the requirements of sowing and achieve the required seeding rate, row spacing and plant spacing, saving a large amount of seed, increase the utilization rate of the seeds, ensure production, fully meet the demand for Chinese farmers. The structure and the arrangement of the seed-metering device was optimized, and can be adjusted according to the actual requirements. Also takes into account the economic savings, take discharge device and a furrow opener together, reduce the complexity, and the seeding effect is not affected. So as to achieve the purpose of the design of the seeding machine to achieve the desired.

Keywords - millet seed-metering; negative-pressure; air-suction; sowing; precision seeding; furrow

I. INTRODUCTION

As the head of grains, millet is nutritious and rich in protein, fat, carbohydrates, crude fibre and trace elements, containing 11.42% average gross protein value. Most of millet are planted in China hilly and mountainous areas, as well as in extremely cold areas. According to their agricultural requirements, it shall arrange several seeds in the seed channel at short range so that it will cultivate group effect for seedling. Generally, millet is sowing in drill at present. It has large seeding amount and uneven sowing quantity which create extra work on subsequent thinning and final singling. It has negative effects to the quality and binds the extension of planting areas. In the regions where it develops high-power tractors, it tends to enlarge the seeder’s working width and operational speed as well as the seeding quality under high speed operation. Moreover, seeding methods have been improved constantly. For instance, it takes the seeding method of glue solution that discharge seeds by the peristaltic pump, which may avoid the negative effect of poor soil conditions to seedlings, and give pesticide-added fertilizers at the same time. When it comes to the tiny-seed millet seeding, such as the millet, it can only realize the sowing in drill. But it fails to satisfy the production requirements of the planting. Existing lots of problems lead to great differences of the planting density, high thinning intensity, as well as low seedling rate, waste of seeds, poor productivity, and bad effect. To develop the device of precision seeding aiming at tiny-seed millet is crucial for the mechanized production of minor millet crops. At present it has little development in the air suction precision seeder in China. In the long term, the air suction precision seeder has prominent social and ecological benefits. It may promote the seeding precision, saving seeds, and making fertilizers more effective. The research and popularization of this kind of product play a significant role to surge the seeding efficiency, enhance crops yield, reduce operation costs, boost farmers’ income, and protect natural environments.

II. MATERIAL AND METHODS

Seeder can be divided into mechanical and pneumatic, and pneumatic is divided into the air suction seeding machine, and the blowing type seeding machine. Because of its principle structure, the air suction millet seeder has the characteristic of precision, position accurate and no damage to the seed. The traditional mechanical cannot solve problems of precision seeding or seed damage.

According to crops row width and need to be adjusted, seeding machine often used the monomeric form, each seeding monomer comprises a set of working parts to complete whole process, such as ditching, seeding, soil covering and compacting.

Multiple monomers are arranged on the same beam, according to the required row spacing, which constitutes a hill drop seeder has different rows and working width, and can matched tractors with different power levels.

This paper designs an air suction seeder suit for millet. In the same general frame can install groups seeding or intertillage parts by the required row spacing, used for hill drop operation.

The overall characteristics of the millet seeder is shown in Figure 1.

The structural style:

1) Based on the designed working width, working resistance and the matched tractors of different horse powers, it can be divided to the trail-behind type and the mounted type. The overall designed seed-metering device selects the mounted type, the matched horsepower 50 Hp, operational rows five lines, row distance 300 mm, and the seeding depth 10-20 mm.

2) The working seeding speed depends on speed adaptability of working parts and running apparatus.
Domestic speed is 5-7 km/h and high speed operation over 12 km/h. In this design it selects 6 km/h.

3) The working width is determined by the formula (1):

\[ B = n \times r = \frac{T \times \eta \times 5.1}{P \times r} = 1.5 \text{m} \]  

\( T \) -- tractor traction, kgf;  
\( n \) -- number of rows, 5;  
\( \eta \) -- efficiency, 0.8-0.9;  
\( P \) -- working resistance, about 250 kgf;  
\( r \) -- row spacing, 0.3 m;

4) The trail-behind type and the mounted type must be no less than 200 mm overhead clearance. The mounted one must be no less than 300 mm, and the overhead clearance must be increased with that of the working width. Hereby it selects the overhead clearance 400 mm.

5) Seeds parameters: seeds length, width and height range from 1.55-1.65 mm, 1.35-1.45 mm, and 1.45-1.55 mm. It arranges four to six seeds in one hole. For instance, rapeseed, millet and radish seed. We can adjust the seeding disc gap to meet the requirements of different size of seeds or amount.

Common seed-metering devices include the external force seed-metering device, the seed-metering disc, the negative-pressure device, and the blowing type seed-metering device. This paper disused a negative-pressure precision millet seed-metering device, directly connected with the furrow opener without the millet tube.

2) The parameters of the seed-metering disc gap

There is a strong relationship between the form of the seed suction gap and its diameter on the one hand and the required suction chamber vacuum degree on the other hand. The seed-metering device has a direct influence to the adhesive force of seeds. The larger the hole diameter is, the stronger the suction capacity is. But if the hole diameter is overlarge, it will have high pressure loss. On the basis of other experiments, the formula (2) of the suction whole diameter:

\[ d = (0.6 - 0.7)b \]

\( d \) -- diameter of the seed suction hole;  
\( b \) -- seeds average width.

Based on the abovementioned seeds parameters and seed metering amount, together with the formula, the hole diameter (d)=1 mm. According to the requirements of the plant, the number of seeds per plant was 3-5, so the diameter (dw) of the seed cavity is 4 mm, depth (h) is 2.5 mm. The structure is shown in Figure 2.

Numbers of suction holes have a great bearing of the seeding speed, frequency and seed spacing. If the seed metering device rotating speed is constant, seed metering efficiency increases with the increase of number of holes accordingly. But when number of holes exceed to some constant value, seed suction capacity starts to decline, consequently it declines the qualification index, as a result of much total area of the suction hole, much leakage of the airspace and much pressure loss, which have weakened seed suction capacity [1-5]. The shortened distance between the other two suction holes, as well as the mutual influence of air flows make worse seed suction efficiency. More suction
holes should be better under the condition that it does not have bad effect for the suction hole to suck and scrape seeds as well as for seeds dropping. In this design, on the basis of requirements, it calculates the row spacing is around 6.28 cm and there are ten holes in total.

According to related documents, the required maximum vacuum degree of the suction chamber has the formula (3):

$$ H_{c_{min}} = \frac{2c_1c_2c_3}{S \cdot D} (G + F + J) $$

Where:
- $H_{c_{min}}$: critical vacuum degree of seeding working condition, Pa;
- $D$: the diameter of seed-metering device, m;
- $S$: seed cavity area, m$^2$; $S=(dw)^2/4$;
- $G$: seed weight, N; $G=mg$;
- $J$: centrifugal force, N; $J=m\pi^2 r, \pi=2\pi n$, n--speed of seeding disc;
- $F$: friction force between seeds, N;
- $K1$: absorption coefficient, 1.8-2.0;
- $K2$: external conditions influence coefficient, 1.6-2.0;
- $K3$: Seed moisture content, 1.1-1.2;

When the vacuum degree in the working cavity is greater than the critical value $H_{c_{min}}$, the seeds can be reliably adsorbed into the seed cavity.

It calculates that in seeding millet, the required maximum vacuum degree for the suction chamber is 3.236 KPa.

Structures and the mechanism design of the air suction seed-metering device is shown in Figure 3.

Working principles of the negative-pressure precision seeding disc: when it is in operation, the high speed fan generates the negative pressure through tube 2 and holes 3, conveying to the vacuum chamber of seeding monomer 1. When the seeds plate 5-6 rotates back, under the negative pressure of the vacuum chamber, it sucks seeds and rotates with the plate. When seeds are rotated out of the vacuum chamber, without the negative pressure, they are fallen into the furrow 8 according to the weight or under the effect of the scraper 7. The air suction seeding device has the main influences such as the vacuum degree, the suction hole shape, seeds dimension, the structure and adjustment of the scraper.

The diameter of the seed sucking plate is 200 mm, having 10 holes. In one side of the seed sucking plate there is a scraper, which can save the space. In the other side there are four holes, being incoherent, so that the seeds can be sucked solidly.

At the front cover of the seed-metering device, there is a part to connect the fan. The inner is the vacuum chamber and the lower part is the wind screen.

Based on the structure of the seed-metering device, the area of each suction hole is 12.566 mm$^2$, the area of total valid suction holes 125.66 mm$^2$.total required vacuum pressure for five seed-metering devices is 0.021MPa.

The effective power of the wind turbine is:

$$ Ne=QP $$

Where:
- $Q$: the total air required by 5 rows, $Q=0.101$ m$^3$/s;
- $P$: the wind pressure, $p=0.021$ MPa;

The total power of the fan is:

$$ N = \frac{K \cdot Ne}{\eta_1 \cdot \eta_2} $$

Where:
- $K$: power reserve coefficient, 1.1;
- $\eta_1$: the efficiency of the wind turbine, 0.7;
- $\eta_2$: the mechanical efficiency of the fan, 0.92;

So the required power of the seeding machine must be less than 3.69KW.

Functions of the furrow opener: when the seeder is in operation, the opener makes the seed channel, guides seeds and fertilizers to fall into the furrow, and covers it by humid soil. In this design it takes the ploughshare type acute furrow opener. When it operates, firstly the ploughshare falls into the soil and makes the furrow, and then the two landsides divide the soil and form the seed channel. The plough point angle is 20°.

As one of the prominent parts of the seeder, the performance of the fertilizer distributor plays a decisive role in the seeding quality. In this design it takes square container. When the land wheel rotates, the fertilization shaft turns through chains. The cam rotates fertilizers from the container to the guidance device, mixing them and pushing them to the inlet and making them flow to the fertilizer delivery tube. The fertilizer quantity is controlled by the adjusting plate in the guidance device.

The covering device: the furrow opener can only cover seeds by little humid soil. If the required thickness cannot be satisfied, it shall install the covering device behind the
furrow opener. The seeding requires that earthing depth performed by the covering device shall be equal. The position of millet in the seed channel cannot be altered when it is in earthing. Making a comprehensive consideration, it takes the scraper covering device.

The press wheel: the rolling by the press wheel may reduce large holes in the soil when it is seeding. It will lower the water evaporation and preserve soil moisture, as well as adjust the moisture. So that seeds closely contact the soil for better seedling and growth. In this design it takes the cylinder press wheel, its diameter \(d = 260\) mm. It has simple structure, wide rolling surface, even pressure distribution and strong performance to solid the soil.

The framework: the designed seeder takes the mounted type and the whole framework is connected by welding, adopting \(5\) mm square tube. At the lower part of the framework it welds the land wheel support. The designed land wheel diameter is \(400\) mm and the land axle \(30\) mm.

The drive mechanism: according to other researches, the seed-metering device drives by the electric motor. The fertilizer distributor rotates synchronously with the launching speed. The seeder for millet takes the land wheel as the driving wheel. It moves the fertilizer distributor through the chain drive.

The drive of the fertilizer feed shaft: numbers of total gear teeth \((z) = 18\). after the calculation the chain pitch, it consults the form and gets \(101.8\) mm, pitch numbers \(L = 79.4\), taking the round-off number, \(L = 80\) mm, the chain speed \(v = 0.4\). The chains are lubricated by drop lubrication.

The profiling mechanism: it refers to the furrow opener of the millet seeder, cultivator operating parts of the seedling-cultivating toolbar, as well as the mechanism connecting the framework. When it is in operation, the profiling mechanism works under the condition of the changing of the surface roughness and resistance. It makes the stable operating depth to ensure the outstanding working quality. The profiling mechanism includes whole profiling and individual profiling. In this design it takes the individual one.

The whole machine structure is shown in Figure 4.

III. Conclusion

In this paper it purposes a kind of millet seed-metering device aiming to millet seeds. It optimizes the furrow opener, the seed-metering device, and other parts to get even seeds flow or constant single seed. It may adjust seeding quantity according to actual requests to satisfy required row spacing and planting distance. All make it possible to save seeds and to promote seeds utility rate. So that it ensures the output and satisfies market needs. It also gives a consideration to the economy, combining the seed-metering device with the furrow opener, which makes it easier and will not influence seeding effects.

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