Numerical Simulation and Experiment on the Adsorption Seeds Properties of Air-Suction Peanut Seed-Metering Device

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***Abstract* — In this paper we design an air-suction seed-metering device. Facilities used and steps included: i) Numerical Simulation equations, ii) standard k-E turbulence model and the SIMPLE numerical calculation method, iii) these were applied to calculate the velocity and vacuum pressure fields in a gas chamber of the seed-metering device, iv) Computational Fluid Dynamics (CFD) software. The effect of the vacuum pressure, nozzle diameter and rotating speed on the performance of seed-metering device were analyzed by bench testing. The simulation and testing results show that: i) at the entrance of the gas chamber, the velocity and the vacuum pressure are highest, ii) the velocity and the vacuum pressure of adsorption seed area are slightly larger than of metering seed area, and iii) the distribution is relatively uniform, which is favorable for the seeds in adsorption area and placing the seed in metering area. With the decreased in vacuum, the qualified index and the multiples index showed a downward trend, and the leakage index showed an upward trend. With the increased nozzle diameter, the adsorption seeds ability is to improve, and leakage index is to decline. When the nozzle diameter is larger than 5.0mm, the performance of the adsorption seeds is decreased with the increase in nozzle diameter. With the increased rotation speed of the seed-metering device, the performance of the adsorption seeds is gradually increased and then decreased. When the rotation speed is 92r/min, it was still able to meet the requirements of the adsorption seeds performance. In conclusion, the study: i) proved the distribution of the gas chamber flow field of the seed-metering device, and ii) the influence of related factors of the adsorption seeds performance, and iii) provided the technical basis and reference for the optimum design of the seed-metering device.**

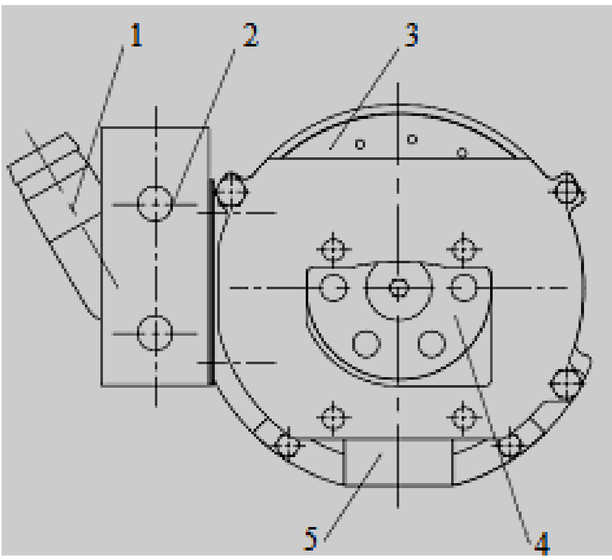
Key words* — *Seed-metering device, Adsorption seeds performance, CFD, Numerical simulation, Performance test

I. INTRODUCTION

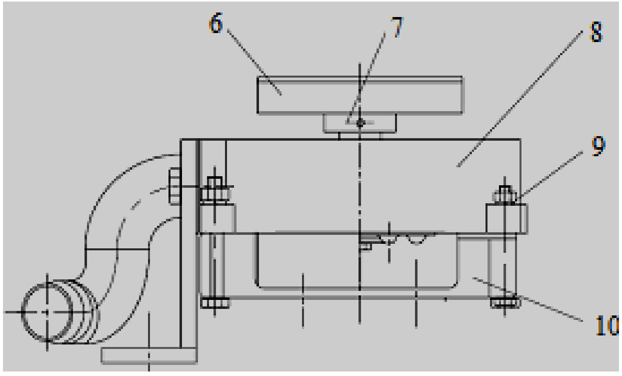
The planting peanut belongs to precision seeding, and the seeding quality of the planter directly affects the process of the peanut industry mechanical development. The seed-metering device is a key part of peanut planter, and its performance directly affects the seeding accuracy, seeding uniformity and seedling rate. Due to the air-suction seed-metering device have the characteristics of not strict requirements to seeds size, not broken to the seeds, good versatility, good adaptability, and high seeding speed, it is regarded as a relatively advanced seed metering device [1-3]. When Air-suction seed-metering device works, the distribution of the chamber flow field directly affects its quality and efficiency of the adsorption seeds. With the computer processing speed increased, it is widely used that computational fluid dynamics software to accurate calculation of complex mechanical properties of multiphase flow field [4-10]. In this paper, based on the study of the designed air-suction peanut metering device, simulation analysis was carried out on the device`s chamber flow field in the process of adsorbing seeds by FLUENT computational fluid analysis software, and the influence rules were researched on the factors of affecting adsorption seeds performance of the seed-metering device by bench test. It provided reference for the structure design and parameter optimization of the air-suction peanut seed-metering device.

II. BASIC STRUCTURE AND WORKING PRINCIPLE OF THE SEED-METERING DEVICE

Air-suction peanut seed-metering device mainly consists of the gas chambers, metering disc, seed chamber, pipes and other components, as shown in Figure 1.



(a) front view



(b) vertical view

Figure 1. Structure diagram of air-suction seed-metering device
1. pipe 2. connecting board 3. metering disc 4. stirring parts
5. guiding parts6. Internal roller sprocket 7. Transmission shaft
8. gas chamber 9. connected components10. seed chamber

The air pipe is connected with the fan through the air conveying pipe, and the negative pressure in the gas chamber is supplied. The gas chamber is installed on the transmission shaft by the bearing, and its connecting board fastened to the bracket of seeding wheels by bolts. The gas chamber is a fan-shaped cavity. Metering disc is fastened to transmission shaft, its inside fitted with concave edge of gas chamber, and outside fitted with the inside of the seeds chamber. When machine working, the metering disc is relative revolved to the air chamber and seeds chamber by transmission shaft driving, the seeds are adsorbed on the adsorption seeds pore under the effect of negative pressure of gas chamber and the stirring seed disc. After the clear seeds device clears off extra seeds down to seed chamber, leaving a seed to be taken out of seed chamber. Due to the negative pressure terminated, the seeds fall into picking box by guiding parts in the effect of weight. It was finished the process of the adsorbing seeds and metering seeds of the seed-metering device.

III. SIMULATION ANALYSIS OF THE GAS CHAMBER FLOW FIELD OF THE SEED-METERING DEVICE

A. Fluid Control Equation

The simulation analysis of the gas chamber of the seed-metering device makes the following hypothesis: (1) the fluid is steady, continuous and incompressible; (2) the inlet pressure and the velocity of the seed-metering device are uniform; (3) the gas chamber is sealed without leakage. Because of the Reynolds number of the airflow near the adsorption seeds pore has greater than or equal to 2000, the airflow is turbulent state. According to the Boussinesq hypothesis and the Reynolds average equations, the differential control equations of the gas dynamics is [11-13]:

The continuous equation is:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho_{ui})=0 \tag{1}$$

Navier-Stokes equation:

$$\frac{\partial}{\partial t}(\rho_{ui})+\frac{\partial}{\partial x_i}(\rho_{uiuj}) = -\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\frac{\partial u_i}{\partial x_j}-\rho\overline{u_i^{'}u_j^{'}}\right]+S_i \tag{2}$$

In order to close the equation (1) and (2), the turbulence model is also needed. Using standard k-E turbulence model, the model is widely used in the calculation and analysis of the gas-solid two phase flow field of agricultural machinery [12,13]. Its control equation is:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k_{ui})=\frac{\partial}{\partial x_j}\left[\left[\mu+\frac{\mu_i}{\sigma_k}\right]\frac{\partial k}{\partial x_j}\right] + G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{3}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon_{ui})=\frac{\partial}{\partial x_j}\left[\left[\mu+\frac{\mu_i}{\sigma_\varepsilon}\right]\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \tag{4}$$

Among above equations:

$$\mu_t=\rho C_\mu\frac{k^2}{\varepsilon} \quad G_k=\mu_t\left[\frac{\partial \mu_i}{\partial x_j}+\frac{\partial \mu_j}{\partial x_i}\right]\frac{\partial u_i}{\partial x_j}$$

$$G_b=\beta g_i\frac{\mu_t}{\mathrm{Pr}_t}\frac{\partial T}{\partial x_i} \qquad Y_M=2\rho\varepsilon Ma^2$$

In the equations: μt—turbulent viscosity, Pa.s; ρ—air density, kg/m; Gk—generation term of the turbulent kinetic energytur K induced by mean velocity gradient; Gb—generation term of the turbulent kinetic energy K induced by the buoyancy; YM—the contribution of pulse extension in compressible turbulent; Si, Sk, Sε—source term; Prt—the turbulent Prandtl number; β—coefficient of thermal expansion; Ma—Mach number.

Under the normal temperature, the simulation is done. The air density is 1.205kg/m3, the viscosity of the fluid is 1.83×10- 5Pa.s. The end face of the air pipe is defined as the output end face, the surface of adsorption seeds pore is defined as the input end face, and the rest parts are defined as the wall. The wall is not slipping (i.e. the velocity and pressure components are zero), input pressure is 0kPa, and the output pressure is -5.65kPa.

B. *Calculation Results and Analysis*

As shown in Figure 2, from the calculation results of velocity vector of chamber flow field can be known: at the chamber entrance of the seed-metering device (1 area in figure), the velocity is larger, and the velocity distribution gradually decreases under the resistance from the metering disc and seeds; the velocity in adsorption seeds region (2 area in figure) is slightly larger than that in metering seeds area (4 area in figure); the velocity in metering area is relatively less, it is conducive to fall off of the seeds of taken out the seed chamber, and prevent seed damage by excessive adsorbing seed force when the seed is being taken out of seed chamber; in the gas chamber (3 area in figure) the velocity distribution is uniform and stable, conducive to uniformity and stability of the adsorption seeds; in the place of the entrance and the gas chamber connection(2 area in figure) and edge of the adsorption seeds of the seed-metering disc (2 area and 3 area in figure) have obviously vortex phenomenon, the velocity of the vortex area in gas chamber flow field is relatively smaller.

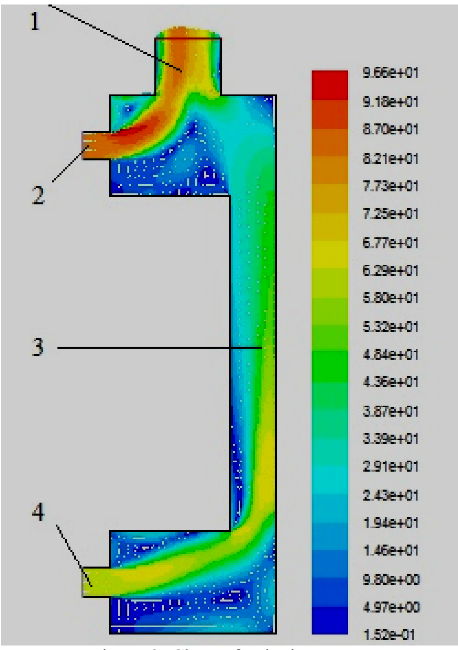


Figure 2. Chart of velocity vector

As shown in Figure 3, from the results of vacuum pressure distribution in seed-metering device gas chamber can be known: the vacuum pressure is relatively larger at the chamber entrance of the seed-metering device (1 area in figure); vacuum pressure distribution is uniform and stable in the gas chamber (3 area in figure), which is conducive to the uniformity and stability adsorption seeds of metering disc at the machine working; the vacuum pressure of the adsorption seeds area (2 area in figure) is greater than that of the seed-metering area (4 area in figure), it is conducive to improve adsorption seeds and carrying seed of the metering disc at adsorption seeds area, and prevent seed damage when the seed is being taken out seed chamber.

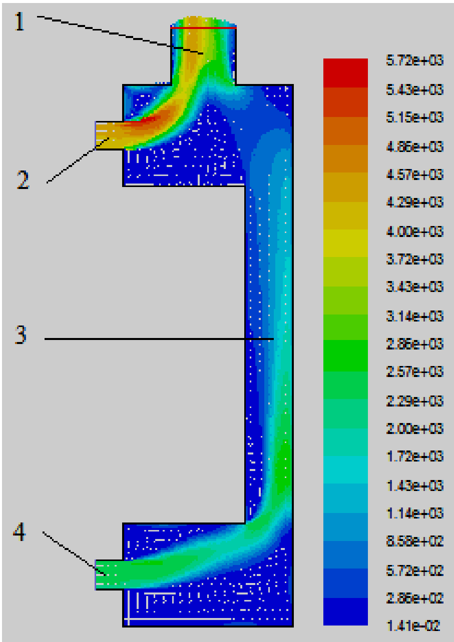


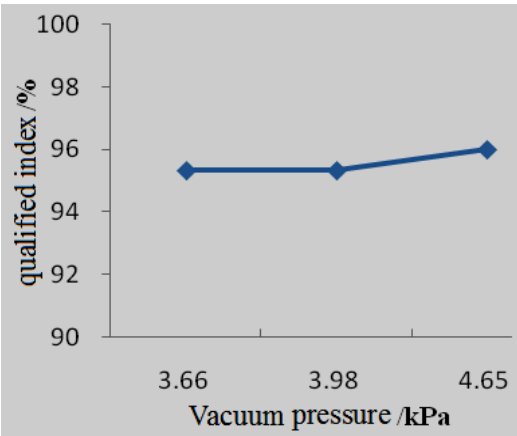
Figure 3. Distribution chart of pressure.

IV. ADSORPTION SEEDS PERFORMANCE TEST

Through the bench test, the adsorption seeds performance of the designed air-suction peanut seed-metering device was tested under different conditions, and it was studied on the influence of the factors to the performance of the seed-metering device. Chosen vacuum degree, nozzle diameter and rotating speed as experiment factors, and the qualified index (1 seed on per nozzle), multiples index, leakage index as the test indexes in accordance with the national standard GB/T6973-2005 《single (precision) planter testing method》. In the test, each sample includes seeds in consecutive 50 pore on the metering disc, the corresponding index is calculated by the following formula: $\theta i = Ni/N \times 100\%$ (θi: the qualified index, multiples index, leakage index; N:the total number of each group; Ni: the performance indicators number of meeting requirements in each group). The each group test is repeated 3 times, and the average number is taken as the index value [14]. Selected four red peanut varieties in test, the peanut seeds need be graded and cleaned before the testing. The chosen seeds is no debris, particles uniform, no damage and no dry seeds, etc..

A. Effects of Vacuum Degree to Adsorption Seeds Performance

The vacuum degree in the gas chamber determines adsorption seeds ability of the seed- metering device, which can directly affect the ability of the peanut kernel to be adsorbed to the adsorption seeds pore, and adsorption seeds the number, state of the peanut. That vacuum is too large or too small will be seriously affected to adsorption seeds effect and working performance. When the vacuum is too small, due to the lack of adsorption seeds force, the leakage phenomenon is easy to be caused. When the vacuum is too large, more seeds are easily adsorbed on the metering disc, the multiples phenomenon is intensified. In order to determine the range of the vacuum degree of the seed metering device, it is required to study on the influence rule of the vacuum degree to the performance of the seed- metering device. Chosen 5.0mm nozzle diameter and the 55r/min rotating speed, the performance test of the seed-metering device was done on the testing bench. The test results are shown in figure 4. The as seen in Figure 4, with the decline of the vacuum degree, the qualified index and the multiples index showed a downward trend, and the leakage index showed an upward trend.



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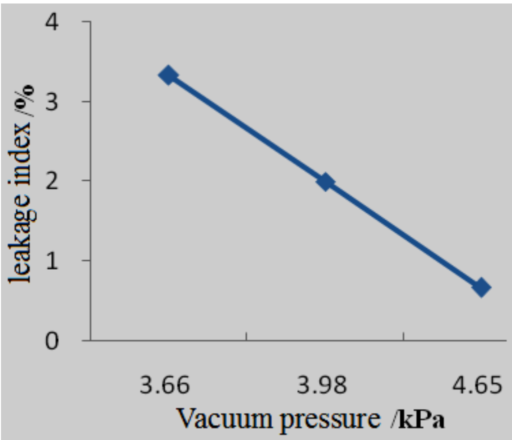

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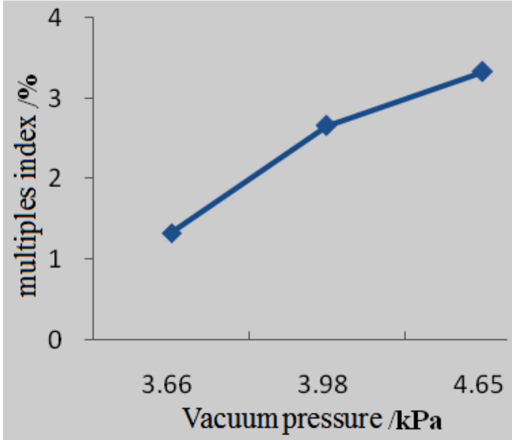
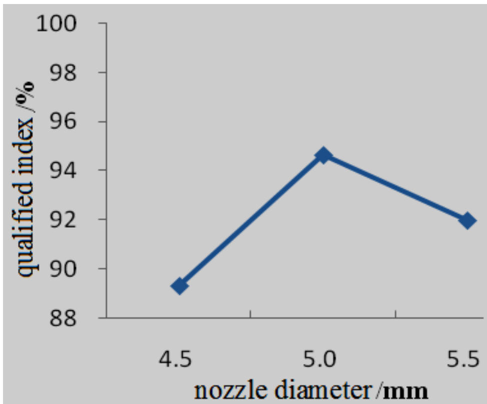


(c)

Figure 4. Effect of vacuum pressure to adsorption seeds performance.

B. Effect of the Nozzle Diameter to Adsorption Seeds Performance

When the vacuum degree is constant, the performance of the seed metering device increases with the increase of the adsorption seeds nozzle diameter. When the nozzle diameter reaches a certain value, the adsorption seeds performance of the seed-metering device is decreased because of the increase of the leakage gas amount and the suction seed area. In order to determine the optimum nozzle diameter, the 4.5mm, 5.0mm and 5.5mm nozzle diameter were selected and tested under the condition of vacuum degree 4.65 kPa and rotating speed 55r/min. The test results are shown in Figure 5. The test results shown that with the increase of the nozzle diameter, the suction seed area increases, that further results in the adsorption seeds force increases, adsorption seeds performance is improved, and the qualified index and multiples index were increased, leakage index was decreased. When the nozzle diameter is greater than 5.0mm, the adsorption seeds performance begins to decline with nozzle diameter increasing, and qualified index falls, multiples index increases.



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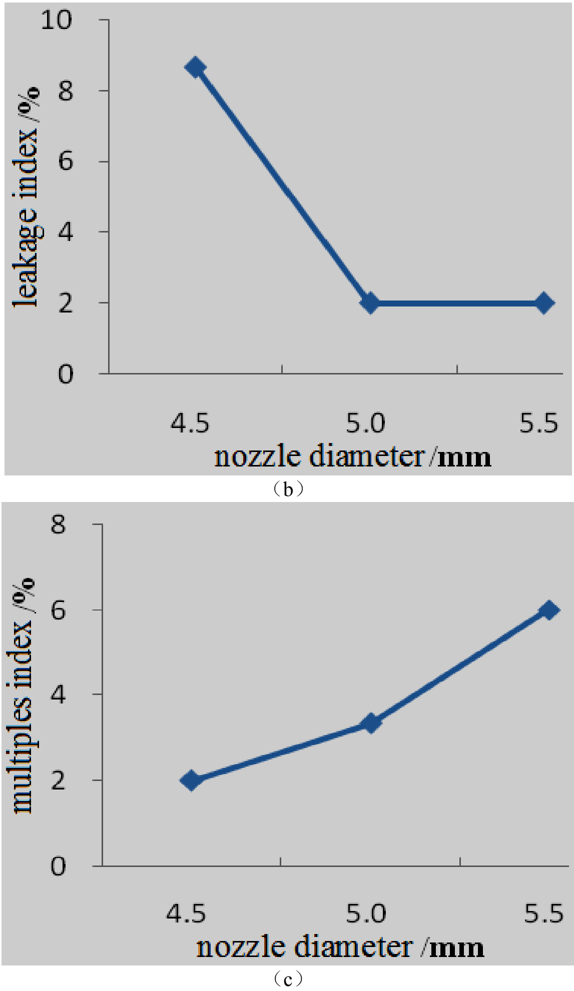

Figure 5. Effect of the nozzle diameter to adsorption seeds performance.

C. Effect of the Rotating Speed to Adsorption Seeds Performance

The rotating speed is an important factor that affects the performance of the seed-metering device. With the rotating speed increases, the adsorption seeds frequency and the seeding efficiency are improved. Due to the adsorption seeds time is relatively reduced with the increase of the rotation speed, when the speed reaches a certain value, the adsorption seeds effect is difficult to meet the performance requirements. Select the nozzle diameter 5.0mm, vacuum degree 4.65kPa in the test, test results as shown in figure 6. The result of the test shows that with the rotation speed increases, the qualified index, leakage index gradually increase, the multiples index relatively decreases. When the rotation speed is 92r/min, adsorption seeds performance of the metering disc is still good, which the qualified index is 96%, leakage index was 2.67%, the multiples index is 1.33%, can better meet the performance requirements of the seed-metering device.

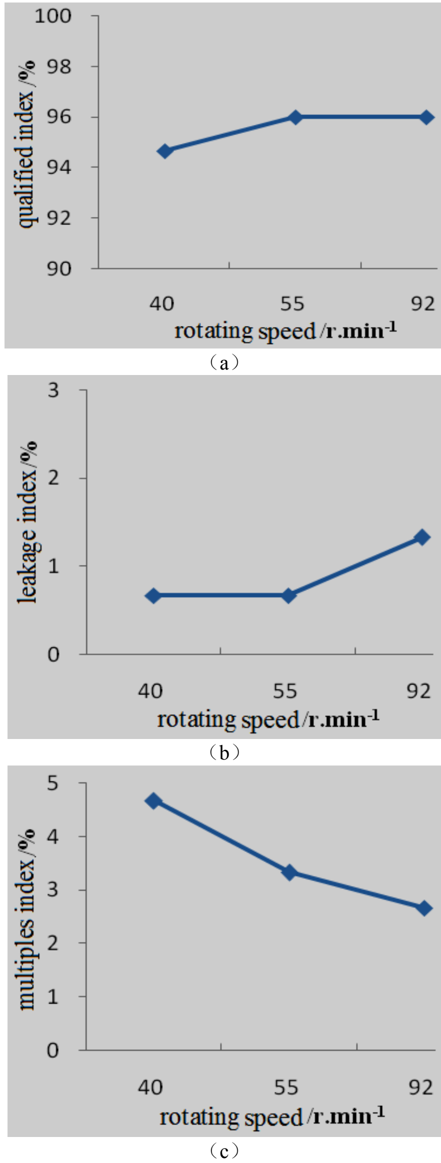

Figure 6. Effect of the rotating speed to adsorption seeds performance.

V. CONCLUSIONS

The chamber flow field at the seed-metering device working is analyzed with the FLUENT software. From the simulation results of the seed-metering device gas chamber can be known: the velocity is larger at the entrance of the seed-metering device gas chamber. The velocity value is gradually reduced from the adsorption seeds area to putting seed area, and the adsorption seeds performance is gradually weakened, which is conducive to adsorption seeds and putting seeds.

The vacuum degree, nozzle diameter and rotating speed have a significant influence on adsorption seeds performance of seed-metering device. When the vacuum is too small, the leakage phenomenon is aggravated. When the vacuum is too large, the multiples phenomenon is aggravated. Under constant condition of the vacuum degree and rotating speed, the adsorption seeds performance is relatively increased with the increase of nozzle diameter. when the nozzle diameter is greater than 5.0mm, with nozzle diameter continue increase, the qualified index decreases, the multiples index increases. The chosen nozzle diameter is different for different peanut varieties. The optimum nozzle diameter of peanut varieties in test is 5.0mm. With the rotation speed increases, the qualified index, leakage index gradually increase, the multiples index relatively decreases. When the rotation speed is 92r/min, adsorption seeds performance of the metering disc is still good, can better meet the adsorption seeds performance requirements of the seed-metering device.

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