SIMULATION AND DESIGN ON AIRFLOW DISTRIBUTION CHAMBER OF PNEUMATIC SEED METERING DEVICE
/
气力输送式排种器流场模拟与气流分配室结构设计

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ABSTRACT
The pneumatic conveying metering technology is used to enhance the filling and clearing capacity of the seed metering device by forming a rotary air flow field inside the airflow distribution. The simulation test results show that the increase of the number of fan blades, the velocity of flow field at different outlets of the seed cleaning area decreases linearly, but the average velocity basically remains unchanged. The flow field velocity in the seed filling area decreased significantly with the increase of fan angle, and the difference between seed filling area and clearing area remains unchanged. When the blade angles in the filling area are the same, the fan blades size has no effect in flow field velocity.

摘要
提出气力输送式排种技术，在排种器内形成旋转气流，增强吸种和清种能力，设计了一种以气流分配室为核心的风送式排种器。试验结果表明随着气流分配室中扇叶数量的增加（7 叶-10 叶）清种区的平均速度呈线性下降趋势，清种区的平均速度保持不变；冲种区速度随着扇叶角度的增加而明显降低，但是冲种区与清种区平均速度差不变，当冲种区扇叶角度一直时，速度与扇叶大小无关。

INTRODUCTION
The seed metering device is an important part of the seeder, and its performance affects the operation quality of the seeder (*Zhai et al, 2016; Zhang et al., 2016*). Pneumatic seed metering device which depends on air suction or pressure can be used directly to seed for improving the success rate in filling and clearing (*Zang et al, 2015; Yuan et al., 2008*). Compared to the mechanical seed metering, the pneumatic seed metering device has advantages in high seeding and adaptation to seeds. So far, it has been applied widely to the seeder for corn, rice, rape and so on (*Cong et al, 2014; Han et al., 2022; Hu et al., 2012; Pasha et al., 2016; Markauskas et al., 2010; Cao et al., 2013; Li et al., 2013*).

The computational fluid dynamics (CFD) and high-speed photography are used to realize the technology upgrade and structural optimization of seed metering device (*Cao et al, 2015; Wang et al., 2021; Hou et al., 2020; Zhang et al., 2015*). Zhang Ying has monitored the process of clearing seeds by high-speed photography, and the technology of active retaining structure was proposed to improve the precision of the seeder (*Zhang et al., 2022*). On the other hand, Li has simulated the flow field of seed metering device of rice, through the bench experiment, optimized the structure of air distribution chamber, and then improved the performance of seed metering (*Chen et al., 2022; Ma et al., 2020; Liu et al., 2012*).

In summary, most studies about structural optimization of pneumatic seed metering device was based on traditional device, and there are little studies on the new structures and new methods. A new study on the pneumatic forming device for seeds has attracted more and more attention. The seed flow is formed in the seed metering device and seed drop tube, through the transportation of air. The clearing capacity of the seed metering device and the precision of seeding are greatly improved.

This study designed a special flow field forming technology inside the device. Through both forward and reverse blades laying out in the area of filling and cleaning seed, the flow parameters of air will change. The negative pressure (-) is close to the filling area, and nearby the cleaning area, the pressure is higher (+). Meanwhile, a part of the flow passes through the area of cleaning with seed, therefore, it can transport the seed outside the device. The theoretical analysis, simulation analysis and the bench experiment of the pneumatic forming device have been completed with both forward and reverse blades. The results show that the structure and number of blades had significant effect on the flow parameters.

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MATERIALS AND METHODS

The structure of the pneumatic forming device

The pneumatic forming device includes seed case, forming machine, seed metering wheel and so on, as shown in Fig. 1. The useful flow field is generated inside the forming machine for seed filling and cleaning by installing different numbers of both forward and reverse blades.

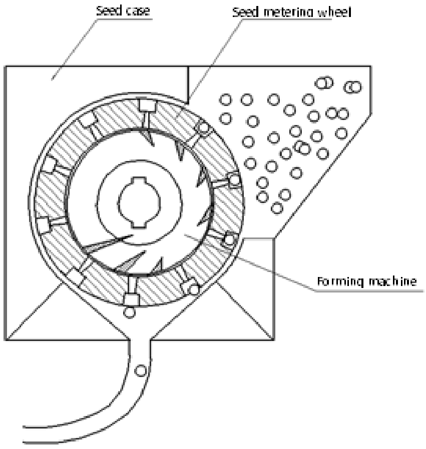

Fig. 1 - Structure of pneumatic forming device

The air flow from the fan enters into the forming machine along tangential direction and forms rotary flow filed. In the function of both forward and reverse blades, the area of negative pressure and high pressure are formed inside the forming machine. When the air flow passes through the forward blades in the forming machine, the negative pressure will be formed nearby the seed filling area, so the suction force on seed is forming, which can improve the filling capacity. When the flow passes through the reverse blades in the forming machine, the high pressure will be formed nearby the cleaning area, so the forming force on seed is forming, which can improve the cleaning capacity.

Principle of the forming machine

The seed flow passes through the seed drop tube quickly, without the impacting between seed and tube, which improves the precision of seeding. At the end of the seed drop tube, the separating device was designed so that the seed would not be blown out of the seed bed. With rotation of the seed metering wheel, it is helpful for seed filling in the function of negative pressure, and seed cleaning in the function of high pressure in the seed metering device.

As shown in Fig. 2, the flow in the forming machine is passing through both forward and reverse blades. The negative pressure will be formed in the function of forward blades near the filling area. And when the flow passes the reverse blades, the high pressure will be formed between blades, which is helpful for seed cleaning.

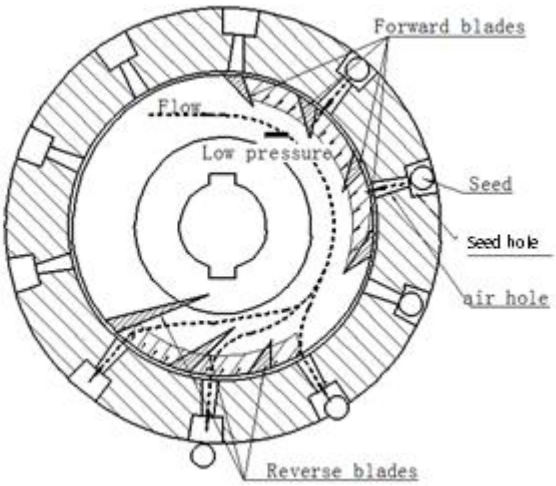

Fig. 2 - The flow in the forming machine

Therefore, the useful flow is mainly determined by the structure of forward blades and reverse blades, including the number and degree of blades, the distance between adjacent blades, and the size of air hole. Fig. 3 shows that the seeds in the filling area are pressed into the seed hole through force effect (F_x), which is formed by the negative pressure.

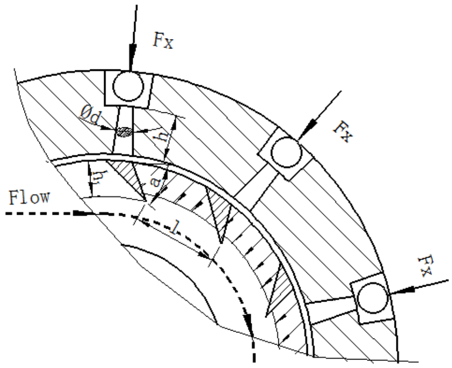

Fig. 3 - The force analysis about seed in the function of flow

As shown in Fig. 3, when the inlet flow parameters are kept invariable, the force in the function of flow is determined by the structure of blades and air hole. Therefore, the Strength of negative flow is related to the height of blade (h_1), the degree of blade (a) and the distance between adjacent blades (l). Meanwhile, the capillary effect will be formed when the flow is passing through the air hole, and the length and diameter (h and d) of the air hole will directly affect the force (F_x) acting on the seed. The parameters of blades and air hole are shown in Table 1.

Table 1

The parameters of blades and air hole

Project	Parameters	Symbol
Blades	Height /mm	h_1
	Degree /°	a
	Distance /mm	l
Air hole	Diameter /mm	d
	Length /m	h

The seed is pressed into the seed hole in the function of negative pressure, and the force is Fx,

$$F_x = P\,\pi d^2/_4 - F_{ds} \quad (1)$$

where: F_{ds} is the pressure loss, N; p is the flow pressure intensity, Pa; d is diameter of air hole, m.

The flow velocity has a decisive role on the formation of pressure intensity. When the flow passes through the forward blades with a blade angle, the velocity will decrease.

Simulation and analysis of the flow in the forming machine

The 3D model of the forming machine was built by SOLIDWORKS, and the mesh was generated by GAMBIT. As shown in Fig. 4, the fluid was defined in the blades and the middle area of the forming machine, the surface of the model was wall in soft. The inlet was set at the first forward blade, and the outlet was set at the other blades. The flow could pass through between the blades and the middle of the model in order to form the rotational flow.

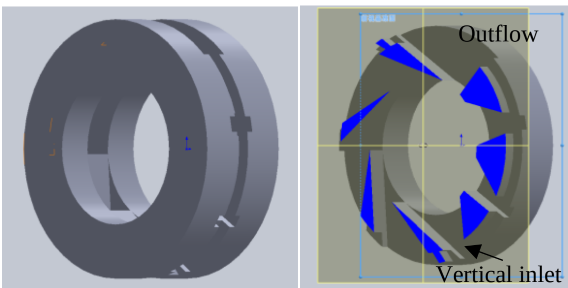

Fig. 4 - The 3D model of forming machine

SIMPLE was used to couple calculation. And air was selected to the flow, which density is 1.29 kg/m^3, and 1.85×10^{-5}Pa.s is for viscosity. The wall is stationary and no slip. Flow velocity is 4 m/s at the vertical inlet and is perpendicular to the face of the inlet. The first blade is inlet, and the others are outlet, which are outflow. The residual precision is10^{-4}.

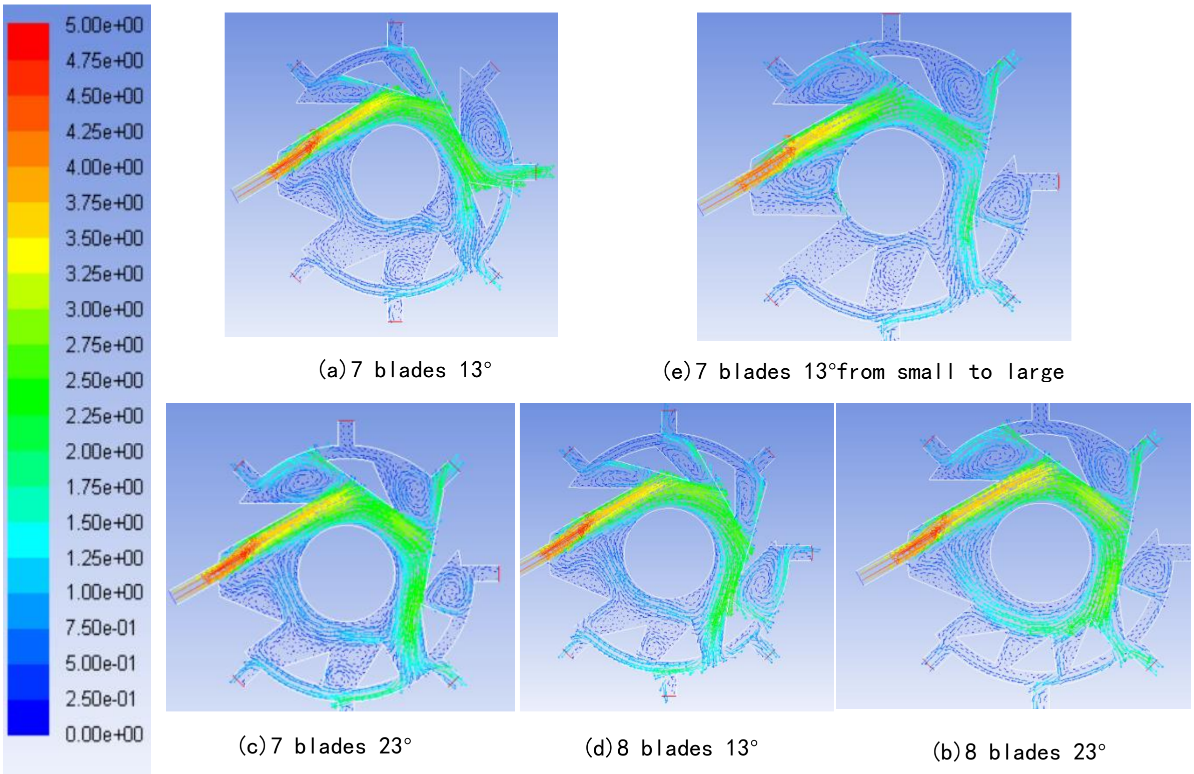

Fig. 5 - The speed vector of different blade structure parameters

Fig. 5 and Fig. 6 show the flow section of the forming machine in different structure parameters of blades, which include the number of blades (7, 8, 10), the angle of blades (10°, 13°) and the size of blades (from big to small). The speed ranges from 0 to 15 m/s.

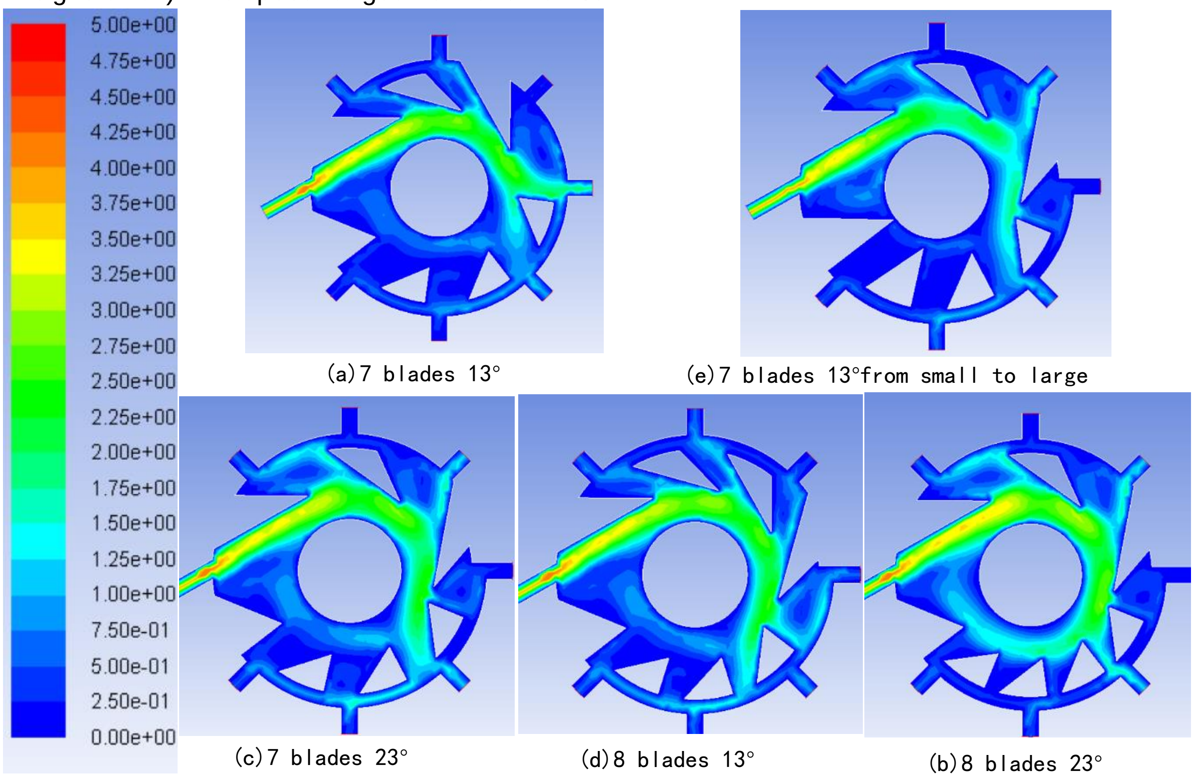

Fig. 6 - The speed cloud of different blade structure parameters

The flow entered into the forming machine from the first forward blades, and rotational flow field was forming in the circular inside.

The flow speed is from 0.7 m/s to 5m/s in the area of forward blades, and the maximum speed was present at the top of the blades, where the hydraulic diameter of the forming machine was the smallest.

The flow speed has a large span in the area of reverse blades, and in the first blade is larger than the others. From fig (c), (d) and (e), the speed in the area of first blade is becoming smaller and smaller when the number of blades is higher.

Two axial symmetric rotational flows with low speed were formed in the middle of the forming machine. At the bottom of the blades, the distance of adjacent blades is smaller and smaller, the speed of the flow increases gradually, and the low pressure forms in the forward blades and the high pressure forms in the reverse blades.

The bench experiment of forming machine

The experimental device is shown in Fig. 7, including the computer, the forming machine, the fan, and the flow velocity sensor, in which, the forming machine was manufactured by 3D printer, the type of speed sensor is AW with a range of 1-10 m/s, and the fan is FH6250 from FEIKE with the precision of 0.05 m/s.

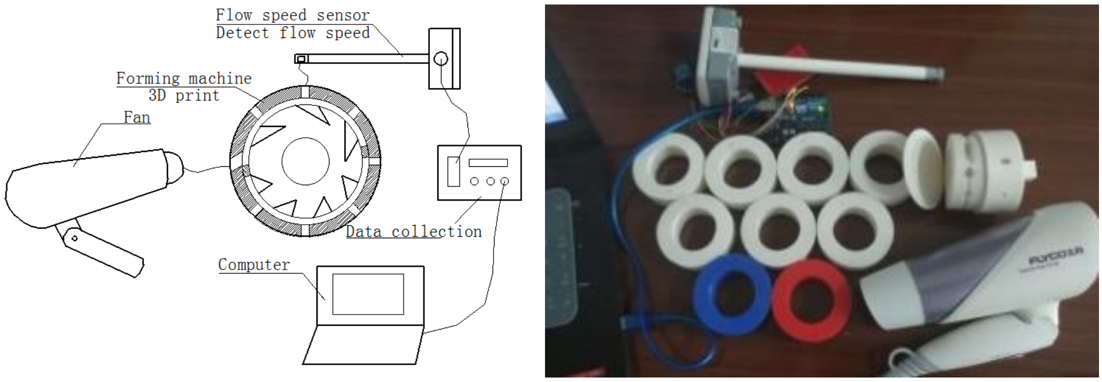

Fig. 7 - The sketch and physical figure of the experiment equipment and program

The different number and arrangement of fan blade structures are used as experiment factors, the parameter of the experiment is the flow velocity at the outlets of the forming machine. Each experiment is repeated three times. As shown in table 2, five different fan blade structure parameters were designed in the experiment.

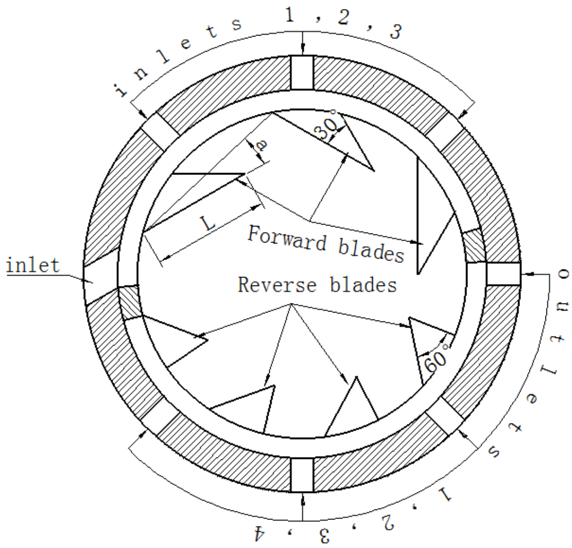

Fig. 8 - Air outlets and inlets numbers of the forming machine

The air outlet number is shown in Fig. 8. During the experiment, the outlet flow velocity is detected by the sensor.

Table 2

Design of experimental factors

The number	blade structure parameters
1	7 blades，13°
2	7 blades，23°
3	8 blades，13°
4	8 blades，23°
5	7 blades，13°（from small to large）

RESULTS

The single factor experiment results and analysis

(1) The influence of the number of blades on flow speed

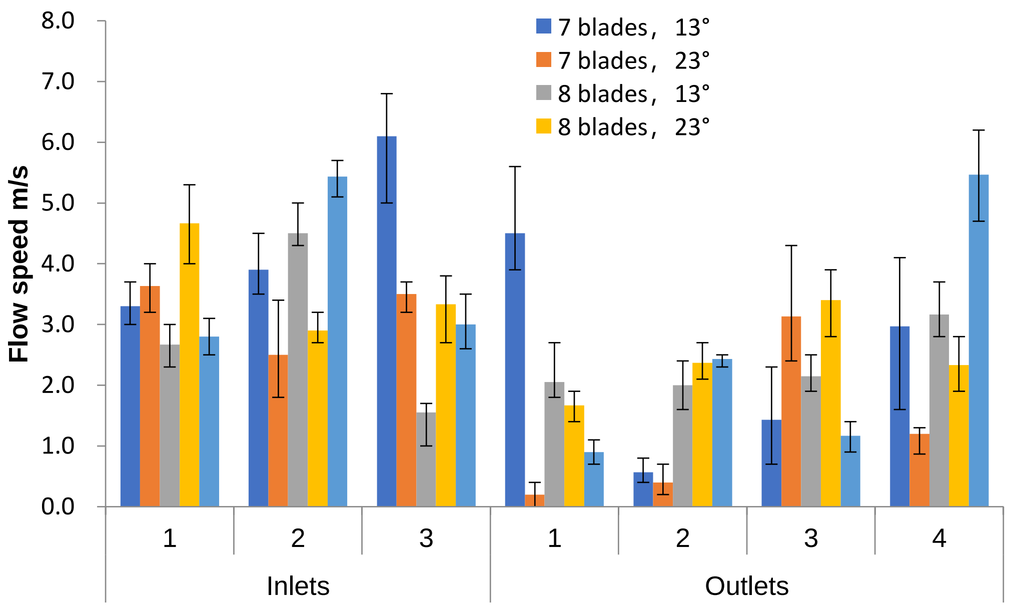

Fig. 9 - The flow speed of measuring point under the condition of different structural parameters of blades

As shown in Fig. 9, the average flow velocity is 4.4 m/s and 2.4 m/s respectively at the inlets and outlets. The closer to the outlet, the greater the speed of the flow, which is basically a linear distribution. It shows that under the function of the forward blades, the negative pressure was generated at the inlets of the forming machine, and the positive pressure was generated at the outlets.

As the flow is formed inside the forming machine, the speed gradually decreases, the negative pressure effect is weakened. When the blade angle is 13°, as the number increases, the average flow velocity is 4.4, 3.6 and 2.9 m/s respectively at the outlets, at the same time, the speeds at the inlets are 2.4, 2.4 and 2.3 m/s respectively. It shows that as the number of blades increases, more flow will pass through the seeding area (inlets) and will be discharged from the cleaning area (outlets). This is because the number of blades at the inlets is increased, and the distance between the two fan blades becomes smaller, which will be covered by more blades, and it is easier to form negative pressure, which is consistent with the theoretical analysis. The special result is that when the blade angle is 13°, when the number of blades is 7, the flow velocity of the nearest inlet is much higher than the other number blades.

(2) The influence of the blade angle on flow velocity

As shown in Fig. 10, the flow velocity at the inlets and outlets is measured, when the number of blades is 7, and the blade angle is 13° and 23° respectively.

In general, the angle of the blade has little effect on the flow velocity at inlets and outlets. However, the increase in the angle of adjacent blades will weaken the negative pressure in the filling area, which will reduce the flow velocity at the inlets. Therefore, increasing the angle of the blades can reduce the absolute flow velocity in the filling area.

(3)The influence of the order of blade on flow velocity

As shown in Fig. 11, the flow velocity at the inlets and outlets is measured, when the number of blades is 7, and the blade angle is 23°, and the order of blades is from small to large and the size of blades is average respectively.

The experiment results show that when the size of the blade is average, the average speeds of the inlets and outlets are 3.7 and 2.4 m/s, respectively. And when the size of the blade is from small to large, the average speeds of the inlets and outlets are 4.4 and 2.5 m/s, respectively. When the blades are arranged in different order, the flow velocity at the inlets varies greatly, increasing by about 18.9%, and there is little difference in speed at the outlets. The reason is that when the inlets blades are arranged from large to small, the size of the fan blade at the end is small, which causes the inlet to be blocked by the blade and the area is too small to generate sufficient negative pressure. Therefore, the highest flow velocity of the No. 4 air outlet is up to 5.5 m/s. As a result, the average flow velocity of the air outlets increases when the size of the blade is from small to large.

In summary, increasing the number of fan blades, the average flow velocity in the cleaning area is approximately linearly reduced, and the average flow velocity in the filling area remains basically unchanged. Increasing the angle of the blades has little effect on the flow velocity difference on the filling and the cleaning operations, but it can reduce the absolute flow velocity. When the blades are arranged in order from large to small, the average flow velocity in the cleaning area decreases.

Experiment results and analysis of multiple factors

Orthogonal experiment with interaction is used to verify the influence of various factors and their interaction on the flow field formation. The experiment factors are the number, angle and arrangement order of the blades. The experiment parameter is the average flow speed at the inlets and outlets. The experiment can get the significance of the influence of each factor on the parameter. The experiment design is shown in Table 4.

Table 4

Multifactor experiment design

factors		A Number	B Angle/°	C Arrangement order
Level	1	7	8	Small to large
	2	8	10	Large to small
	3	10	13	Average

The three-factor orthogonal experiment with interaction is designed through SPSS. The significance analysis of each factor was carried out according to the experiment results, and the results are shown in Table 6. It can be seen from the table that the number of blades, and the interaction between the number and the angle of the blades (AB) have a significant impact on the flow speed of inlets and outlets. Other factors are not significant.

According to the impact on the parameter, the order from largest to smallest is the number of blades, the interaction of the number and angle of the blades, the interaction of the angle and arrangement order of the blades, the arrangement order of the blades, the interaction of the number of blades and the arrangement order, and the angle of blades. Table 5 shows the significance experiment analysis.

Table 5

The variance analysis

Project	Mean square sum	df	Mean square	F	Significance
Modle	4.770[a]	12	0.398	5.238	0.040
A	4.014	2	2.007	26.449	0.002
B	0.034	2	0.017	0.227	0.805
C	0.168	2	0.084	1.105	0.400
AB	0.241	2	1.21	15.89	0.029
AC	0.081	2	0.041	0.534	0.616
BC	0.231	2	0.116	1.523	0.304
Error	0.379	5	0.076		

a. decisive factor = 0.926

CONCLUSIONS

(1) Using the pneumatic conveying metering technology, designed a seed metering device with forming machine. The simulation results show that the filling and clearing ability of the 7 blade 10° forming machine is better than that of other groups of blade structure parameters.

(2) When the blade angle is 10°, as the number increases from 7 blades, 8 blades to 10 blades, the average flow speed of the outlets (cleaning area) is close to linear distribution, and the inlets (seeding area) is basically unchanged. It shows that as the number of blades increases, more flow will pass through the filling area and be discharged from the cleaning area.

(3) Increasing the angle of the blade (10°, 13°) has little effect on the flow rate difference between the filling area and the cleaning area, but it can reduce the absolute flow speed.

(4) When the blade angles in the filling area are the same, the speed has nothing to do with the arrangement order of the blades, but the speed distribution of the cleaning area is related to the size of the blade at the end of the cleaning area. As the size decreases, the speed in the cleaning area increases. The experiment results show that when the blade size is reduced by half, the flow speed increases by about 18.9%.

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