ANALYSIS ON THE UNIFORMITY OF SEED SOWING IN THE SPRAYING MACHINE OPERATING ON THE GRASSLAND
/
草地作业喷播机喷播落种均匀性分析

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ABSTRACT
In the process of revegetation of degraded grassland by pneumatic seed sprayer, the working parameters of the sprayer, such as the position of the sprayer and the air velocity of the inlet of the sprayer, have an impact on the uniformity of spraying. In this paper, 4BQD-40C pneumatic sprayer is taken as the research object. The influence of the compensation mechanism on the airflow velocity at the inlet of the barrel nozzle and the spraying quality is analyzed. The conclusions show that: (1) The planting trajectory of the sprayer inlet compensation mechanism is analyzed, and the planting trajectory equation is obtained, which lays a foundation for subsequent research. (2) The influence law of the opening height on the inlet airflow velocity of the nozzle is obtained, and the drop trajectory is adjusted by adjusting the inlet airflow velocity of the nozzle, and the area of the missed seeding area is reduced. (3) The time points of opening height adjustment and reset of the compensation mechanism in one cycle were obtained. At the same time, there is a lag time t_1 due to changing the seed drop trajectory by adjusting the nozzle inlet airflow velocity. Due to this lag time, the compensation mechanism can be used to change the seed drop trajectory when the swing frequency is less than 7.3 min^{-1} to achieve optimization of the reseeded and missed seeding areas.

摘要
气力喷播机对退化草地进行植被修复的过程中，喷播机的工作参数，如喷播机姿态和喷筒入口气流速度对喷播均匀性均有影响。本文以4BQD-40C型气力喷播机为研究对象，分析安装喷筒补偿机构后喷筒入口气流速度对喷播质量的影响。结论表明：(1)分析了喷播机喷筒入口加装补偿机构的落种轨迹，得到了落种轨迹方程，为后续研究奠定基础。(2)得到了补偿机构开口高度对喷筒入口气流速度的影响规律，并且通过调节喷筒入口气流速度，调节落种轨迹，减小漏播区域面积。(3)得到1个周期内补偿机构开口高度调节的时间点与复位的时间点；同时由于通过调节喷筒入口气流速度改变落种轨迹时存在滞后时间 t_1，受限于该滞后时间，当摆动频率小于7.3 min^{-1}时，可通过补偿机构改变落种轨迹，实现对落种区域重播、漏播面积的优化。

INTRODUCTION
Judging from the early spraying test, the spraying operation is a technical measure to restore grassland vegetation with faster speed and high efficiency under natural climatic conditions. The relevant research on the restoration of grassland vegetation by pneumatic spraying has achieved important research results (*Chen et al., 2022; Wang et al., 2015; Zhang et al.,2013; Xuan et al., 2016; Zhang et al., 2013; Tai et al., 2022; Zhang et al., 2022*). However, in the process of revegetation of degraded grassland by pneumatic seed sprayer, the working parameters of the sprayer, such as the influence of sprayer position, sprayer structure (*Grella et al., 2022)*, reservoir units optimization (*Liu et al., 2019*), sprayer working airflow and spraying amount on spraying uniformity, air speed and liquid flow rate on the droplet size and homogeneity (*Balsari et al., 2018)*, the vertical position and constructional variants of the diffuser (*Gierz et al., 2020)*, shaping air holes (*Li et al., 2019*), surface coverage by impact of droplets (*Dalili, et al., 2020*), and the relationship with the existing grassland vegetation cover were not considered (*Sylvain et al., 2022; Tai et al., 2022*).

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When 4BQD-40C pneumatic sprayer is spraying, under the action of airflow of the seed delivery pipe, the ice grass seeds go from the seed discharge area to the seed dropper. Seeds in the seed dropper are attracted by the negative pressure of the main air duct throat, suspended and accelerated into the main air duct, and then sprayed out with the high-speed airflow of the barrel nozzle. The sprayer moves forward. At the same time the sprayer barrel nozzle swings from 0° to 180° in the horizontal plane. (*Fan et al., 2013; Chen et al., 2018*).

The inlet airflow velocity of the sprayer canister is provided by the fan. Due to the fact that the fan rotational inertia is large, it takes a long time to adjust the inlet airflow velocity of the sprayer by changing the fan speed, and the swing frequency of the sprayer is faster, so the seed falling trajectory cannot be changed in real time by adjusting the fan speed. In order to further improve the uniformity of spraying and improving the quality of spraying, a spraying uniformity compensation mechanism (hereinafter referred to as the compensation mechanism) is designed and installed at the entrance of the barrel nozzle. The real-time adjustment of the airflow velocity at the inlet of the spray drum is realized by adjusting the opening height of the mechanism. This mechanism can change the seed drop trajectory and improve the uniformity of spraying and falling seed. This paper focuses on the relationship between the position of 4BQD-40C sprayer and the seed drop area, the relationship between the airflow velocity at the inlet of the barrel nozzle and the seed drop area. Adjust the airflow velocity at the inlet of the barrel nozzle by installing a spraying uniformity compensation mechanism. This method changes the trajectory of seed fall, at the same time it can improve the spraying uniformity and improve the quality of spraying.

MATERIALS AND METHODS

Analysis of compensation mechanism location

The 4BQD-40C sprayer can adjust the airflow velocity at the inlet of the nozzle by increasing the airflow channel. Therefore, a compensation mechanism is installed at the inlet of the sprayer to adjust the airflow velocity at the inlet of the sprinkler. The compensation mechanism is shown in Fig.1, h_b is the opening height of that mechanism, ε_b is the angle of the sector area corresponding to the mechanism opening area, r_b is the radius of the mechanism circulation cross-sectional area ($r_b = 25\ mm$), and S_b is the opening area of the mechanism.

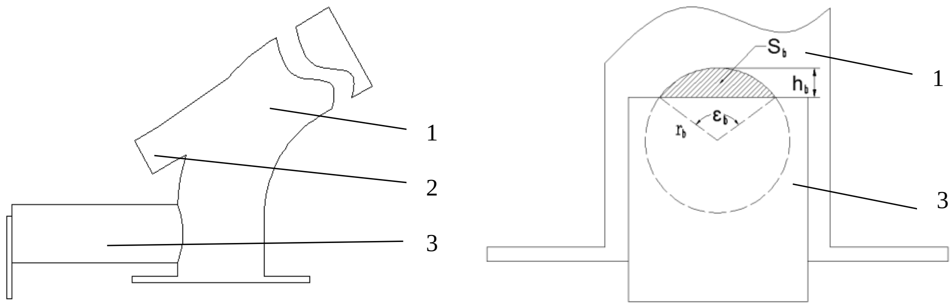
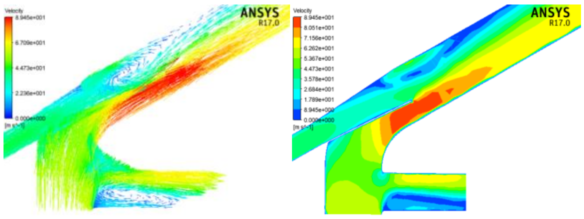


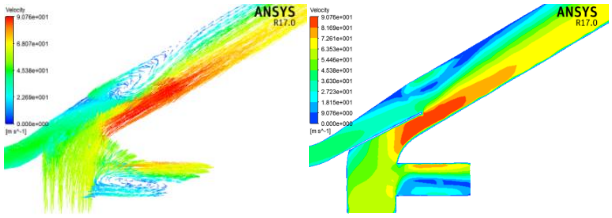
Fig. 1 - Schematic diagram of compensation mechanism
1 – Sprayer; 2 – Seed tube; 3 – Compensation mechanism

The opening height of the compensation mechanism affects the airflow velocity in the barrel nozzle, and its installation position affects the air flow distribution in the barrel nozzle. Therefore, the installation position is numerically simulated to find out its optimal installation position. The air flow enters the nozzle through the throat pipe from the fan outlet, and the seed ejection speed is mainly formed in the seed tube insertion section in the nozzle. Therefore, the compensation mechanism can be installed at the entrance of the nozzle or the sprayer throat to adjust the inlet air velocity.

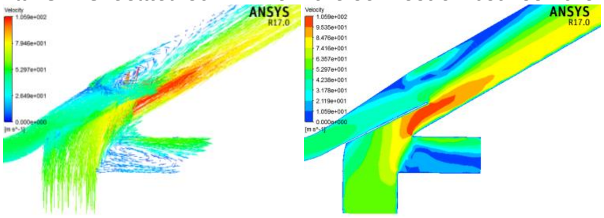
The airflow distribution in the nozzle corresponding to different installation positions of the compensation mechanism was simulated using Fluent software. In this paper, the diameter of this mechanism is 50 mm, and the mechanism is set to be fully open and the air velocity at the nozzle inlet is 60 m/s. The simulation analysis is carried out for the installation positions of the compensation mechanism at 30 mm, 50 mm and 80 mm away from the connection between the nozzle and the throat. The simulation results are shown in Fig. 2. (*Shivam et al., 2022; Yin et al., 2022; Tao et al., 2020*).



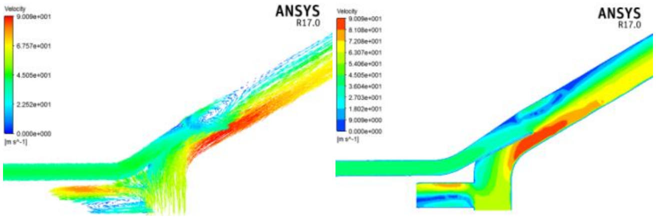
(a) The compensation mechanism is located 30 mm from the connection between the barrel nozzle and the hose



(b)The compensation mechanism is located 50 mm from the connection between the barrel nozzle and the hose



(c)The compensation mechanism is located 80 mm from the connection between the barrel nozzle and the hose

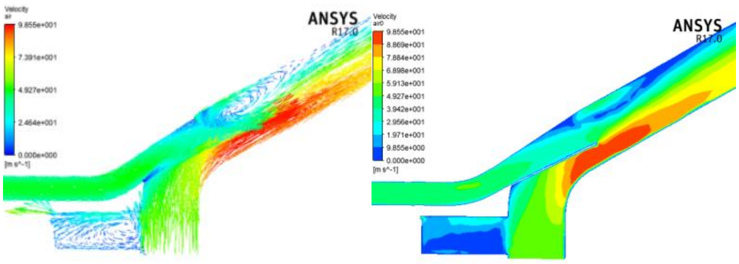


(d)The installation position of the compensation mechanism is opposite to (a)

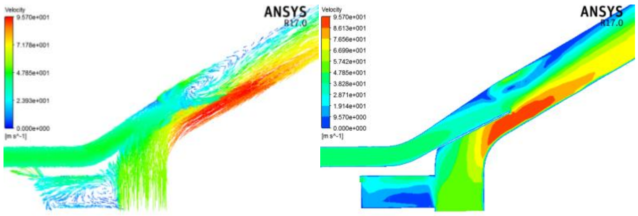
Fig. 2 - Influence of installation position of the compensation mechanism on air distribution in barrel nozzle

From the numerical simulation results, it can be seen that different installation positions of the compensation mechanism have different effects on the airflow in the barrel nozzle. When the distance of the compensation mechanism from the throat connection is changed from 80 mm to 30 mm, the airflow in the insertion section of the seed tube is reduced from 105.9 m/s to 90.0 m/s. The installation position of the compensation mechanism is closer to the insertion section of the seed tube, which is a big change to the original structure. It is easy to cause the airflow direction to shift from the centre of the nozzle to the edge of the nozzle. This causes the seed to accelerate towards the wall of the nozzle, and at the same time causes seed breakage. Comparing Fig. 2(a) and 3(d), it can be seen that the compensation mechanism has less influence on the direction of the airflow in the nozzle cylinder when it is installed at the position as shown in Fig. 2(d). Therefore, the compensation mechanism is selected to be installed at the mounting position shown in Fig. 2(d).

When the air velocity is 55 m/s, the numerical simulation is carried out for the opening heights of 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, and 32.5 mm, and the simulation results are shown in Fig. 3.

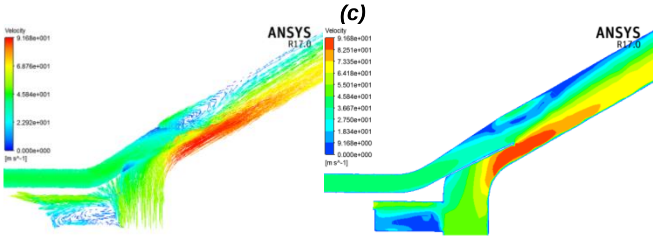


(a) The opening height of 5 mm

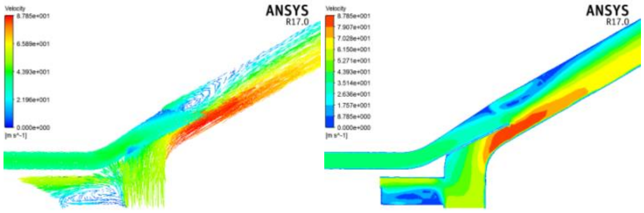


(b)The opening height of 10 mm

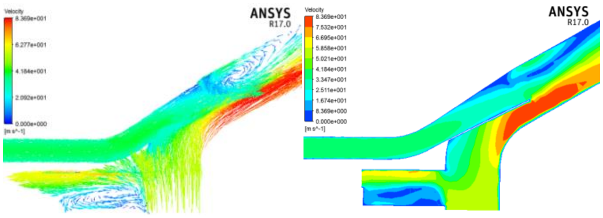
(c)



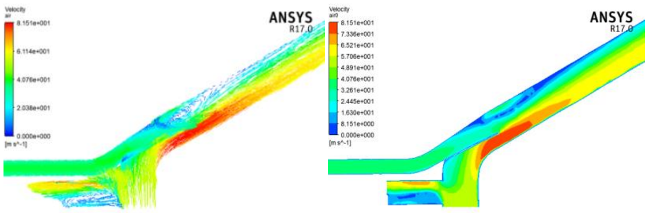
(d)The opening height of 15 mm



(e)The opening height of 20 mm



(f) The opening height of 25 mm



(f) The opening height of 30 mm

Fig. 3 - Influence of opening height of compensation mechanism on gas flow distribution in barrel nozzle inlet

From the numerical simulation results, the relationship between the compensation mechanism opening height and the air velocity at the inlet of the nozzle can be obtained as shown in Table 1. It can be seen from Table 1 that the larger the opening height of that mechanism, the greater the influence on the inlet airflow velocity of the nozzle. But when the opening height exceeds the radius of that mechanism, increasing the opening height has less and less effect on the inlet airflow velocity of the nozzle.

Table 1

Relationship between opening height of compensation mechanism and air velocity at inlet of barrel nozzle after splitting

Compensate for the opening height of the mechanism [mm]	5	10	15	20	25	30
Nozzle inlet airflow velocity after shunting [m/s]	53.8	51.5	49.3	47.5	45.8	44.2
The velocity of the nozzle outlet after shunting [m/s]	67.6	66.1	62.1	59.3	57.0	55.6

It can also be seen from Table 1 that as the opening height increases, the airflow velocity entering the insertion section decreases. However, the proportion of airflow velocity reduction is not proportional to the height of the opening. Due to the fact that the compensation mechanism is a circular pipe, the relationship between the opening height and area of the mechanism installed on the bypass pipe can be converted by equations (1) and (2). The ε_b is the angle of the sector area corresponding to the mechanism opening area.

When the opening height is $h_b \le r_b$:

$$\begin{cases} \varepsilon_b = 2 \times arccos\left(\frac{r_b - h_b}{r_b}\right) \\ S_b = \frac{\varepsilon_b}{360} \times \pi \times r_b^2 - \frac{1}{2} r_b^2 \times \sin(\varepsilon_b) \end{cases} \tag{1}$$

When the opening height is $r_b < h_b < 2r_b$

$$\begin{cases} \varepsilon_b = 2 \times arccos\left(\frac{h_b - r_b}{r}\right) \\ S_b = \frac{360 - \varepsilon_b}{360} \times \pi \times r_b^2 + \frac{1}{2} r_b^2 \times \sin(\varepsilon_b) \end{cases} \tag{2}$$

After converting the area according to the above formula, the relationship between the opening area of the compensation mechanism and the inlet airflow velocity of the nozzle is shown in Table 2.

Table 2

The relationship between the opening area of the compensation mechanism and air velocity at inlet barrel nozzle after splitting

compensation mechanism opening area [mm^2]	102.0	279.3	495.0	732.9	981.2	1229.6
Nozzle inlet airflow velocity after shunting [m/s]	53.8	51.5	49.3	47.5	45.8	44.2
The amount of speed reduction [m/s]	1.2	3.5	5.7	7.5	9.2	10.8

Table 2 shows that when the airflow velocity before adjusting is 55 m/s, the correspondence between the opening area and the inlet airflow velocity of the nozzle after shunting is:

$$\vartheta'_{pr} = 55.0 - 0.0083 \times S_b - 1.0213 \tag{3}$$

In the formula, S_b represents the area of the opening of this mechanism and ϑ'_{pr} represents the inlet airflow velocity of the nozzle after shunting.

From the above analysis, it can be seen that adjusting the opening height of the compensation mechanism can change the inlet airflow velocity of the nozzle. The seed drop trajectory can be changed by adjusting the opening height of the compensation mechanism during spraying. This can further reduce the reseeding and missed seeding area of the seed falling area.

The analysis of the sprayer shows that when the oscillation frequency of the barrel nozzle is optimized, the seeds fall in the same trajectory. At this point, the idea of optimizing the seed drop area is used to determine the compensation mechanism start adjustment time, end adjustment time and opening height.

The opening height of the compensation mechanism is adjusted to reduce the missed seeding area of the seed drop area and to improve the spraying quality. The goal of optimizing the missed seeding area is to minimize it by adjusting the opening height of the compensation mechanism without increasing the reseeding area. From the above analysis, it can be seen that when the swing time of the spray drum is 0.5T~T, the seed drop trajectory is changed by adjusting the opening height of this mechanism. The offset distance of the seed trajectory is d_L, and the d_L<8 m is set.

From the analysis of the seed drop trajectory formula of the sprayer, it can be seen that the optimization of the missed seeding area of the seed drop region should be in the time [0.71T, T]. The seed drop trajectory in the first 1/2 cycle is symmetric with the second 1/2 cycle. Therefore, the missed seeding area is optimized during the [0.29T, 0.5T] time of the first 1/2 cycle.

After the optimization of the seed drop area, the compensation mechanism starts to regulate at 0.34T and 0.84T in 1 nozzle swing cycle, the recovery time is 0.44T and 0.94T. The seed drop trajectory regulation distance $d_L = 2.8\,m$, at this time, the seed drop trajectory curve formula is (*Cao et al., 2023*):

$$\begin{cases} x_1 = R \cdot cos\omega t \\ y_1 = R \cdot sin\omega t - \vartheta \cdot t \end{cases} \quad t \in (0, 0.34T) \cup (0.44T, 0.5T) \tag{4}$$

$$\begin{cases} x_1 = (R + d_L) \cdot cos\omega t \\ y_1 = (R + d_L) \cdot sin\omega t - \vartheta \cdot t \end{cases} \quad t \in (0.34T, 0.44T) \tag{5}$$

$$\begin{cases} x_2 = r \cdot cos\omega t \\ y_2 = r \cdot sin\omega t - \vartheta \cdot t \end{cases} \quad t \in (0, 0.34T) \cup (0.44T, 0.5T) \quad (6)$$

$$\begin{cases} x_2 = (r + d_L) \cdot cos\omega t \\ y_2 = (r + d_L) \cdot sin\omega t - \vartheta \cdot t \end{cases} \quad t \in (0.34T, 0.44T) \quad (7)$$

$$y_3 = -\vartheta \cdot t \quad t = 0, x \in [r, R] \quad (8)$$

$$y_4 = -\vartheta \cdot t \quad t = 0.5T, x \in [-r, -R] \quad (9)$$

$$\begin{cases} x_5 = R \cdot cos(\pi - \omega t) \\ y_5 = R \cdot sin(\pi - \omega t) - \vartheta \cdot t \end{cases} \quad x \in (0.5T, 0.84T) \cup (0.94T, T) \quad (10)$$

$$\begin{cases} x_5 = (R + d_L) \cdot cos(\pi - \omega t) \\ y_5 = (R + d_L) \cdot sin(\pi - \omega t) - \vartheta \cdot t \end{cases} \quad t \in (0.84T, 0.94T) \quad (11)$$

$$\begin{cases} x_6 = r \cdot cos(\pi - \omega t) \\ y_6 = r \cdot sin(\pi - \omega t) - \vartheta \cdot t \end{cases} \quad x \in (0.5T, 0.84T) \cup (0.94T, T) \quad (12)$$

$$\begin{cases} x_6 = (r + d_L) \cdot cos(\pi - \omega t) \\ y_6 = (r + d_L) \cdot sin(\pi - \omega t) - \vartheta \cdot t \end{cases} \quad t \in (0.84T, 0.94T) \quad (13)$$

$$y_7 = y_3 - \vartheta \cdot t \quad t = T, x \in [r, R] \quad (14)$$

Based on the above analysis, the opening height of the compensation mechanism can be adjusted to obtain the seed drop trajectory as shown in Fig. 4.

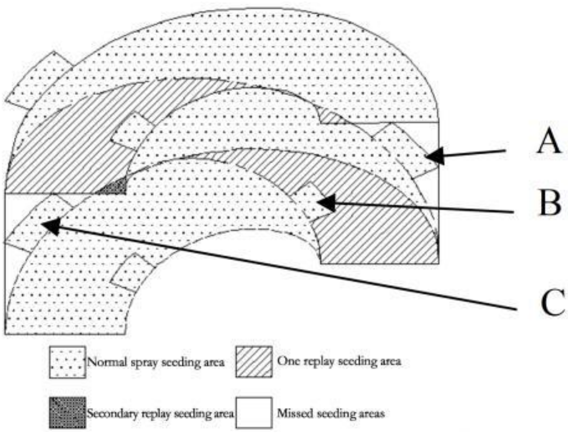


Fig. 4 - Diagram of the seed drop area after adjustment of the compensation mechanism

As can be seen in Fig. 4, there is a large area of missed seeding before the seed drop trajectory is not adjusted. Area A changed from a missed seeding area to a normal spraying area when the seed drop trajectory is adjusted using the compensation mechanism. The missed seeding area of the barrel nozzle was reduced by 28.3% in one swing cycle. Area B changed from a reseeded area to a normal sprayed area and the reseeded area decreased by 14.1%. The optimization of the seed drop area using the compensation mechanism not only reduces the area of missed seeding, but also reduces the area of reseeding. Area C is the new seed drop area after compensating for the missed seeding area in the later swing cycle. The seed drop trajectory of the sprayer has symmetry, so the areas of region A and region C are equal.

Seeds are sprayed onto the land from the seed delivery tube. The spraying time includes the time of acceleration of the seed inside the canister, and the time of movement of the seed from the outlet of the canister to the land. The use of the compensation mechanism to adjust the seed drop trajectory increases the compensation mechanism response time t_{11}, and the transition time t_{12} for the change in velocity of the seed caused by the adjustment of the airflow velocity at the nozzle inlet. In the actual use of the compensation mechanism to regulate the seed drop trajectory, it is necessary to determine t_{11} and t_{12}, which in turn determines the regulation lead time in the actual regulation process t_1.

From the above analysis, it can be seen that when the inlet air velocity of the barrel nozzle is adjusted by the compensation mechanism, the trajectory of the seed drop is changed. In the actual regulation process due to the data transmission and the response of the controller and actuator there is a certain lag, so that the compensation mechanism has a response time t_{11}. This response time is determined by the compensation mechanism and the control system.

The stepper motor type 86BYGH-350E and the ball screw model SFU1204-3 adjust the opening height of the compensation mechanism. This mechanism was tested to obtain the system response time shown in Table 3.

Table 3

Compensation mechanism response time at different opening heights

Compensate for the opening height of the mechanism [mm]	5	10	15	20	25	30
System response time [s]	0.29	0.35	0.37	0.39	0.40	0.41

As can be seen from Table 3, the system response time does not change much when the opening height of the compensation mechanism is increased. The system response time is 0.41 s when the opening height of the compensation mechanism is 30 mm. From the above analysis, the time to adjust the opening height of the compensation mechanism is [0.29T, 0.34T]. The compensation mechanism starts to adjust at 0.29T and adjusts appropriately at 0.34T. The reset time of the compensation mechanism is [0.44T, 0.5T].The compensation mechanism starts to reset at 0.44T and returns to its original position at 0.5T. Therefore, the length of time to adjust the compensation mechanism is 0.05T and 0.06T. When the length of time for adjusting the compensation mechanism 0.05T is greater than the maximum response time of the system 0.41 s, and the oscillation frequency of the barrel nozzle is less than 7.3 min^{-1}, this mechanism can be used to adjust the seed drop trajectory in order to reduce the missed seeding area.

From the simulation analysis, it can be seen that when the airflow velocity at the inlet of the barrel nozzle is changed, the seed velocity inside the barrel nozzle is changed accordingly. There is a transition time t_{12} for the seed to reach the desired velocity from the initial velocity at the nozzle outlet. The speed of seed is continuously changing inside the barrel nozzle. The transition time for the accelerated movement of the seed to the required velocity at the nozzle exit after adjusting the compensation mechanism is t_{12}. Analysing the time t_{12} taken for the seed to move from the insertion section to the exit of the spray canister, the acceleration of the seed inside the spray canister is approximated as a uniformly accelerated process.

The seed acceleration time in the spray canister can be calculated by formula (15).

$$t_{12} = \frac{2l}{v_c + v_r} \tag{15}$$

In the formula l is the length of the barrel nozzle, l= 1.5m, v_c is the speed of movement of the seed in the insertion section of the nozzle, v_r is the speed at which the seed moves at the outlet of the barrel nozzle.

When the compensation mechanism adjusts the airflow rate at the inlet of the nozzle, the airflow rate inside the nozzle changes gradually. The start time for adjusting the opening height of the compensation mechanism should be advanced $t_1 = t_{11} + t_{12}$. At this time, the compensation mechanism opening height adjustment time becomes $0.34T - t_1$,$0.44T - t_1$,$0.84T - t_1$and$0.94T - t_1$, that can ensure the actual seed drop trajectory is the same as the theoretical analysis.

Test

The test was conducted in a flat soil site at Inner Mongolia Agricultural University. The test conditions were wind speed less than 1 m/s and temperature of 15-20°C. The experimental equipment used for this test was: 4BQD-40C pneumatic seed sprayer, a number of coated ice grass seeds, a 9565-P multifunctional air gauge of TSI in the United States, a hot wire wind speed probe, a tape measure, a stopwatch, and a number of white powders.

The designed compensation mechanism is mounted on the lower end of the nozzle. The test is mainly completed by adjusting the opening height of the compensation mechanism to test the air velocity at the outlet of the nozzle in a seedless state. Test the effect of the compensation mechanism on the spraying quality by adjusting the opening height of this mechanism in the presence of seed.

Nozzle outlet air velocity test

Ensure that seed boxes, seed delivery tubes, and barrel nozzle are clear and free of seed prior to test. The frequency converter was adjusted so that the air velocity at the nozzle inlet was 40 m/s during the test. The air velocity at the nozzle outlet was tested when the opening height of the compensation mechanism was adjusted to 0 mm, 5 mm, 10 mm, 15 mm, 20 mm, 25 mm and 30 mm. The probe is placed at the nozzle outlet perpendicular to the nozzle centreline. The probe is faced the direction of the incoming flow. The nozzle outlet air velocity is tested after the anemometer data has stabilized. The centre of the nozzle is selected as the measuring point and 10 instantaneous values are recorded. Then the average value is calculated.

Spray quality test

Follow the test procedure to adjust the sprayer prior to the test. The grid of the test area was also divided. The air velocity at the nozzle inlet was set to 55 m/s by a frequency converter before the test. At the same time, the opening height of the compensation mechanism was adjusted. When the opening height is 13.6 mm, the airflow at the nozzle inlet is reduced from 55 m/s to 50 m/s. The sprayer was loaded with coated ice grass seeds at this time. The sprayer was moved forward at 0.5 m/s and the barrel nozzle started spraying at an oscillation frequency of 1.57 min^{-1}. At the same time, the speed of the seed discharger was set to 0.63 min^{-1}. The opening height of the compensation mechanism was adjusted from 13.6 mm to 0 mm to continue spraying when the oscillation time of the barrel nozzle was 12.5 s. When the oscillation time of the barrel nozzle was 16.3 s and the opening height of the compensation mechanism was adjusted to 13.6 mm the sprayer continues to spray. Adjustment of the seed drop trajectory is done during the first 1/2 cycle of the barrel nozzle oscillation. The barrel nozzle oscillation time was 31.6 s and the opening height of the compensation mechanism was adjusted from 13.6 mm to 0 mm. The sprayer continues to spray. The barrel nozzle oscillation time was 35.4 s and the opening height of the compensation mechanism was recovered 13.6 mm. The sprayer continues to spray. Adjustment of the seed drop trajectory is done during the last 1/2 cycle of the barrel nozzle oscillation. The sprayer reaches the end position and stops working after 1 cycle of barrel nozzle oscillation. At the same time, the test data statistics are carried out in the divided grid.

RESULTS

Nozzle outlet air velocity results

As can be seen from Table 4, the compensation mechanism can adjust the airflow velocity in the barrel nozzle in real time. The spraying quality of the sprayer can be improved by adjusting the opening height of the compensation mechanism during spraying operations. So the basic requirements for designing a compensation mechanism are met. And the nozzle outlet air velocity decreases with the increase of the opening height of the compensation mechanism. However, when the opening height is adjusted from 25 mm to 30 mm, the air velocity at the nozzle outlet decreases from 36.88 m/s to 35.29 m/s. The reduction in nozzle outlet air velocity is small. This is consistent with the numerical simulations obtained when the opening height is greater than the radius of the compensation mechanism. Continuing to increase the height has a decreasing effect on the nozzle outlet air velocity. It is verified that the numerical analysis of the opening height of the compensation mechanism on the airflow is correct. The results of the simulation analysis can be used in the analysis of seed drop trajectory regulation.

Table 4

The relationship between the opening height of the compensation mechanism and the airflow velocity at the outlet of the barrel nozzle

Opening height [mm]	Real-time test value 1/ [m/s]	Real-time test value 2 / [m/s]	Real-time test value 3 / [m/s]	Real-time test value 4 / [m/s]	Real-time test value 5 / [m/s]	Real-time test value 6 / [m/s]	Real-time test value 7 / [m/s]	Real-time test value 8 / [m/s]	Real-time test value 9 / [m/s]	Real-time test value 10/ [m/s]	average value/ [m/s]
0	47.63	47.72	47.61	47.58	47.68	47.57	47.61	47.57	47.63	47.59	47.62
5	45.74	45.73	45.77	45.78	45.74	45.73	45.68	45.75	45.69	45.79	45.75
10	43.35	43.31	43.34	43.28	43.37	43.29	43.34	43.27	43.31	43.38	43.32
15	41.12	41.11	41.09	41.08	41.07	41.08	41.13	41.15	41.08	41.06	41.09
20	38.90	39.01	38.86	38.93	38.98	38.97	38.99	38.96	38.95	38.97	38.95
25	37.01	36.98	36.75	36.80	36.85	36.92	36.78	36.95	36.93	36.87	36.88
30	35.26	35.27	35.33	35.32	35.82	34.93	34.97	34.79	34.87	34.96	35.29

Spray quality results

The forward speed of the sprayer was 0.5 m/s and the oscillation frequency of the barrel nozzle was 1.57 min^{-1}. The seed drop area was adjusted using the compensation mechanism. The amount of seed dropped was counted as shown in Table 5. A comparison of this seed drop with the seed drop before adjustment shows as Table 6. The reseeding area of the seed drop area was reduced from 60 m^2 to 48 m^2 after adjustment with the compensation mechanism.

The area of missed seeding was reduced from 64 m^2 to 40 m^2. Both the reseeded area and the missed seeding area were reduced. The reduction in the area of missed seeding was greater than the reduction in the area of reseeding. It can be seen that the designed and installed compensation mechanism can adjust the seed drop trajectory of the sprayer in real time. Reduce the reseeding and missed seeding area in the seed drop area to improve the spraying quality.

Table 5

The amount of seeds in seed drop area is counted when the oscillation frequency is 1.57 min^{-1}

Vertical distance (m)	Lateral distance(m)																			
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
2	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0
4	0	0	0	0	0	0	0	2	3	6	5	9	6	6	1	1	0	0	0	0
6	0	0	0	0	0	1	5	11	17	14	15	15	14	12	14	6	1	0	0	0
8	0	0	0	0	2	5	8	12	19	16	19	18	17	19	16	15	12	1	0	0
10	0	0	2	1	7	13	16	19	12	12	14	13	13	17	18	17	14	10	1	0
12	0	1	9	15	13	14	14	14	10	4	4	3	5	3	12	14	17	17	6	1
14	0	8	11	14	18	14	14	12	6	6	1	2	0	1	9	11	21	21	14	1
16	1	7	16	16	23	17	10	14	14	11	11	9	3	1	6	10	17	19	16	2
18	1	8	17	26	22	14	18	17	17	18	14	14	8	6	4	1	0	0	0	0
20	2	9	22	32	19	17	16	17	14	14	18	19	16	12	12	1	0	2	0	0
22	1	11	24	22	18	13	9	8	4	7	10	15	14	19	15	10	14	5	4	0
24	3	19	29	23	17	8	2	1	0	5	1	6	9	17	16	14	17	12	8	0
26	2	28	35	16	20	5	0	0	0	0	0	1	5	9	4	14	15	10	3	2
28	1	15	23	14	13	3	0	0	0	0	0	0	1	0	2	4	16	22	12	1
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	11	18	9	1
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	9	14	10	1
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	12	13	15	3
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	9	12	17	14	1
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	14	14	10	2
40	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0

Table 6

Comparison of reseeding and missed seeding area in the falling area before and after adjustment

Compensation mechanism status	Reseeding area / [m^2]	Missed seeding area / [m^2]	The sum of reseeding and missed seeding areas / [m^2]
Shut down	60	64	124
Open	48	40	88

CONCLUSIONS

Spraying quality is an important indicator to measure the spraying performance of the sprayer. The factors affecting the quality of spraying were analysed by simulation analysis, numerical simulation and test analysis. The following conclusions were drawn:

(1) The seed drop trajectory of a sprayer with a compensation mechanism installed at the nozzle inlet of the sprayer was analysed. The obtained formulas for the seed drop trajectories provide a basis for subsequent studies.

(2) The opening height of the compensation mechanism installed to the nozzle inlet is analysed. The law of the influence with the opening height on the airflow velocity at the nozzle inlet was obtained. By adjusting the air velocity at the nozzle inlet, the seed drop trajectory can be changed to reduce the size of the missed seeding area.

(3) The adjustment time points are 0.34T and 0.84T for the opening height of the compensation mechanism in one cycle. The adjustment time points at which the opening height began to reset were 0.44T and 0.94T. There is a lag time t_1 when changing the seed drop trajectory by adjusting the nozzle inlet air velocity. This time is determined by the response time of the compensation mechanism and the seed acceleration time. The compensation mechanism opening height adjustment time becomes 0.34T-t_1, 0.434T-t_1, 0.84T-t_1 and 0.94T-t_1. The oscillation frequency is limited by the response time of the compensation mechanism. When the oscillation frequency is less than 7.3 min^{-1}, the compensation mechanism can be used to change the seed drop trajectory to achieve the optimization of reseeding and missed seeding area.

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