Design and test of an inside-filling pneumatic precision centralized seed-metering device for rapeseed

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Abstract: The pneumatic precision seed-metering devices used in combination with negative air pressure to suck seed and positive air flow to drop seed could overcome the problem of rapeseed precision planting. However, these devices can only plant a single row at a time or need high airflow pressure, which complicates the seed-metering system and the seeder structure, deteriorate the working reliability and have high power consumption. To overcome above shortcomings, a novel prototype of pneumatic precision centralized seed-metering device with seed inside-filling, sowing six rows at a time, was developed. The main structure and working principle of the prototype were described and the technical parameters were given. Experiments were conducted to investigate the influences of positive pressure, negative pressure, and rotating speed on the seeding performance. The stability of each row and the consistency between all rows associated with the seeding precision were analyzed to evaluate the performance of the prototype. The results indicated that the prototype can meet the requirements of precision seeding and the seed keep intact without any obvious damage. The performance of the prototype was no significant difference when the positive pressure was fluctuated from 200 Pa to 1200 Pa. The best seeding precision parameters in one row of the prototype was 92.48% of the qualified seeding index (I_{qs}) and 2.55% of the miss-seeding index (I_{miss}), when the rotating speed was 16 r/min, the positive pressure was 200 Pa and the negative pressure was –1600 Pa. When the rotating speed was 16 r/min, the positive pressure was 200 Pa, and the negative pressure was –1400 Pa or –1600 Pa, the I_{qs} of six rows were above 86.5%, the stability coefficient of variation (*CV*) of each row were below 4.6%, and the consistency *CV* were below 0.9%. Further field experiment showed that the rapeseed sowed by the prototype had acceptable seeding precision. The *CV* of the numbers of rapeseed seedlings in the field of the total and each row were 6.17% and 6.32% respectively. The research confirmed that the inside-filling pneumatic precision centralized seed-metering device satisfied the agronomic requirements of rapeseed planting and can be a reference for the development of precision seed metering devices.

Keywords: centralized seed-metering device, seed inside-filling, pneumatic, precision sowing, rapeseed

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1 Introduction

The seed-metering device is the most crucial component on seeder to ensure planting performance[1]. There are two types of metering technology: mechanical metering technology and pneumatic metering technology. The former work by gravity, centrifugal force or other mechanical forces typically. The latter is referred to airflow pressure by employing additional pneumatic system.

The rapeseed has small particles, light weight, high oil content, low shear strength, good spherical shape and smooth skin[2,3]. All of these properties hamper in the way of using existing mechanical precision metering devices to satisfy the seeding agronomic requirements: the sowing quantity is difficult to control more precisely, the seed is tend to damage and gathered to jam socket or

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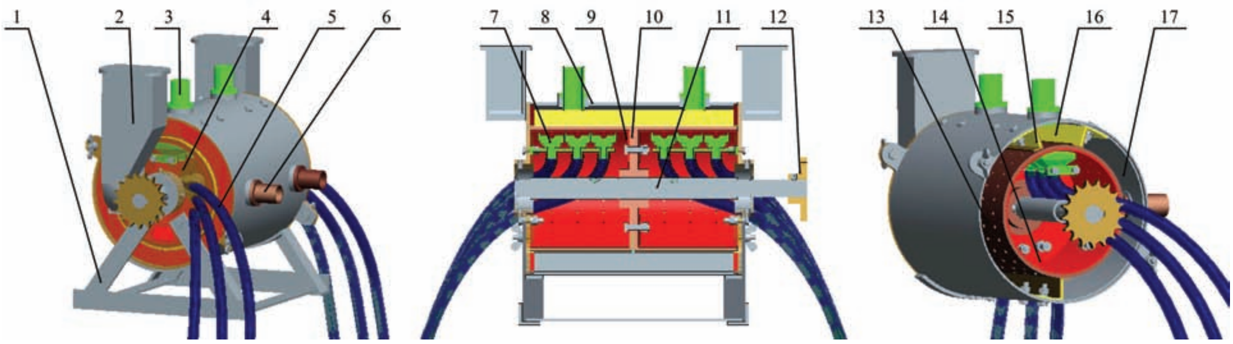
hole of the device[4]. Pneumatic metering technology is actually preference for precision seeding because the airflow has little damage on the seeds and well fits their various shapes for its flexible characteristics, which has been widely applied in precision seeding[5-8]. Three typical pneumatic metering technologies have been applied in rapeseed precision metering devices development. The first way is using positive air flow to clear seed and positive air pressure to protect seed individually or in combination[9,10]. The second way is employing positive air flow to deliver seed, in which a mechanical seed feeder is also necessary[11]. The last way is using in combination with negative air pressure to suck seed and positive air flow to drop seed, by which the small rapeseed could be sucked singly without shearing force and could be throwing orderly. Meanwhile, the dust and impurities adhered on hole could be clear by the positive air flow. As a result of its great advantages, the metering devices adopted this technology could overcome the problem of rapeseed precision planting[12-15]. However, the developed rapeseed pneumatic metering devices characterized by the vertical disc[12] and inside-filling drum[13] can plant only one row at a time, which would complicate the transmission system and airflow system of the rapeseed planter as well as the layout of the metering device. The developed pneumatic metering devices characterized outer-surface sucking cylinder are "one device, multi-rows planting" centralized metering devices, in which the seed was adhesion on the outer surface of the seeding cylinder by vacuum suction and. There was needed a higher negative-pressure to overcome the gravity and centrifugal force[14,15]. It means the manufacture and installation of the device and the seal require high accuracy, as well as high power consumption of airflow system.

To overcome this disadvantage, a six-row pneumatic inside-filling cylinder-type centralized metering device was developed in this study. The seed filling room was specifically designed to locate inside the seeding cylinder and the air chamber was designed to locate outside the seeding cylinder. So the device used negative pressure to suck seeds on the inner surface of the seeding cylinder using negative pressure, centrifugal force and gravity on collaboration instead of confrontation. This innovative design guaranteed that there was just need a less negative pressure and also ensured that there were sufficient seeds to contact the type holes in the seeding cylinder by gravity.

2 Structure design and main parameters

2.1 Structure and working principle

The prototype of the inside-filling pneumatic precision centralized metering device was shown in Figure 1. The annular air chamber was composed of the external cylinder and the internal cylinder, which was divided into a positive pressure air chamber, a negative pressure air chamber and a no-pressure zone by three sealing strips. Two air chambers were communicated with the vortex air pump. The seeding cylinder was fixed on the internal cylinder by bolts. The internal cylinder and the drive sprocket were joined together with the drive shaft. The seed collectors were fixed on the side plate. The seed delivery tubes across the side plate were connected at the end of the collectors. Seeds were put into the seed box and filled into the seed chamber.



1. Mounting bracket 2. Seed box 3. Positive pressure nozzle 4. Side plate 5. Seed delivery tube 6. Negative pressure nozzle 7. Seed collector 8. External cylinder 9. Seeding cylinder 10. Internal cylinder 11. Drive shaft 12. Drive sprocket 13. No-pressure zone 14. Seed chamber 15. Sealing strips 16. Positive pressure air chamber 17. Negative pressure air chamber

Figure 1 Schematic of the prototype

When the prototype was working, the seeding cylinder rotated counter clockwise driven by the input force via the drive sprocket. The suction holes sucked seeds under the suction of negative pressure, gravity and centrifugal force on collaboration as seeds enter the negative pressure zone. Then, the seeds were charged into the seed guiding tube subjected the pushing forces of positive pressure and gravity. Ultimately, the prototype achieves the desirable effect of sowing six rows at a time. The prototype could sow various kinds of seeds with different size by altering different seeding cylinders with different suction holes.

2.2 Parameter design

In the middle and lower Yangtze River region, one ridging filed is always two meters wide and planted six rows rapeseed seeds or seedlings and the seeding amount is 2.25-3.75 kg/hm^2. A peace of filed round about low bank is no greater than 0.67 hm^2 owing to the household production system and previous rice cultivating system.

Given these agronomic requirements and the structure of existing rapeseed planters[16], the centralized seed-metering device was design to sow six rows at the same time and the length of the device was designed to be 240 mm. The internal diameter of the seeding cylinder which was made by stainless steel tubing was 136 mm and the total effective length on both sides to load the seeds was 200 mm. As known from the calculation, the volume of the seed chamber is 1.4×10^{-3} m^3. In consequence of avoiding interference between the drive shaft and the seeds, there was resolved to only half-fill the seed chamber. Through calculation and analysis, the maximum mass of rapeseed filled in the chamber would be nearly 1.0 kg and the maximum mass place in the seed box would be nearly 1.0 kg, so the prototype can contain sufficient rapeseed at a time to sow a peace of filed to decrease auxiliary time of planter work. The seeding cylinder was designed to install in the internal cylinder of the air chamber which was convenient to replace others seeding cylinder with different seed suction holes.

The internal cylinder was assembled the exterior surface of the seeding cylinder without gap. The air chamber was constituted by the external surface of the internal cylinder (148 mm in diameter) and the internal surface of the external cylinder (192 mm in diameter). It was divided to negative and positive pressure air chambers and a no-pressure zone, where the negative pressure air chamber was 1.05×10^{-3} m^3 and the volume of the positive pressure gas chamber was 2.3×10^{-4} m^3.

The diameter of the seed suction hole was chosen according to the size of small grain seeds with the following formula[17]:

$$d_x = (0.64 \text{ to } 0.66)b \tag{1}$$

For the physical properties of the seed, the mean width of rapeseed ranged from 1.5 mm to 2.4 mm[10,13]. When the mean width is used in the formula, the diameter of the suction holes ranges from 0.96 mm to 1.58 mm. The preliminary investigation demonstrated that the diameter of 1.2 mm was most preferred[18] .

Considering factors such as the productivity of the planter, the rotating speed of the seeding cylinder, and the performance of prototype, the quantity of radial holes was set to 30, and the arc distance was 14 mm between two adjacent holes on the internal surface of the seeding cylinder. Three rows of holes evenly axially were distributed in the seeding cylinder. The distance between adjacent rows was 30 mm.

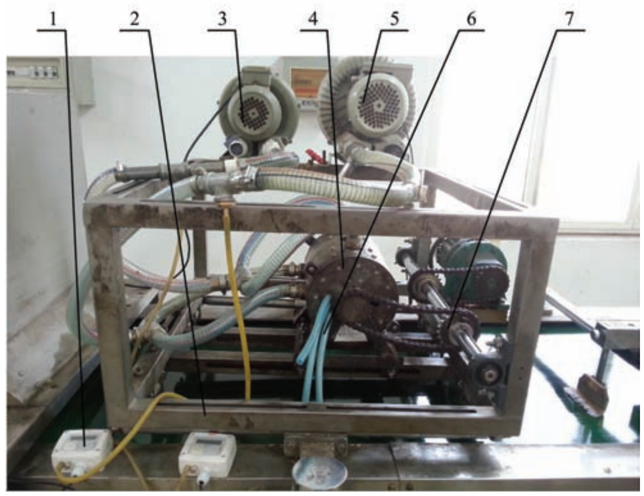
3 Performance experiments

3.1 Experimental description

Since several factors, such as positive pressure, negative pressure, and rotating speed would affect the seeding performance of the metering device, the performance tests of the prototype were conducted on a seed-metering device performance test-rig, model JPS-12[2].

The evaluation indexes of the metering device's seeding performance included the qualified seeding index (I_{qs}), the miss-seeding index (I_{miss}), and the stability variation coefficients of row and the consistency variation coefficients of six rows[20]. The experimental equipment was shown in Figure 2. The experiment seed was the rapeseed variety "Hua Oil Hybridization 62".

Firstly, the influence of performance on positive pressure was investigated using a multi-level experiment. The positive pressure ranged from 0 to 1200 Pa with interval of 200 Pa. The rotating speed and negative pressure were set at 9 r/min and –1200 Pa, respectively. The experiment at each positive pressure level was repeated five times. The mean value of I_{qs}, I_{miss} and the variation coefficients of I_{qs} of the five times on the outermost row were measured to evaluate the influence.



1. Differential manometer 2. Metering device performance test rig 3. Positive pressure source 4. Physical prototype of metering device 5. Negative pressure source 6. Seed delivery tube 7. Adjustable speed drive

Figure 2 Experimental equipment

Secondly, an experiment on the influence of negative pressure and rotating speed on single row performance was conducted and the best performance of the prototype would be observed. The positive pressure was set at 200 Pa. The negative pressure ranged from –800 Pa to –2200 Pa with interval of –200 Pa. The rotating speed ranged from 8 r/min to 32 r/min with interval of 2 r/min. The tests at each level of negative pressure and rotating speed were repeated five times. The mean value of I_{qs}, I_{miss} and the variation coefficients of I_{qs} of the five times on the outermost row were measured for performance evaluation.

Finally, the stability of each row and the consistency of six rows of the prototype were evaluated. Four working conditions were selected for testing: the positive pressure was set at 200 Pa , the negative pressure were set at –1400 Pa and –1600 Pa, the rotating speed were set at 10 and 16 r/min. The test at each condition was repeated five times. The variation coefficients of the I_{qs} of five times of each row at each level were calculated to evaluate the stability of each row. The variation coefficients of the mean I_{qs} of six rows were calculated to evaluate the consistency of the six rows.

3.2 Results and discussion

3.2.1 Influence of positive pressure on the performance

The influences of positive pressure on the seeding performance indexes of the outermost row are shown in Figure 3. The performance indexes, I_{qs} and I_{miss}, ranged from 88% to 92% and from 3% to 6%, respectively. The coefficient of variation of the I_{qs} from the replicated experiments at each level ranged from 1% to 3%. The result is like others advanced pneumatic precision seed-metering devices[19-21] and it was correspondent with the single-row vertical disc and inside-filling seed-metering devices with nearly negative air pressure[12,13]. It worked best when the positive air pressure was 200 Pa, where I_{qs} was 91.34%, the I_{miss} was 3.61%, and the *CV* of the I_{qs} was 1.03%. The analysis of variance showed when the positive pressure ranged from 200 Pa to 1200 Pa, the effect of the positive pressure and the seeding performance indexes were not significant (p>0.05). This is much better than vertical disc seed-metering device which was remarkably influenced by the positive air pressure[12].

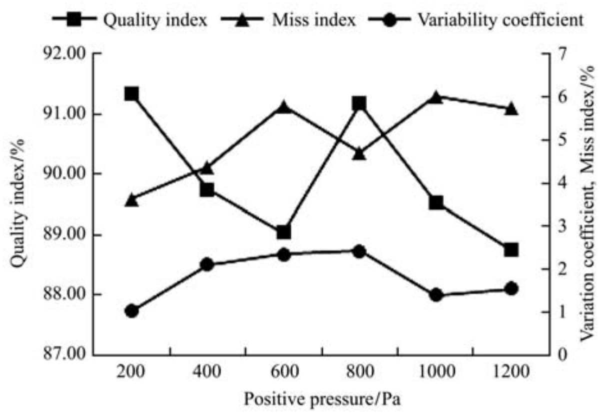


Figure 3 Influence of positive pressure on experimental indexes

3.2.2 Influence of negative pressure and rotating speed

Figure 4 showed the interaction of the negative pressure and the rotating speed of the prototype on feed index (I_{qs}), miss-seeding index (I_{miss}) and variation coefficients of I_{qs}. It demonstrated that with the increase in rotating speed, I_{qs} decreased and I_{miss} increased when the negative pressure was in the range of –800 Pa to –2200 Pa. An increase in speed adversely affects the seed-metering performance[12,22]. The dominant reason was that the interaction time between the seeding cylinder and seeds in the negative pressure zone decreased with increasing rotating speed.

When the negative pressure gradually increased, the probability of seed sucking increased, which led to a decrease in the I_{miss}. But, unfortunately, the probability of seed multi-sucking could also increase. Taken together, the I_{qs} was fluctuated irregularly.

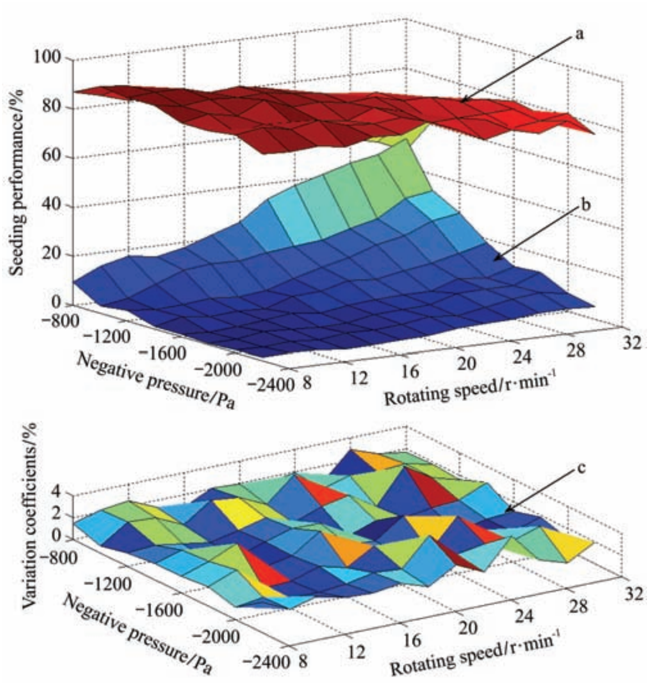


Figure 4 Effect of negative pressure and rotating speed on the performance of the prototype: (a) the I_{qs} , (b) the I_{miss} and (c) the variation coefficients of I_{qs} of the five times

As shown in Figure 4, the I_{qs} continued to increase when the rotating speed was held constant and the negative pressure was gradually increased from –800 Pa to –1200 Pa. The I_{qs} remained at a high level and did not increase further when the negative pressure was gradually increased from –1400 Pa to –2200 Pa. The I_{qs} and I_{miss} did not change significantly when the negative pressure was held constant and the rotating speed gradually increased from 8 r/min to 20 r/min. The I_{qs} and I_{miss} decreased significantly when the rotating speed exceeded 22 r/min. In addition, the variation coefficients of I_{qs} of the five times varied between 0.30% to 4.00% with the average of 1.69%, which mean the performance of the prototype at each positive and negative pressure level is stable.

The experiment also showed that when the negative air pressure was ranged of –1400 Pa to –1800 Pa, the positive air pressure was 200 Pa, the rotating speed ranged from 8 r/min to 26 r/min, the I_{qs} could exceed 85%. By contrast, the negative air pressure of the outside-filling pneumatic centralized precision metering device for rapeseed requires at least –1900 Pa and the optimal value of the negative and positive air pressures were 2200 Pa and –2200 Pa, respectively[15], so the inside-filling seed-metering device has a distinct advantage in reducing power-consumption of airflow system.

In addition, counting the broken seeds during the experiment indicated that the damage rate was 0. Moreover, when the rotating speed was 14 r/min and the negative pressure was –1600 Pa, the I_{qs} was 92.48% and the I_{miss} was 2.55%, which was the best working status of prototype.

3.2.3 Experiment on stability and consistency of the prototype

The I_{qs} and stability CV of each row and the consistency of six rows were shown in Table 1, which was demonstrated that the prototype has a good precision, stability and robustness. In the four working conditions, each row I_{qs} was above 86.5% and each row I_{miss} was below 5.5%. It was confirmed that the prototype has a good sowing precision. The row consistency CV in the four working conditions were 0.73%, 0.80%, 0.56%, and 0.55%, respectively. The values of performance indexes within different rows and multiple times were random fluctuations in a narrow data range. The stability CV of each row was below 4.6% and the consistency CV of six rows was below 0.9%. The consistency CV was less than the stability CV, by which the seed-metering uniformity of the prototype between each row was be verified.

Table 1 Results of experiment for stability and consistency of the prototype %

Test Condition		Row 1	Row 2	Row 3	Row4	Row 5	Row 6	Consistency CV
1	I_{qs} [a]	89.58	88.28	88.71	88.68	87.83	87.91	0.67
	Stability CV[b]	4.29	2.34	3.67	3.85	3.3	4.09	
2	I_{qs} [a]	88.87	87.09	87.33	87.12	87.03	87.3	0.73
	Stability CV[b]	3.33	2.6	4.22	2.97	2.69	3.39	
3	I_{qs} [a]	88.53	87.93	88.56	87.69	88.2	89.06	0.51
	Stability CV[b]	3.38	2.29	4.53	4.2	2.71	2.21	
4	I_{qs} [a]	87.64	87.12	87.2	86.76	87.02	88.09	0.50
	Stability CV[b]	3.16	2.54	3.01	2.73	3.81	3.41	

Note: [a] I_{qs} = qualified seeding index. [b] CV = coefficient of variation.

To further investigate the working performance of the seed-metering device, the prototype was mounted on a pneumatic precision combined planter for rapeseed, 2BFQ-6 model to conduct field test. The forward speed of the tractor was 2.53 km/h (the rotating speed of the prototype was nearly 24 r/min). The negative pressure was adjusted to the range of –1500 Pa, and the positive pressure was adjusted to 200 Pa. The experimental field is shown in Figure 5a. The seedling was measured after 65 days (Figure 5b), 9 sampling points were chosen, and the size of each sample point was 1 m^2. The results showed that the CV of the total seedling number was 6.17%, and the CV of the seedling number in each row was 6.32%, which agreed with the results of the bench tests for the stability and consistency of each row. The field experiment indicated that the rapeseed sowed by the prototype had acceptable field emergence as well as even row and plant spacing. No significant differences in plant distribution or seeding deficiency were observed. The prototype satisfied the agronomic requirements for rapeseed precision planting.

a. Filed experiment

b. Seedling after 65 d

Figure 5 Field experiment and seedlings after emergence

4 Conclusions

An inside-filling pneumatic precision centralized seed-metering device for rapeseed with the ability to sow rapeseed six rows at a time was developed. The device used negative pressure to suck seeds on the inner surface of the seeding cylinder by creative design, in which negative air pressure, centrifugal force and gravity was on collaboration instead of confrontation to suck the seed. This innovative can decrease the negative air pressure and also ensure the seeds contacted the suck holes more fully.

The main structure and technical parameters of the prototype were analyzed and determined. Experiments were conducted to evaluation the influences of positive pressure, negative pressure and rotating speed. The results showed that positive pressure had no significant effects on the seeding performance indexes. Negative pressure and rotating speed had significant influences on the seeding performance indexes. The I_{qs} was over 85% when the negative pressure was –1600 Pa and the rotating speed ranged from 8 r/min to 26 r/min. it was correspondent with the single-row vertical disc and inside-filling seed-metering devices with nearly negative air pressure and the negative air pressure is less than the outside-filling pneumatic centralized precision metering device. An increase in speed adversely affects the seed-metering performance. When the rotating speed reduced to 14 r/min, the I_{qs} could up to 92.48%, and the I_{miss} was 2.55%.

The experiments on the stability and consistency of the prototype showed that with four working conditions, the I_{qs} of all rows were above 86.5%, the I_{miss} of all rows were below 5.5%, the stability CV of each row was below 4.6% and the consistency CV of six rows was below 0.9%. Further field experiment also showed that the rapeseed sowed by the prototype had acceptable seeding precision. The research concluded that the inside-filling pneumatic precision centralized seed-metering device satisfied the agronomic requirements of rapeseed planting.

However, there were other influences including the form and position of the seed collector, the distribution characteristic of the airflow in the air chamber, subsequent researches on the seed-metering device will be investigated in further research.

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