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Research Article

Design of Millet Seed-metering Device under Hole-seeding Conditions

[1]Xiaoshun Zhao, [1]Pengyun Xu, [1]Zhanliang Liu, [1]Huali Yu and [2]Xiong Du
[1]College of Mechanical and Electrical Engineering, Agriculture University of Hebei, Baoding 071000,
[2]College of Agronomy, Agricultural University of Hebei, Baoding 071001, P.R. China

Abstract: In order to solve the problem that traditional millet drilling method needs labor-intensive artificial thinning-out, a hole-seeding method is proposed to replace it. Under hole-seeding conditions, an air-suction millet seed-metering device was designed. The design of air-cutting valve can assure that suction-holes are not clogged and reliably falling seeds. Suction-hole structure of the seed-metering device takes chamfer type. The dimension parameter of the chamfer hole is as follows: diameter of 4 mm, chamfer depth of 2.5 mm, fissuriform bottom of suction-hole is 1 mm width, number of holes is 32. The passing rate of hill spacing, repeat-sowing rate, leak-sowing rate and hill formation were analyzed by seed-metering test platform, which meets the precision of millet seed and agronomic requirements.

Keywords: Air-suction, bench test, hole-seeding, millet, seed-metering device

INTRODUCTION

With the improvement of living standards, people affirm role of millet to balancing dietary structure and therapeutic health care. The planting areas for millet in north China occupies 10-15% of the grain-sown area, ranking the third following those for wheat and corn. To ensure the seedling emergence, full stand and healthy seedling, it still adopts the traditional vast seeding drill method due to special agricultural requirements of millet growth, which wastes seeds. Moreover, it has great worker's labor intensity for manual thinning out and high labor cost during the millet seeding stage (Bian *et al*., 2007; Yang and Zhao, 2007). Therefore millet precise seeding is the crucial process of production. During the popularization of fine seeds, it has urgent need for the research of relevant key technology and equipments of precise seeding for seeding promotion, to save seeds and to lowering labor intensity for manual thinning out. Seed-metering device is the decisive part of the seeding precise of the seeder (Liao *et al*., 2012; Liu *et al*., 2008; Zhao *et al*., 2011). Tests have proved that seed metering performance of air-suction seed-metering device is far superior to that of mechanical seed-metering device, which saves seeds, injuring no seed. It is universal to seeds of different dimensions, having high seeding uniformity and being easy to achieve precise seeding (Zhao *et al*., 2013).

Matured foreign air-suction precise seeding operating machines are mainly applied to intertilled crops such as corn and soya bean. For instance, NG PLUS series and MONOSEMNC series air-suction seeders by French MONOSEM Company, America John-Deere 1700 series air-suction precise seeders, ED series air-suction single-seed precise seeders by Germany AMAZONE Company (Tian *et al*., 2013; Xu *et al*., 2008). Foreign countries made long period researches to air-suction precise seeders for drilled crops like wheat and millet, of which one-step centralized type air-suction seeding system has a large application to grain drills field plot experiment. Satisfying high speed operating precise seeding, seed-metering device performance has no mass field seeding operation (Barut and Ozmerzi, 2004; Sun, 2003; Zheng, 2007). In China the researches on intertilled crops air-suction precise seeder are also matured, but most of millet precise seeders are mechanical. It includes the seeder of indented seed-metering device, the seeder of reciprocating seed-metering device developed and designed by Agricultural Machinery Bureau of Yuncheng City Shanxi Province and Yuncheng City Fertilizing Seeders Plant, allotype spiral taper precise seeding seeder invented by Shanxi Agricultural University and multifunctional precise seed-metering device developed and researched by Institute of Agricultural Sciences of Baoji City Shanxi Province.

Considering millet has small seed diameter, light weight and irregular shape, to research a kind of air-suction millet precise seeder is effective for suction-hole stoppage and seed destroy and for millet precise seeding.

Corresponding Author: Xiaoshun Zhao, College of Mechanical and Electrical Engineering, Agriculture University of Hebei, Baoding 071000, P.R. China, Tel.: 0312-7526463

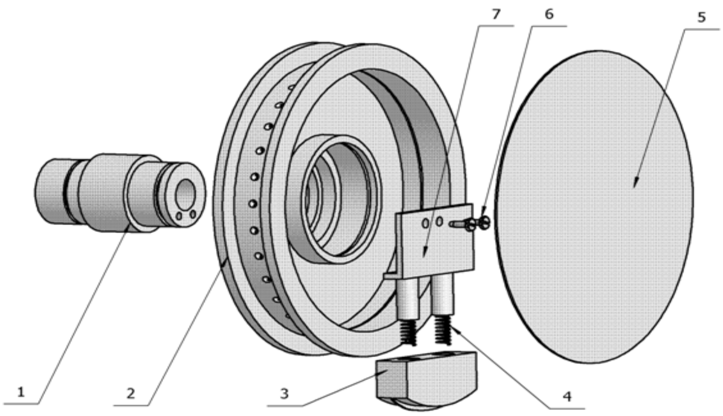

Fig. 1: Structure diagram of the seed-metering device; 1: Hollow mandrel; 2: Seed-metering device shell; 3: Air-cutting valve; 4: Adjusting spring; 5: Sealing cover; 6: screw; 7: Air-cutting valve support

MILLET SEED-METERING DEVICE STRUCTURE AND OPERATING PRINCIPLES

Seed-metering device whole structure and operating principles: As shown in Fig. 1, negative-pressure precise seed-metering device is composed by seed-metering device shell, hollow mandrel, air-cutting valve, air-cutting valve support, adjusting spring and sealing cover.

Seed-metering device shell and sealing are fixed by securing bolt and sealant, operating by land wheel driving chains. When it works, seeds flow to the seed chamber from the grand seed box by soft catheter, fixing the hollow mandrel as the airway, connecting with the fan inlet scoop through the inlet pipe. The seed metering shell operates with the land wheel, installing air-cutting valve in the seed metering shell suction chamber, fixing it onto the hollow mandrel by adjusting spring and air-cutting valve support to act as air-cutting. The air-cutting valve projection may squeeze seeds out which can not be fallen by dead weight so that they are fallen into seed suction shaped orifice. When the fan works, the vacuum space (air space) which has negative pressure produces the pressure difference in both sides of the seed suction shell, under the action of the negative pressure, seeds in the seed chamber are sucked onto the shaped orifice and rotate with the seed-metering device. When the seeds rotate to the pressure relief area where there is no negative pressure, under the action of dead weight, the seeds fall into the trenches through the trumpet seed pipe. As the seed metering wheel continuously rotating, shaped orifice entered into the vacuum space a second time, under the action of the pressure difference (negative pressure), sucks seeds again, continuously to realize the seed metering.

Air-cutingt valve structure: Considering that millet is tiny, light, having little friction and rich chaff, it designs a peculiar air-cutting valve structure under and inside the seed-metering device shell, illustrated by Fig. 2, the

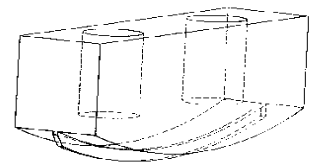

Fig. 2: Structure of air-cutting valve

outer edge projection of the air-cutting valve tightly holds deep notch of the inner ring surface of the seed metering shell. When the suction-hole is at seeds unloading area, the air-cutting valve cuts off the connection with the vacuum space to cut off negative pressure to suck seeds and the seeds fall by dead weight. If some seeds influenced by chaffs and impurities fail to be squeezed out of the suction-hole, the air-cutting valve serves as seeds erector.

Form of suction-hole of the seed-metering device: Suction-hole of air-suction seed-metering device has many types such as nozzle, direct sucking nozzle, lug boss sucking nozzle, chamfer angle sucking nozzle and taper sucking nozzle. Different shapes of suction-hole have great influence to airflow stability and inside airflow stability will directly influence the seed filling (Cui *et al*., 2003). Liu (2011) respectively has made finite element analysis to suction-hole of direct sucking nozzle, taper sucking nozzle and chamfer angle sucking nozzle suction-hole. The results show that under the same boundary conditions, inner space speed distribution in suction-hole of chamfer angle type is descending. Straight hole inner space speed is consistent and is two strong. While taper hole inner space speed is mal-distributed, even it has no airflow distribution around the hole wall, which is incidental for incomplete seed sucking or stoppage of shaped orifice (Liu, 2011). Zhao *et al*. (2013) have tested seeding performation of air-suction seed-metering devices of V-shape, U-shape and trapezoid groove, respectively. The test results show that seed

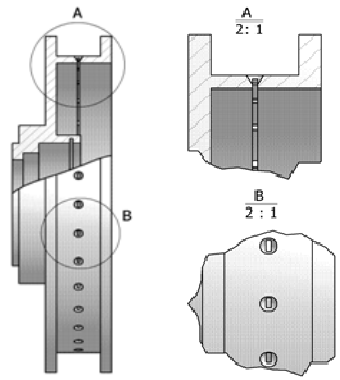

Fig. 3: Suction-hole location and structure

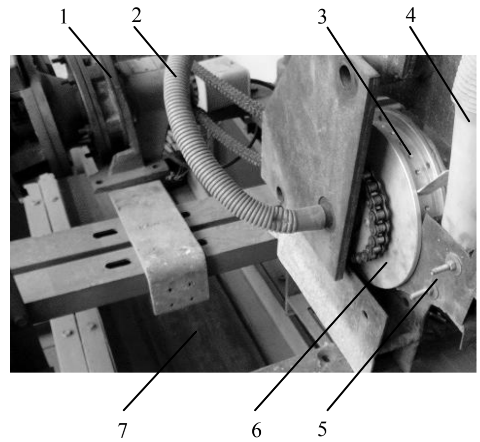

Fig. 4: Figure of seed-metering device test-bed; 1: Regulation speed motor; 2: Air tube; 3: Suction hole; 4: Seed guide pipe; 5: subsidiary seed box; 6: Seed-metering device; 7: Conveyor belt

metering uniformity of seed-metering devices with trapezoid groove structure is the best (Chen *et al*., 2011; Zhao *et al*., 2013). Considering the above simulation testing and results, the seed-metering device takes chamfer angle type shaped orifice structure. It makes holes equably on the circumference of the outer ring surface of the seed metering shell and makes a deep dotch on the same circumference of the inner ring surface. Suction-hole is formed by the cross of the chamfer angle hole and inner ring deep notch. It guarantees speedy seed filling, complete seed metering to satisfy precise hill seeder seeding and millet planting agronomic requirements.

Suction-hole aperture and number of holes of seed-metering device:

Aperture: In the stable vacuum degree, the seeds sorption probability declines due to small suction-hole diameter, small contact area of seeds suction shaped orifice and seeds, insufficient sorptive attraction, consequently leads to the leakage sowing. Amid the aperture increase, it decreases the vacuum degree that is required by seeds suction and seed metering performance gradually increases. When the aperture increases to a definite value, the air leakage increases and the seed metering performance decreases accordingly, meanwhile, it is possible for one suction-hole sucks several seeds at the same time to increase the re-seeding rate. Firstly the design confirms the diameter of suction-hole according to the following empirical formula:

$$d = (0.6 \sim 0.7)b$$

where,
b = Millet average grain diameter (around 1.5~1.9 mm)
d = The diameter of suction-hole

According to the above formula, suction-hole diameter has the rough range of 0.96~1.33 mm, taking 1.0 mm as the experimental investigation parameter. In accordance with millet seeding agronomic requirements, to satisfy that each suction-hole holding 3 ~5 seeds, it tested that the dimension parameter of the chamfer angle hole is diameter 4 mm, pour depth 2.5 mm, fissuriform bottom air hole of width 1mm, as illustrated in Fig. 3.

Number of holes: If the seed-metering device rotating speed is constant, seed metering efficiency increases with the increase of number of holes accordingly. But when number of holes exceed to some constant value, seed suction capacity starts to decline, consequently it declines the qualification index, as a result of much total area of the suction-hole, much leakage of the airspace and much pressure loss, which have weakened seed suction capacity. The shortened distance between the other two suction-holes, as well as the mutual influence of air flows make worse seed suction efficiency. Comprehensively considering the designed inner ring circumference of the seed-metering device shell, suction-hole aperture and the limitation of procession technique, the numbers of suction-hole of the experimental machine is 32 and circumference distribution perimeter of suction-hole is 140 mm.

SEED-METERING DEVICE BENCH TEST

Seed-metering device is fixed on the beam of the test bed by the bearing. The three phase asynchronous motor drives axles by chains to drive seed-metering device. The test bed is illustrated in Fig. 4. On the speed adjustable power belt it spreads adhesive tape as the belt of the seed metering. The spread seeds are adhered to the adhesive tape to avoid seeds jumping so that it influences results, being convenient for data reasoning and statistical analysis. Negative pressure is provided by 1.1 kW fan driven by frequency converting regulating speed motor. The operation rotating speed of the seed-metering device is adjustable in the range of 10

Table 1: The bench test results

	Number per hill (number)			Hill spacing (mm)			Diameter of hill (mm)		
Test number	A	B	C	A	B	C	A	B	C
1	4	2	3	8.5	7.0	6.5	1.5	0.2	1.5
2	2	3	6	7.5	6.5	6.0	1.5	2.0	2.0
3	4	2	4	8.0	10.0	6.0	0.4	0.6	2.0
4	4	4	4	8.0	7.0	4.0	1.0	0.7	1.2
5	5	3	3	8.0	7.0	2.0	0.3	0.6	1.5
6	3	4	3	7.5	6.5	2.5	0.8	0.5	0.5
7	3	3	5	6.5	5.5	2.5	0.5	1.0	0.4
8	3	4	3	7.2	3.5	6.2	0.3	0.8	0.4
9	4	3	4	6.0	4.5	7.0	2.0	0.2	0.8
10	5	4	2	2.5	4.0	9.0	0.5	0.3	0.8
11	3	4	5	6.0	5.0	5.5	0.5	1.2	0.4
12	6	6	5	5.5	7.0	5.0	0.8	1.2	0.5
13	4	3	2	7.0	5.2	2.8	0.2	1.0	0.5
14	4	7	1	6.0	3.5	2.5	0.1	2.0	0.8
15	5	5	3	5.0	3.5	6.0	0.3	0.6	0.5
16	6	3	4	4.0	4.0	5.5	0.4	0.6	1.0
17	5	4	4	4.0	4.4	7.0	0.5	0.7	0.5
18	6	4	3	5.5	6.0	6.5	2.0	1.0	1.2
19	4	3	1	8.0	5.0	5.5	1.0	1.5	0.5
20	1	6	4	7.0	8.0	8.0	0.2	0.3	0.1
Average value	4.05	3.85	3.45	6.39	5.66	5.30	0.74	0.85	0.86
Whole average value	3.78			5.78			0.82		

A means that rotational speed of seed-metering device is 20 r/min; B means that rotational speed of seed-metering device is 25 r/min; C means that rotational speed of seed-metering device is 30 r/min

~40 r/min. It makes tests under the respective 20, 25 and 30 r/min, respectively rotating speeds, analyzes seeds obtained by seed metering belt within 10 circles, measures the distance between seed number per hill, hill diameter and hill spacing. Consequently it analyzes hill spacing qualification rate, re-seeding rate, leakage sowing rate and hill formation. Test data and results are shown in Table 1.

According to agronomic requirements 3~5 seeds per hill is the best seeding numbers and hill diameter is no more than 1cm. Table 1, under the condition that seed-metering device rotating speed is 20, 25, 30 r/min, the corresponding average seed number per hill, respectively is 4.05, 3.85, 3.45 and overall average value is 3.78, which meet agronomic requirements. Under the three different rotating speeds, the hill diameter average value is 0.74, 0.85, 0.86 cm, respectively. Overall average diameter is 0.82 cm, having good hill formation.

According to national standard “Testing methods of Single seed drills (Precise drills)” (GB/T6973-2005), taking Xr as theoretical mass dropping distance (hill spacing), actual measurement dropping distance (hill spacing) is within the scope of (0.5Xr, 1.5Xr) as qualification dropping distance (hill spacing), less than or equal to 0.5Xr is within the scope of re-seeding, above and beyond 1.5Xr is within the scope of leakage sowing. According to agronomic requirement of seeding millet, it selects theoretical mass dropping distance (hill spacing) is 8 cm. Actual measurement hill spacing in the scope of (4 cm, 12 cm) is qualified, less than or equal to 4 cm is re-seeding, above 12 cm is leakage sowing. In the experiments under different rotating speed, the average hill spacing is 6.39, 5.66, 5.30 cm, respectively and the whole average value is 5.78 cm, being within the scope of qualification.

It makes hill spacing data processing in Table 1 according to methods in the national standard “Testing methods of Single seed drills (Precise drills)” (GB/T6973-2005). Hill spacing is equal to dropping distance. Under the conditions that seed-metering device rotating speeds are 20, 25, 30 r/min, respectively, the qualification indexes are 82.35, 66.67, 57.14%, respectively; re-seeding indexes are 17.5, 33.33, 42.86%, respectively, having no leakage sowing. According to “Specifications of single seed drill (Precise drill)” (JB/T10293-2001), under the condition of seeds dropping distance (hill spacing) X≤10 cm, precise seeder performance index shall meet the following requirements: dropping distance qualification index ≥60%, re-seeding index ≤30% and leakage sowing index ≤15%. When the seed-metering device rotating speed is 20 r/min, seed metering has the best performance.

CONCLUSION

It designs a kind of millet air-suction seed-metering device and confirms that under the conditions that the seed-metering device suction-hole has the chamfer angle structure, entrance depth is 2.5 mm, bottom slit-shaped breather width is 1 mm, with 32 pieces of suction-holes, air-cutting valve structure solves the problem that suction-hole is easy to be blocked. It promotes seed metering performance.

Under the combination of seed-metering device suction-hole diameter 4 mm, air-cutting valve arc length dimension 55 mm, suction chamber vacuum degree 1.5

Kpa, rotating speed 20 r/min, it has the best seed metering performance, completely meeting national standard “Specifications of single seed drill (Precise drill)” (JB/T10293-2001).

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