

EXPERIMENTAL RESEARCH ON PERFORMANCE OF MULTI-MODE SEED METERING DEVICE

多模式排种器作业性能试验研究

Jie HAN, Yajun ZHUANG, Meng ZHANG, Zeqi LIU, Yachen JIN, Yulong CHEN^{* 1}

¹) School of Agricultural Engineering and Food Science, Shandong University of Technology, Zibo 255000, China;

²) Research of Institute of Ecological Unmanned Farm, Shandong University of Technology, Zibo 255000, China

Tel: +86 15315206471; E-mail: 1097402292@qq.com

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ABSTRACT

The paper, combined with structural characteristics of mechanical seed metering devices and air-suction seed metering devices, designs a multi-mode seed metering device. According to installation of seed holding rings and application of negative pressure, three modes (mechanical mode, air-suction mode and combination of air-suction mode and mechanical mode) can be realized. JPS-12 seed metering performance test benches and high-speed camera are used for indoor tests. According to results, under the mechanical mode, advancing speed has a significant effect on seed metering performance. At a low speed, the qualification rate is maintained at about 96%; with advancing speed increased, the qualification rate decreases significantly. Seed spacing variation coefficient gradually increases with speed increased and stabilizes at about 30%. Under the air suction mode, negative pressure and advancing speed have a significant effect on qualification rate and miss seeding rate. With negative pressure increased, qualification rate increases while miss seeding rate decreases. Negative pressure has no significant effect on seed spacing variation coefficient, but advancing speed has a significant effect on seed spacing variation coefficient. With speed increased, seed spacing variation coefficient increases significantly. Under the multi-mode, advancing speed and negative pressure have a significant effect on qualification rate and miss seeding rate. Negative pressure has no significant effect on seed spacing variation coefficient, but advancing speed has a significant effect on seed spacing variation coefficient. Upon comparison of three modes, when speed is 6 km/h, qualification rate of air suction mode is close to multi-mode, which is significantly higher than that of mechanical mode. When speed is 8-12 km/h, qualification rate of multi-mode is significantly higher than that of air suction work. With negative pressure increased, gap between them gradually decreases.

摘要

本文结合机械式排种器和气吸式排种器的结构特点,设计一种多模式排种器,根据是否安装护种环,以及是否施加负压,可实现机械、气吸和气吸-机械复合三种作业模式。利用 JPS-12 排种性能试验台和高速摄像机进行室内试验。结果表明:机械作业模式下,前进速度对充种性能具有显著影响,在速度较小时,合格率维持在 96% 左右;随着前进速度的增加,合格率出现显著下降。粒距变异系数随着速度的增大,逐渐增加,并稳定在 30% 左右。气吸作业模式下,负压和前进速度对合格率与漏播率都具有显著影响。随着负压的增大,合格率增加,漏播率降低。负压对粒距变异系数影响不显著,然而前进速度对粒距变异系数影响显著,随着速度的增大,粒距变异系数出现显著提高。复合作业模式下,前进速度和负压对合格率与漏播率均具有显著影响。负压对粒距变异系数影响不显著,前进速度对粒距变异系数影响显著。对比三种作业模式,在 6km/h 时,气吸与复合作业模式的合格率接近,显著大于机械模式。在 8-12km/h 时,复合式作业的合格率显著大于气吸式作业,随着负压的增大,两者之间的差距逐渐减小。

¹ Jie Han, M.S. Stud. Eng.; Yajun Zhuang, M.S. Stud. Eng.; Meng Zhang, M.S. Stud. Eng.; Zeqi Liu, M.S. Stud. Eng.; Yachen Jin, B.S. Stud. Eng.; Yulong Chen, As. Ph.D. Eng.

INTRODUCTION

As core of seeders, seed metering devices are divided into mechanical seed metering devices and pneumatic seed metering devices by operating principle (Dylan *et al.*, 2013; Jia *et al.*, 2018; Liao *et al.*, 2018; Liu *et al.*, 2015; Yang *et al.*, 2016). Air-suction seed metering devices are the most widely used pneumatic seed metering devices. Mechanical seed metering device are designed in simple structures, but are difficult to adapt to high-speed operation. Air-suction seed metering devices are designed in complex structures, and can complete high-speed seeding, but the seeding performance decreases when the negative pressure is unstable.

Domestic and overseas researchers have carried out a lot of researches on these two kinds of seed metering devices, optimized the structure of seed picking mechanism of mechanical seed metering devices, and analyzed seed movement laws, influencing factors of seed picking effects, during mechanical seed picking (Chen *et al.*, 2021; Vianna *et al.*, 2014; Wang *et al.*, 2017). Also, researchers investigated laws of effects of suction hole shape, negative pressure and speed on performance of air-suction seed metering devices (Cujbescu *et al.*, 2019; St Jack *et al.*, 2013; Yu *et al.*, 2015; Zhang *et al.*, 2015).

In researching seed metering devices, indoor bench test (Dylan *et al.*, 2013; Zhao *et al.*, 2010), high-speed camera analysis (Karayel *et al.*, 2006; Shen *et al.*, 2021; Yu *et al.*, 2015; Zhang *et al.*, 2015), discrete element simulation, etc. are the most commonly used research methods.

Generally, designed seed metering devices can only realize mechanical seed metering or pneumatic seed metering, but cannot realize simultaneous multi-mode seed metering. A multi-mode seed metering device designed in the paper can switch among mechanical mode, air suction mode and multi-mode with changes to structures and parameters, and has advantages of both mechanical seed metering devices and air-suction seed metering devices, providing innovative ideas and methods for design of seed metering devices.

MATERIALS AND METHODS

Seed metering device

Author has designed a vertical disc mechanical seed metering device, analyzed characteristics of population structure in seed filling, and optimized design of seed stirring mechanisms and seed holding rings (Chen *et al.*, 2021; Liu *et al.*, 2021; Zhuang *et al.*, 2022). According to research results, when depth and inclination of groove stirring structures are 3.1 mm and 60.5° respectively, best seed stirring effects will be achieved; when initial angle of seed holding rings is 35.7°, and a flexible buffer zone with length of 60 mm is used, the best seed cleaning and seed conveying effects will be achieved.

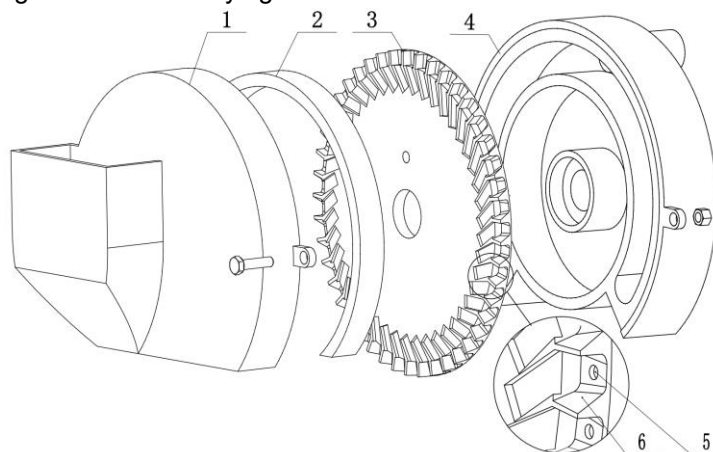


Fig. 1 – Multi mode seed metering device

1. Shell; 2. Seed holding ring; 3. Disk; 4. Suction base; 5. Suction hole; 6. Seed hole

The above seed metering devices involve 3 operating modes according to the necessity of seed holding rings and negative pressure. As to the first mode, seed metering devices are provided with seed holding rings, to which no negative pressure is applied. During operation, seed holding is completed through mechanical structures of seed holes, and seed cleaning and conveying are completed through seed holding rings. This is mechanical seed holding mode. As to the second mode, no seed holding ring is installed, but negative pressure is applied. During operation, negative pressure and seed holes are used simultaneously in seed holding, while negative pressure suction is mainly used in the seed conveying. As to the third mode, seed holding rings are installed, and negative pressure is applied. Negative pressure and seed holes are used simultaneously in seed holding, and seed conveying is completed under joint actions of negative pressure suction and seed holding rings.

Table 1

		Seed holding ring	
		YES	NO
Negative pressure	YES	Multi-mode	Air suction mode
	NO	Mechanical mode	/

Test plan

Seed metering performance tests are carried out on JPS-12 indoor seed metering test bench (Figure 2). Many researchers use the test bench for the seed metering tests (Zhang *et al.*, 2015; Zhao *et al.*, 2010). Performance of the test bench is reliable and can accurately verify operating capacity of seed metering devices. Seeds discharged from seed metering devices fall on conveyor belts with grease, and information about seeds on conveyor belts is collected with CCD camera. The data of the seed metering performance is automatically calculated through the computer program.



Fig. 2 - Indoor test system

According to GB/T 6973-2005 Testing Methods of Single Seed Drills (Precision Drills), indexes of quality of feed index A, multiple index D, miss index M and precision index C are set as the evaluation indexes of seed metering performance

$$A = n_1/N \times 100$$

$$D = n_2/N \times 100$$

$$M = 100 - A - D$$

$$C = \sigma \times 100$$

Where: n_1 is the number of seeds with the seed spacing greater than 0.5 times the theoretical seed spacing and less than 1.5 times the theoretical seed spacing (the theoretical seed spacing herein is 10 cm); N is the number of seeds determined through test; n_2 is the number of seeds with the seed spacing less than 0.5 times the theoretical seed spacing; σ is the standard deviation of seed spacing.

RESULTS AND ANALYSIS

Seed metering performance under mechanical operation mode

In previous researches, the optimal seed discharging angle in air suction mode is 39.5° (Zhuang *et al.*, 2022), so seed discharging angle in mechanical operation mode is also set at 39.5° . The seed discharging angle depends on seed holding plates, so termination angle of seed holding plates is also 39.5° .

Table 2

Seed metering performance under mechanical operation mode				
Speed[km·h ⁻¹]	A[%]	D[%]	M[%]	C[%]
1	95.82	3.25	0.93	14.59
2	96.32	2.88	0.80	16.35
3	96.41	3.08	0.51	17.52
4	92.06	5.74	2.20	18.88
5	88.65	6.78	4.57	20.26
6	86.44	8.35	5.21	23.15
7	83.98	9.57	6.45	21.85
8	81.25	8.03	10.72	22.79

Table 2
(continuation)

9	76.68	10.68	12.64	25.96
10	73.54	13.47	12.99	29.18
11	71.37	13.69	14.94	29.06
12	70.56	15.74	13.70	30.62

In the speed range of 1 - 12 km/h, seed metering performance tests on seed metering devices in mechanical operation mode are conducted (Table 2).

Advancing speed has a significant effect on seed filling performance. When speed is less than 3 km/h, changes of *A* are not significant, remaining at about 96%. When speed is more than 4 km/h, with advancing speed increased, *A* decreases significantly.

When speed is less than 3 km/h, changes of *D* and *M* are both not significant, *D* remaining at about 3%, *M* being less than 1%. When speed is more than 4 km/h, with advancing speed increased, *D* and *M* increase significantly. With speed increased, *C* gradually increases. When speed is more than 10 km/h, *C* remains at about 30%.

Seed metering performance under air suction mode

Two-factor tests are conducted under advancing speed and negative pressure, with seed metering device in air suction mode, and seed discharging angle of 39.5° (Table 3). Negative pressure has a significant effect on *A*. With negative pressure increased, *A* increases. When speed is 6 km/h, negative pressure has no significant effect on *A*, remaining at about 95%. With speed increased, negative pressure has increasingly obvious effects on *A*. When speed is 12 km/h, negative pressure has the most significant effect on *A*. When the negative pressure is 1 kPa, *A* is 60.88%. With negative pressure increased, *A* increases significantly. When negative pressure is 5 kPa, *A* is 81.62%, with an increase ratio of 34.1%.

Table 3

Seed metering performance under air suction operation mode					
Pressure [kPa]	Speed [km·h ⁻¹]	<i>A</i> [%]	<i>D</i> [%]	<i>M</i> [%]	<i>C</i> [%]
1	6	94.85	1.99	3.16	13.70
	8	80.62	6.22	13.16	15.73
	10	73.47	3.81	22.72	16.41
	12	60.88	2.06	37.06	22.10
2	6	96.94	2.55	0.51	12.84
	8	86.67	4.29	9.05	13.01
	10	79.81	7.04	13.15	15.99
	12	73.85	1.54	24.62	24.75
3	6	95.90	3.59	0.51	10.61
	8	91.67	5.74	2.59	16.04
	10	86.44	5.83	7.73	17.53
	12	78.57	3.98	17.45	24.04
4	6	95.18	4.82	0	12.49
	8	92.65	7.01	0.34	12.68
	10	87.94	7.37	4.69	16.73
	12	81.88	4.61	13.51	21.91
5	6	95.83	4.17	0	11.60
	8	92.49	6.45	1.06	15.90
	10	88.12	5.45	6.44	17.93
	12	81.62	8.76	9.62	24.19

Advancing speed has significant effects on *A*, and the lower the negative pressure, the more significant effects the advancing speed has on *A*. If negative pressure is 1 kPa, when speed is 6 km/h, *A* is 94.85%. With speed increased, *A* decreases gradually. When speed is 12 km/h, *A* decreases to 60.88%, with a decrease ratio of 35.8%.

When negative pressure is larger, effects of the advancing speed on *A* become smaller. With negative pressure of 5 kPa, and speed of 6 km/h, *A* is 95.83%; with speed of 12 km/h, *A* decreases to 81.62%, with a decrease ratio of 14.8%.

Negative pressure has significant effects on *M*. With negative pressure increased, *M* decreases. If speed is 6 km/h, when negative pressure is 1 kPa, *M* is 3.16%. When negative pressure is greater than 2 kPa, changes of *M* are not significant, approaching to 0%. In addition, with speed increased, negative pressure has increasingly obvious effects on *M*. If speed increases to 12 km/h, when negative pressure is 1 kPa, *M* is 37.06%. With negative pressure increased, *M* decreases significantly. With negative pressure of 5 kPa, *M* is 9.62%, with a decrease ratio of 74.0%.

Advancing speed has significant effects on *M*. The higher the advancing speed, the higher *M* is. When negative pressure is 1 kPa, miss seeding frequency is the highest. When advancing speed is 6 km/h, *M* is 3.16%. When speed increases to 12 km/h, *M* increases to 37.06%, increasing by 10.7 times. With negative pressure increased, effects of advancing speed on *M* decrease. With negative pressure of 5 kPa, and advancing speed of 6 km/h, *M* is 0%; with advancing speed of 12 km/h, *M* increases to 9.62%.

Negative pressure has no significant effects on *C*. When negative pressure varies from 1 to 5 kPa, changes of *C* are not significant. Advancing speed has significant effects on *C*. With speed increased, *C* increases significantly. Domestic and overseas scientific researchers have reached similar conclusions.

Seed metering performance under the multi-mode

Seed metering device operate under air suction and mechanical multi-mode with seed holding rings installed and negative pressure applied.

Seed metering devices pick seeds under the action of negative pressure suction, and seeds are adsorbed to suction holes at the bottom of seed holes. However, when seed holes pass through the buffer zone of seed holding plates, seed holding plates will destroy adsorption state of seeds, and seeds will be separated from suction holes. When seed holes pass through the buffer zone, seeds are in a free state at the moment they leave the buffer zone, and then seeds are rapidly absorbed onto suction holes under negative pressure for air-suction seed conveying and seed discharging (Figure 3).

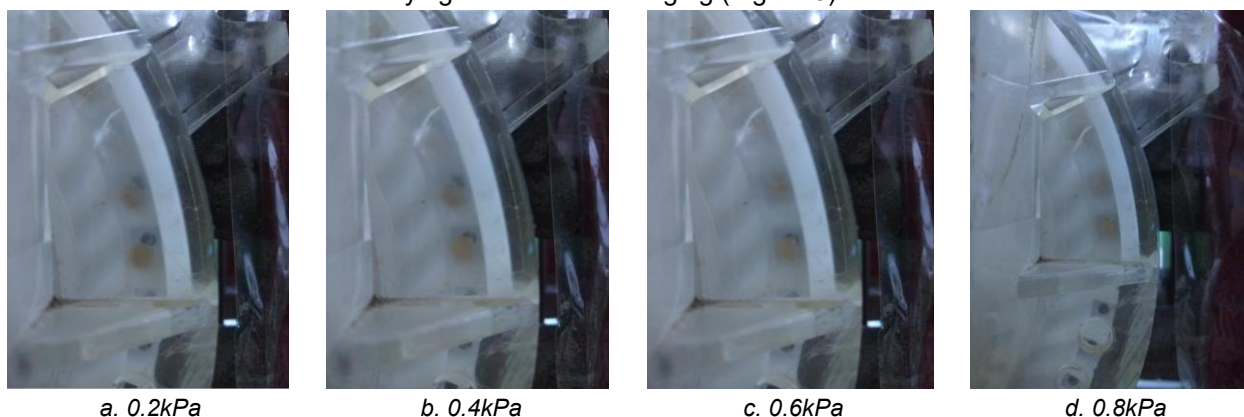


Fig. 3 - Adsorption state of seeds under seed holding ring under different pressure

After seed metering devices operate normally for a period of time, seed metering shafts and fans stop. At this time, 13 seed holes behind the buffer zone at the back of seed holding plates are filled with seeds. Start fans and gradually increase negative pressure to count the number of seeds adsorbed to suction holes (Fig.4).

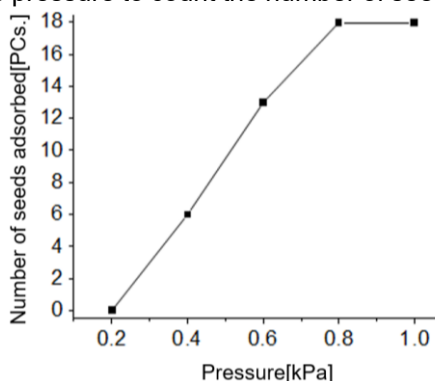


Fig. 4 - Relationship between pressure and the number of seeds adsorbed on the suction hole

When negative pressure reaches 0.8 kPa, which is far lower than normal operating negative pressure of seed metering devices (3-5 kPa), seeds are all adsorbed onto suction holes. Therefore, the buffer zone will not affect air-suction seed conveying and seed discharging. Seed metering performance tests under multi-mode are conducted with negative pressure and advancing speed as test factors (Table 4).

Table 4

Effect of seed metering test under multi-mode

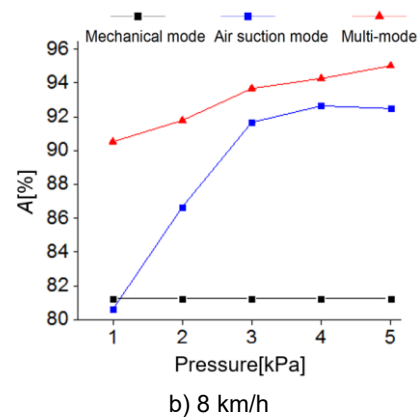
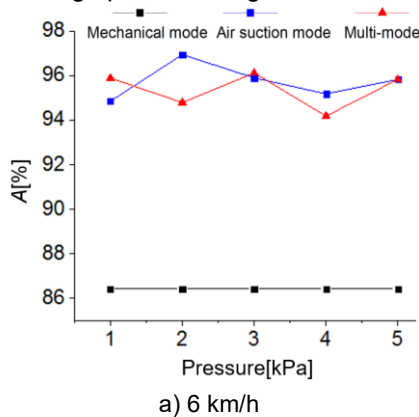
Pressure [kPa]	Speed [km·h ⁻¹]	A [%]	D [%]	M [%]	C [%]
1	6	95.89	2.51	1.6	14.91
	8	90.53	4.42	5.05	19.96
	10	84.34	8.59	7.07	21.68
	12	73.56	11.54	14.9	23.18
2	6	94.79	3.29	1.92	16.76
	8	91.79	5.37	2.84	20.38
	10	85.73	8.15	6.12	22.53
	12	76.86	12.52	10.62	24.67
3	6	96.12	2.57	1.31	15.65
	8	93.68	3.57	2.75	18.79
	10	89.20	5.44	5.36	20.52
	12	85.07	7.96	6.97	23.24
4	6	94.18	5.49	0.33	15.06
	8	94.27	5.21	0.52	19.07
	10	92.94	4.02	3.04	21.44
	12	91.41	5.05	3.54	22.71
5	6	95.83	4.01	0.16	16.31
	8	95.02	3.66	1.32	19.17
	10	92.96	4.02	3.02	20.41
	12	92.13	4.00	3.87	22.19

D is closely related to advancing speed and negative pressure. When negative pressure is 1 kPa, D increases with the increase of speed; when negative pressure increases to 2 kPa and 3 kPa, D decreases with the increase of speed; when negative pressure reaches 4 and 5 kPa, D tends to stabilize.

Advancing speed and negative pressure have significant effects on A. When speed is 6 km/h, A tends to stabilize at about 95%, and negative pressure has no significant effects on A. As speed continues to increase, negative pressure has increasingly obvious effects on A at 8, 10, and 12 km/h, respectively. With speed of 12 km/h, A is 73.56% at 1 kPa negative pressure, and increases to 92.13% at 5 kPa negative pressure, with an increase ratio of 25.2%.

Advancing speed and negative pressure have significant effects on M: M increases with the increase of speed, while M decreases with the increase of negative pressure. At speed of 6 km/h, negative pressure has little effects on M: M is 1.6% at 1 kPa and 0.16% at 5 kPa. With the increase of speed, negative pressure has increasingly obvious effects on M. With speed reaching 12 km/h, M is 14.9% at negative pressure of 1 kPa, and is 3.87% at negative pressure of 5 kPa.

Negative pressure has no significant effects on C, while advancing speed has significant effects on C. When speed remains unchanged, changes of negative pressure will not result in changes of C. While the higher the advancing speed, the higher C.



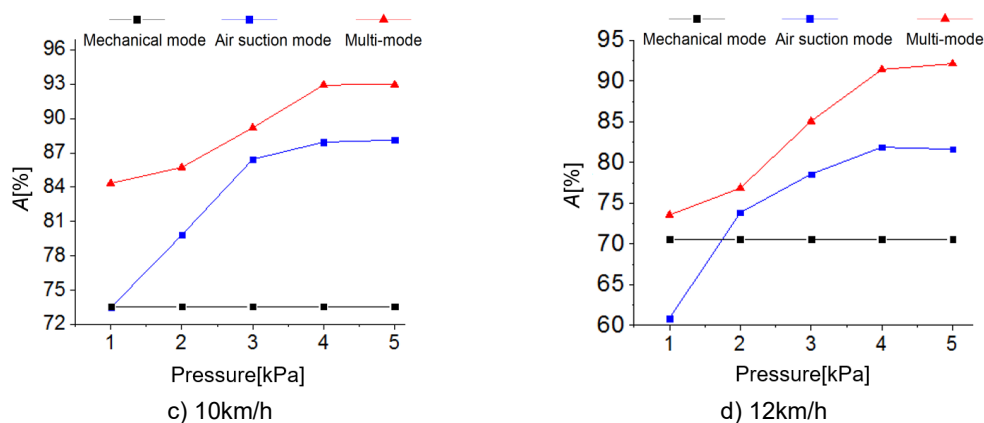


Fig. 5 - Comparison of qualification rate under different operation model

Seed metering performance under mechanical, air suction and multi-mode is compared (Figure 5).

At 6 km/h, A under air suction mode is close to multi-mode, which stabilizes at about 96%, significantly greater than A under mechanical mode, and changes of negative pressure has no significant effects on A.

At 8 and 10 km/h, A under multi-mode is greater than under air suction mode, and the gap between the two gradually decreases with the increase of negative pressure. At 1 kPa, A under air suction mode is close to mechanical mode. When negative pressure is greater than 2 kPa, A under multi-mode and air suction mode is significantly higher than under mechanical mode.

At 12 km/h, A decline under all three modes. At 1 kPa, A in multi-mode is close to mechanical mode, while A in air suction mode is smaller than in mechanical mode. With the increase of negative pressure, A in multi-mode and air suction mode increases gradually.

CONCLUSIONS

(1) A precision seed metering device is designed. The device involves 3 operating modes according to the necessity of seed holding rings and negative pressure mechanical mode, air suction mode and multi-mode.

(2) Under mechanical mode, advancing speed has significant effects on seed filling performance. When speed is less than 3 km/h, changes of A are not significant, remaining at about 96%. When speed is more than 4 km/h, with the increase of advancing speed, A decreases significantly. With the increase of speed, C gradually increases and stabilizes at about 30%.

(3) Under air suction mode, negative pressure and advancing speed have significant effect on A. A increases with the increase of negative pressure, and the lower the negative pressure, the more significant effects the advancing speed has on A. Negative pressure has significant effects on M. With the increase of negative pressure, M decreases. In addition, with the increase of speed, negative pressure has increasingly obvious effects on M. The higher the advancing speed, the higher M. With the increase of negative pressure, effects of advancing speed on M decrease. Negative pressure has no significant effects on C, but advancing speed has significant effects on C. With the increase of speed, C increases significantly.

(4) Under multi-mode, advancing speed and negative pressure have significant effects on A and M. Negative pressure has no significant effects on C, while advancing speed has significant effects on C. When speed remains unchanged, changes of negative pressure will not result in changes of C. While the higher the advancing speed, the higher C.

(5) At 6 km/h, A under air suction mode is close to multi-mode, significantly greater than A under mechanical mode. At 8 and 10 km/h, A under multi-mode is greater than that under air suction mode, and gap between the two gradually decreases with the increase of negative pressure. At 12 km/h, A declines significantly under all three modes.

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