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Research Progress and Performance Analysis of Air-suction Seed Metering Device in China

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Abstract:
The Air-suction seeder is widely used in the field of precision seeding in China. Air-suction metering device is the core component of the air-suction precision seeder, and its performance has a significant impact on the quality of sowing. By introducing the research status of domestic air-suction metering devices, the related factors and research methods affecting the performance of air-suction seed metering devices were elaborated on in detail, which provided the reference for the design and performance research of domestic air-suction metering devices.

Key word: *air-suction metering device; precision seeding; performance*

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I. Introduction

The stable development of agriculture is of great significance to the economic stability of the whole country, and sowing is one of the most important links in agricultural production. Promoting the development of precision and high-speed seeding machinery is of great significance for ensuring grain yield and promoting agricultural science and technology progress. High-speed precision seeding can meet the operation requirements at a high speed, which can not only save costs, but also improve production efficiency. It has become the trend of agricultural modernization.

Since the early 1970 s, China began to study precision seeding machinery. Precision seeders can be divided into mechanical and pneumatic types according to the types of seed metering devices [1]. The air-suction precision seeder is the most widely used type of pneumatic precision seeder. It has the advantages of lax seed requirements, good versatility, no damage to seeds, and high operating efficiency. Seed-metering device as the ' core ' of the planter, the quality of planter work, to a large extent depends on the quality of work of the seed-metering device. Therefore, it is of great significance to understand the structure and working principle of the air-suction metering device and master the research methods of its working performance [2]. This paper mainly describes the development of air-suction seed metering device in China, the factors affecting the performance of seed metering device and the detection methods, which provides a reference for the development and performance research of air-suction seed metering device.

composition and working principle of air-suction seed metering device

According to the different structures of the air-suction metering device, it can be divided into three types : vertical disc type, spoke type and drum-type, among which vertical disc type is widely used. The air-suction seed-metering device is mainly composed of seed chamber, seed plate, seed clearing sheet, air chamber assembly, etc., which uses the fan to extract the air in the air chamber to form a vacuum degree to produce negative pressure.The main working part is a seed-metering plate with a suction hole. The vacuum chamber on the back of the seed-metering plate is connected with the fan suction port to form a negative pressure in the vacuum chamber [3]; When the seeding plate rotates, under the negative pressure of the vacuum chamber, the seeds are adsorbed on the suction hole and rotate with the seeding plate. When transferred to the position of the clearing sheet, the clearing sheet can clean up the excess seeds at the suction hole and avoid reseeding. When the seeds are transferred out of the vacuum chamber, the negative pressure of the suction hole disappears, and the seeds fall into the seed groove by self-weight or under the action of the seed pusher[4].

Research on development of air-suction seed metering device

Since the early 1980s, various air-suction metering devices with different structural forms and working principles have been introduced and independently developed in China[1].The research on air-suction precision seed-metering devices has been more in-depth, and various seed-metering devices for sowing different crops

have appeared.

Air-suction soybean and maize seed metering device

The air-suction mechanical compound soybean precision seed-metering device designed by Jia Hongleiet al.[5] improved the problem of serious missed sowing due to the sudden reduction of the air chamber pressure of the seed-metering device. Through the study of the population movement law, the structural design of the seed picking mechanism (seed guiding groove and seed picking groove) was focused on. Through discrete element simulation analysis, it is found that the inclination angle of the seed guide groove is 45 degrees and the depth is 2 mm, which can effectively improve the seed performance of the seed metering device. The seed groove is designed as a bell mouth shape, which can improve the filling rate. During the operation, the seed guiding groove will produce a thrust to make the seeds move to the seed taking groove, and the seeds are also supported by the seed taking groove. Under the interaction of the seed taking groove, the suction hole and the seed guiding groove, the seed metering device does not need to clear the seeds during operation, so that the suction hole in the seed taking groove can only absorb a single seed and quickly complete the seed filling. Zhao Jialeet al.[6]designed an offset double disc soybean air-suction metering device, which focused on the design of the structure of the seed collecting mechanism. The shape of the suction hole was set to be conical, and the influence of different apertures on the airflow velocity was verified by single factor test, and the aperture size was determined. The seed clip is designed as a spherical symmetrical curved surface, whose radius is the same as the average radius of the seed, and the suction effect is good. The suction hole and the inner wall of the seed collecting clip are attached with a foam film, which can effectively guarantee the integrity of the seeds.Su Wei et al.[7]designed air-suction soybean high-speed precision metering device, metering plate suction hole shape is cylindrical hole ; the seed scraping device is equipped with three seed scraping wheels, which increases the number of contacts between the seed and the seed scraping device, can better complete the seed scraping operation and ensure single seed sowing ; the air chamber is set to a horseshoe structure with the same width and different depths to ensure consistent vacuum in the air chamber. Wang Guoweiet al.[8]used Fluent software to simulate the seed metering device, and designed an air-suction soybean seed metering device with annular structure of air chamber, adjustable height of seed chamber filling layer and high-speed air pressure operation.

DiaoPeisonget al.[9]designed a single-disc double-row air-suction seed metering device suitable for narrow-row sowing of soybean. The seed-suction hole of the seed-metering disc was set in the form of inner and outer double-rings, and the diameter of the suction hole was 4.5 mm. The chip-type stirring device installed on the seed-metering disc can increase the filling rate; The seed distributor includes the front and rear guide tubes, which can make the seeds cast out of the outer and inner rings enter into them respectively to form a double row seed flow. The inner and outer combined seed cleaning device, in which the inner seed cleaning device is located between the inner and outer suction holes, and the excess seeds are removed by rigid impact action. The outer seed cleaning device is a slider scraper structure, which can adjust the angle and slider stroke according to the seed cleaning amount. The suction type single and double row precision universal seed metering device designed by Zhao Lijun et al.[10]realizes single and double row seeding of corn and soybean by replacing the seeding plate. The diameter of the seed plate is 115 mm, and the suction hole of the soybean double row seed plate is circular socket type, and the number of holes in each row is 40. The suction hole of corn single row seed plate is circular plane, and the number of holes in each row is 30.

The seed cavity self-cleaning air-suction corn seed metering device designed by Yang Wei et al[11]has self-cleaning function. The clearing cavity and filling cavity of the seed metering device are separated by the clearing gate, so that the clearing and filling processes are independent of each other. When the seed cleaning is carried out, the seed cleaning cylinder is controlled by the program to open the seed cleaning valve. Under the action of the negative pressure of the fan and the weight of the seed, the seed enters the seed cleaning the seed cleaning operation is completed, the seed cleaning valve is closed. At the same time, the program controls the seed filling cylinder to open, and the seeds in the next plot enter the seed filling area, which meets the requirement that the breeding interval cannot be mixed.

Yan Bingxin et al[12]designed an air-suction corn seed-metering device without relative motion between the negative pressure chamber seal and the seed-metering plate, aiming at the problem of wear caused by the relative motion between the negative pressure chamber seal and the seed-metering plate. At the same time, the seed plate circumferential uniform linear strip boss disturbing mechanism reduces the resistance of seed filling. Ding Li et al.[13]analyzed and designed four kinds of seed trays with auxiliary filling effect through EDEM simulation method, and carried out orthogonal test with pressure, seed tray speed and seed tray type as experimental factors. Through the analysis of the test results, it was found that the seed tray with type hole convex platform had the best auxiliary filling performance, which improved the problems of large wind pressure demand, poor filling effect and serious missing sowing of air-suction corn precision seed metering device at high speed.

Air-suction rice seedmetering device

Wei Haiminget al.[14]designed a kind of air-suction vertical disc precision seed-metering device according to the operation demand of rice direct seeding machine. The suction hole of seed-metering disc was arranged in arc shape, and the value range of suction hole diameter was determined by theoretical calculation. The influence of different apertures on the seeding effect was studied by single factor test, and the suction hole diameter was finally determined to be 1.4 mm. Hou Chong et al.[15]designed an air-suction plate seed-metering device for seeding super rice. The seed-metering device is mainly composed of a seed-suction plate, a seed-box moving device, and a sub-airway combined gas chamber. The filling and seeding of the seed-metering device are realized by the reciprocating flip of the seed-suction plate and the movement of the seed-box. The gas chamber is connected by 8 transverse airways and 2 longitudinal airways, and is sealed with the suction plate to make the pressure uniformity in the gas chamber better. The vibrator installed at the bottom of the seed box produces vibration and improves the filling performance.

Air-suction potato seed metering device

LvQingjinet al.[16]developed a pneumatic precision planter for the problems of slow operation speed, low sowing accuracy and high replay rate of traditional potato planter, and designed an air-suction multi-arm uniform seed metering device. The structure of the metering device includes suction nozzle, suction arm, suction pipe interface, blow pipe interface, valve, static shaft, pressing spring, seed box, etc. the side wall of the valve body is pressed by pressing spring to ensure the air tightness of the metering device ; the suction wall is connected to the through hole of the exhaust valve, and the negative pressure is formed under the action of the fan. The seed is adsorbed by the suction nozzle at the end of the suction wall. The air-suction disc-type miniature potato seed metering device designed by Lai Qinghuiet al.[17]is designed by combining the working principle of vibration seed supply and negative pressure seed suction, which is mainly composed of pneumatic seed metering mechanism and vibration seed supply mechanism. After the micro potato enters the vibrating plate, the vibration makes the population 'boiling ', which improves the seed absorption performance of the metering device. Through the damage test, it was found that the damage rate of micro potato was less than 1 % under different vibration frequencies, and the vibration mechanism had little damage to the micro potato.

Performance analysis of air-suction metering device

The performance of the air-suction seed metering device is related to many factors, including the working parameters such as the rotation speed of the seed plate, the vacuum degree of the air chamber, the height of the seed, the structural parameters such as the diameter and shape of the suction hole of the seed plate, the physical characteristics of the seed machine and the working environment. Chinese scholars have done a lot of theoretical analysis and experiments to study the impact of different factors on the air-suction metering quality. Li Lin[18]analyzed the vertical disc air-suction metering device, deduced the formula to determine the vacuum degree of the suction chamber, and analyzed the factors affecting the vacuum degree of the suction chamber through preliminary experiments, which provided a basis for the design of vertical disc air-suction metering device. Zhang Jianping and Li Feixiong[19] studied the influence of parameters such as seeding height, seeding angle, seeding radius and number of suction holes on seeding uniformity through Monte Carlo method. The simulation test results show that the larger the casting angle is, the better the seeding uniformity is. The reasonable increase of casting radius is beneficial to improve the seeding uniformity, and the higher the casting height is, the worse the seeding uniformity is.

Wang Yanyao et al[20]designed a quadratic regression orthogonal rotation test, and selected three factors : the rotation speed of the seeding plate, the diameter of the suction hole of the seeding plate and the pressure of the air chamber. The qualified rate and the leakage rate were used as the performance indicators to test the performance of the air-suction corn seed metering device. Feng Zhaohua et al[21]conducted experiments with vacuum degree, suction hole diameter, and operating speed as test factors, tested the effects of these factors on seeding quality, and determined the best parameter combination for seeding quality. Zhao Xiaoshun et al.[22]designed three groups of single factor experiments with dropping height, working speed and vacuum degree as experimental factors to verify the influence of different factors on the performance of air-suction corn seed-metering device, and obtained the level value of each factor when the seeding performance was the best; Mu Zhongqiu et al.[23]designed orthogonal tests based on the results of single factor tests to study the primary and secondary relationship of these three factors affecting seeding performance. Through variance analysis of the test results, it was found that vacuum degree was the main influencing factor. In order to study the factors affecting the seeding performance of air-suction corn seed metering device, Gao Fuqianget al.[24]firstly analyzed and calculated the suction hole diameter, vacuum degree and rotation speed of seeding plate theoretically. Through single factor test, it was determined that the seeding effect was the best when the diameter of the suction hole was 5.5 mm, and the orthogonal test was designed with the and vacuum degree of the seeding disc as the factors. The test results showed that the rotation speed and vacuum degree of the seed metering device

had a significant effect on the performance of the seed metering device.

Effect of seed guiding device on seeding performance

Li Bohai et al.[25]studied the seeding performance of the air-suction corn seed metering device. The motion state of the seed in the seed tube at different speeds of the seed metering device was simulated, and the motion trajectory curve and equation of the seed were drawn and calculated by software. The horizontal and vertical displacements of seeds at different rotational speeds were obtained by experiments, and the dropping trajectory curve and equation were obtained by software. It is found that the horizontal offset and landing speed of the seeds will increase with the increase of the rotation speed of the metering device. Chen Xuegeng et al. [26] designed a belt seed guide device, and selected the rotation speed of the seed plate, the pressure of the air chamber, and the height of the seed point as the factors to design a three-factor four-level orthogonal test. Through the analysis of variance of the experimental results, it was found that the height of the seed point had the greatest influence on the qualified rate of the seed spacing. The seed guide device can adjust the height of the seed point to improve the qualified rate of the seed spacing. Kang Jianminget al.[27]designed a belt seed guide device based on the principle of ' zero speed seed throwing ', and studied the influence of seed plate speed, negative pressure chamber pressure and belt seed guide device dial spacing on the uniformity of air suction seed metering device through experiments. The test results show that the dial spacing is the main factor affecting the qualified rate of plant spacing.

Simulation study on filling performance of seed metering device

Many domestic scholars use finite element software to simulate the structure and internal fluency of the seed metering device to study the filling performance of the seed metering device. Chen Jinet al.[28]studied the influence of the suction hole size, shape and lead of the seed metering device on the suction effect by ANSYS simulation. The simulation results show that the shape and aperture have a greater influence on the suction effect, and the lead has less influence. The effects of suction hole shape and aperture were analyzed by single factor experiment. The results showed that the larger the suction hole diameter, the better the suction effect. The effect of conical hole is better than that of straight hole and sinking hole. Whether the automatic breeding equipment is successfully seeded or not has a great relationship with the adsorption performance of the air suction seeder. Xu Hui et al.[29]used ANSYS software to simulate and analyze the factors affecting the adsorption performance, and tested with soybean as the object. It was found that the aperture of the nozzle and the distance from the seed to the nozzle had a significant effect on the adsorption performance. Li Yaoming et al[30]used Fluent software to analyze the influence of suction pressure difference and pore size on the seed adsorption capacity of the seed plate with conical hole, straight hole and sink hole. It was found that the effective suction space and suction displacement of conical hole were the largest, and increasing the pressure difference and pore size could enhance the suction capacity.

Shi Song et al.[31]aimed at the problem of poor seed filling performance of the seed metering device in the case of high-speed operation of the air-suction seeder, the EDEM-CFD coupling method based on the type hole pressure gradient force was used to analyze the various stages of the seed filling process, and it was found that the curvature coefficient, the inclination angle and the depth of the seed guide groove of the seeding plate were the main factors affecting the seed filling effect. Through the design simulation test and multi-objective optimization analysis, the optimal combination of seed-guiding groove parameters was determined : slope angle 15.33 °, seed-guiding groove depth 2.57 mm, curvature coefficient 0.265. Yan Bingxinet al.[32] explored the effect of gravity on the filling performance of the seed metering device by taking the disc chamber synchronous air suction precision seed metering device as the object. Through the analysis of the force of corn seeds in the filling process, it is concluded that the radial force of the seed to be filled has an auxiliary effect on the filling process. Gravity - assisted filling can reduce the air pressure required for seeding operation and improve the quality of operation. Lai Qinghuiet al.[33] used the DEM-CFD coupling method to study the effects of vibration frequency, vibration angle and blowing air pressure on the filling performance of the air-suction drum seed metering device with Sanchi seeds as the research object. It was found that the appropriate vibration angle and the appropriate increase of vibration frequency and wind pressure were beneficial to improve the filling performance. Zhang Kunet al.[34]studied the effects of vibration frequency, vibration angle and seed layer height on the seed filling performance of seed metering device through EDEM simulation. The results showed that the increase of seed layer height could reduce the leakage rate, and the increase of vibration frequency would increase the population disturbance. The vibration angle could change the seed supply height, and the appropriate vibration angle would increase the seed supply height.

Effect of Vibration on Performance of Seed Metering Device

During the operation of the seeder, the ground vibration will affect the performance of the seeder. Hu Yongwenet al.[35] studied the influence of no-tillage seeder on the performance of corn stubble ground excitation

through the vibration test bench. Through the analysis, it was found that the longitudinal vibration had the greatest influence on the performance of the metering device. Through the collection and analysis of vibration signal, working speed and acceleration, the regression equation of working speed, vibration frequency and acceleration was obtained. The range of vibration frequency was 0 ~ 68Hz, and the maximum acceleration of vibration was 25m/s^2. Dong Shuai et al.[36] used the acceleration sensor and the vibration test system to test the influence of vibration on the seeding performance at different operating speeds by single factor test. The vibration spectrum diagram at different speeds was obtained by Fourier transform of the collected time-domain signal. Through the spectrum diagram, it was found that the main frequency range of vibration during seeding operation was 40 ~ 55 Hz.When the speed was 3.6 km/h, the main frequency of vibration was the smallest.

Performancetest system of seed metering device

In recent years, high-speed camera, computer vision, photoelectric sensor and other technologies have been used in the seed metering device detection system to improve the detection efficiency. Li Fengliet al.[37] observed and analyzed the working process of the seed metering device and the adsorption posture of sunflower seeds in the seed metering device by using high-speed camera technology to shoot dynamic images. It was found that when the filling amount in the seed chamber was 50%, the stirring effect was the best. The more stable adsorption attitude is that sunflower seeds are arranged longitudinally along the center of the seeding plate. Yuan Mingyueet al.[38] found three kinds of seed adsorption postures of rice seeds in the air-suction metering device through high-speed camera technology. The analysis found that the best posture was that the seeds were adsorbed along the long axis. The air chamber pressure and the number of suction holes were the main factors affecting the adsorption posture, but the process of seed filling and clearing was not analyzed. Jia Hongleiet al.[39] designed a seed metering device suction performance detection system. The system consists of photoelectric sensors and rotary encoders. The signal processing collected by the host computer is used to analyze the adsorption of seeds in the seed metering device. The re-absorption is judged by whether the pulse width of the sensor detection signal is greater than 1.5 times the average width; By detecting whether there is a seed passing through the encoder within nine pulse times to determine whether the suction is missed, and based on the encoder, the suction hole is marked to determine the position of the suction hole that is missed or reabsorbed.

II. Conclusion

From the information available, the domestic research on air-suction metering device is more in-depth. The following conclusions can be drawn from the development status of domestic air suction seed metering device, the performance analysis and detection process of seed metering device :

(1) The application of air-suction seeder is very extensive in China.Many kinds of air-suction metering devices for different crops, such as corn, soybean, rice and potato, have been developed. But in contrast, maize and soybean use more air-suction sowing, and the research on air-suction maize and soybean seed metering device is relatively perfect;

(2) In the research and design of the seed metering device, the discrete element method is widely used in the simulation and optimization design of the seeding monomer structure. The combination of simulation analysis and experiment greatly shortens the design and test cycle of the seed metering device and reduces the cost;

(3) At present, in addition to using the seed metering device test bench for manual testing, high-speed camera technology, photoelectric sensor and other technologies are gradually applied to the performance testing of the seed metering device;

(4) The factors that affect the performance of air-suction seed-metering device can be divided into several aspects : the structural parameters of the seed-metering device itself, the working parameters in the seeding process and the working environment.

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