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Original scientific paper

Control Mechanism and Experimental Study on Electric Drive Seed Metering Device of Air Suction Seeder

Shouhua REN, Shujuan YI*

Abstract: Under the condition of high-speed operation, the traditional mechanical seeder is easy to cause problems such as the drop of the qualified rate of sowing, the increase in the rate of missing sowing and the low precision of adjusting the grain distance, which seriously affects the sowing precision and efficiency. In this paper, a brushless DC motor sliding film variable structure control system is designed for the air-suction corn seeder, so as to realize the precise control of the rotation speed and the seed metering amount of the seed metering disc. The experimental results show that the faster the operation speed of the electrically driven air-suction seed metering device, the greater the standard deviation of sowing distance. The qualified rate of seeding, average spacing, standard deviation distribution and coefficient of variation of the electric seeding device are better than those of the mechanical seeding device.

Keywords: electrically driven seed metering device; permanent magnet brushless DC motor; PWM speed regulation; sliding mode variable structure control system

1 INTRODUCTION

Sowing is the key link of corn planting and production, and its operation efficiency and quality directly affect the growth and yield of corn, which is very important in the process of agricultural mechanization production. Precision sowing technology is beneficial to realize single seed sowing, improve the uniformity of planting distance and the utilization rate of water, fertilizer, light and heat, and achieve the purpose of saving cost and increasing income, which has become the main development direction of crop sowing [1]. Seeder is an important equipment to ensure sowing density and uniformity, and its driving mode and structure design are the key to ensure sowing performance. Traditional mechanical seeders operate through land wheel and chain to drive, which has the advantages of low cost and easy processing. However, the increase in slip rate caused by land wheel slipped and chain to jump is inevitable under high-speed operation conditions, which leads to the decrease of seeding qualified rate and the increase in missed seeding rate [2-5]. Therefore, using motor drives technology and modern control technology to change the driving mode of seed metering device and overcome the disadvantage of high slip rate of traditional mechanical seed metering device has important application value for realizing high-speed precision sowing and improving agricultural production efficiency, and is of great significance of promoting the sustainable development of corn precision sowing technology.

The controllable power unit drives the seed metering device to run smoothly and the rotating speed is easy to control [6], which provides ideas of solving the problems existing on the traditional mechanical seed metering device. How to improve the performance of seed metering device by using electric control seeding technology has become an important research content of precision seeding. The research and application of electric control seeding technology abroad is earlier. For example, Kinze Manufacturing Company of the United States designed an electric drive seed metering device instead of mechanical transmission system, which simplified the structure of seeder, realized independent control of seeding situation, and did not need to maintain the traditional system [7]. Case Corp [8] and John Deer Company [9] of the United States respectively use mechanical electronic control stepless speed variator and change hydraulic proportional valve to replace the traditional mechanical speed, so as to realize stepless adjustment of sowing actuator and control sowing distance and sowing amount. At present, a large number of explorations have been carried out on electronically controlled seeding technology in China. Shi Linrong [10] et al. designed an electric-driven direct-insertion holed seeder aiming at the defects of mechanized sowing with corn. The experiment shows that the forward speed compensation mechanism of the seeder runs smoothly, the horizontal displacement difference between the entry and exit of the hole seeder is almost zero, and the qualified rate of the sowing depth of the hole seeder is high, which improves the mechanization degree of seed production corn sowing. Wu Nan [11] et al. studied an automatic compensation system for missing sowing, and realized the control of seed spacing and operation speed by designing sliding mode variable structure controller. The system solved the problem of missing sowing with the operation process of no-tillage planter, completed the reseeding operation quickly and accurately, and effectively improved the sowing quality of no-tillage planter. Zhao Xue [12] et al. developed an intelligent electronic control system of air-suction corn seed metering device to solve the problems of ground wheel slippage, synchronous operation of seed metering device and low operation efficiency in the operation process of traditional corn seeder, which realized the functions of speed adjustment of seed metering drive motor, independent operation of seed metering device, intelligent control of seeding unit and seeding monitoring alarm, etc. Experiments show that the system improves seeding efficiency and quality. Zhang Chunling [13] et al. studied the electronically controlled corn seed metering system, and proposed to use genetic algorithm for PID parameter tuning. The system uses radar to detect the operation speed and encoder to detect the motor speed, and the controller realizes the optimal control of the speed. The test shows that the qualified rate of grain spacing and the precision of seed metering system are obviously superior to those of the traditional corn seed metering device.

To sum up, the electric-driven seeding technology abroad is more mature than that in China, but the price is high, which does not conform to the domestic production reality. However, most domestic researches are still in the experimental stage, and although the seeding uniformity has been improved to some extent, most seeding control systems have not realized the independent control of the seed metering device, and the operation cost is high, which makes it difficult to achieve the agricultural development goal of saving costs and increasing income. In view of the above shortcomings, this paper studies an electro-driven seed metering control system of air-suction corn seeder. In order to improve the control performance of air-suction electric-driven seed metering device, permanent magnet brushless DC motor with large starting torque, good braking performance and strong overload capacity is selected as the driving unit and the corresponding mathematical model is established. Sliding mode variable structure control strategy is adopted to accurately control the air-suction seed metering device. Simulation experiments prove that the control system has the characteristics of good robustness, strong anti-interference and fast response, and can be accurately controlled.

2 CONTROL SYSTEM FOR ELECTRICALLY DRIVEN SEED METERING DEVICE

2.1 Structure and Principle of Control System of Electric Driven Seed Metering Device

In this system, STC12C516AD is used as the main controller, and the industrial controller is used as the upper computer for man-machine interaction, displaying information such as planting distance and equipment parameters, and adjusting parameters. The upper computer is connected with GPS receiving antenna, analyzing the data signal of GPS receiver for collecting the tractor's forward speed, and the user outputs PWM control signal through the timer of handheld terminal equipment to control the DC brushless motor, thereby adjusting the motor speed. According to the requirements of data transmission quantity and processing speed of the system, this design chooses STC12C516AD MCU produced by Hongjing Technology Company as the main control chip. Its main functions include detecting the working state of the frame, receiving the locomotive running speed signal sent by the upper computer, digitally filtering the speed signal, realizing the control algorithm, outputting the electric drive control signal, etc. Its functional block diagram is shown in Fig. 1.

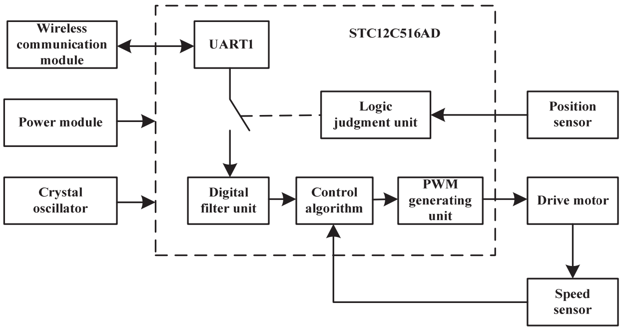

Figure 1 Functional block diagram of lower computer system

2.2 Software Design of Control System

2.2.1 Client Monitoring System

C# language is used as the foreground development tool in the design of industrial computer software, SQL Server is used for background database management, and an electrically driven seeding monitoring system is developed based on C/S mode. The main page of monitoring system platform includes function modules such as setting page, display main interface and statistics management page, as shown in Fig. 2 and Fig. 3. The setting page realizes the setting of operation parameters and mechanical parameters. The system realizes the real-time collection of seed fertilizer data of the seeder, can monitor the empty blockage of fertilizer box, fertilizer pipe, seed box, seed pipe and other equipment, and send abnormal information instructions to the upper computer in time and give an alarm.

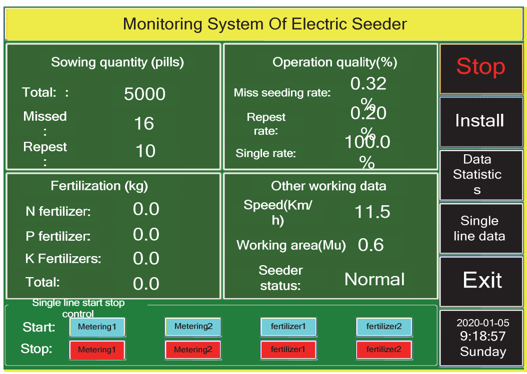

Figure 2 Operation interface of client monitoring system

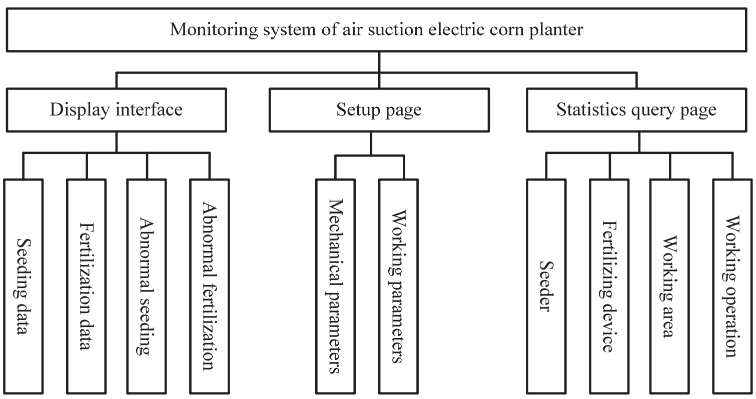

Figure 3 Function module of monitoring system for electrically driven seed metering device

2.2.2 Mobile Terminal APP

The design principle of man-machine interaction interface on Android is simple and easy to understand. The interface of Genymotion simulation software is shown in Fig. 4. Three text boxes in the left column are used to input the transmission ratio, the number of holes in the seeding tray, and the planting distance. After the input is completed, click the setting button, and the parameter information will be transmitted to the main controller. After the setting is successful, the right column will receive the current transmission ratio, the number of holes in the seeding tray, and the planting distance information returned by the main controller.

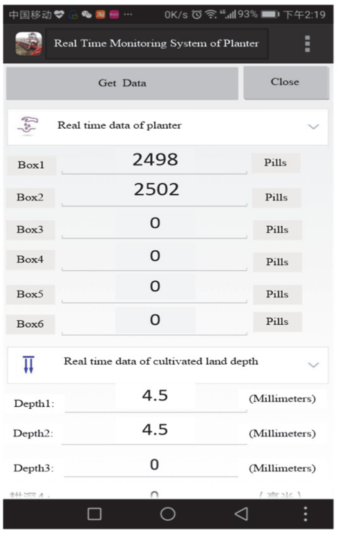

Figure 4 Config APP of seeding parameters

3 MODELING AND SIMULATION OF CONTROL SYSTEM OF ELECTRIC DRIVE SEED METERING DEVICE

3.1 Mathematical Model of Speed Closed Loop Control DC Speed Regulation System

Using S-function modeling method, the mathematical model of permanent magnet brushless DC motor body model is established (as shown in Fig. 5), and the rotational speed signal generated when the motor rotates is led back to the controller, that is, the DC speed regulation system with closed-loop control of rotational speed is constructed, and the motor closed-loop control system model based on rotational speed detection is established.

The ontology model of permanent magnet brushless DC motor is mainly composed of four functional modules [14]:

- Input module: winding phase voltage (U_a, U_b, U_c), rotor position signal (pos) and load torque (T_L) of permanent magnet brushless DC motor.
- Output module: stator current (I_a, I_b, I_c), back electromotive force (e_a, e_b, e_c), angular velocity (ω), motor angle (Theta), etc.
- Parameter calculation and conversion module: speed calculation, torque calculation, flux linkage calculation and rotor position interval calculation; The conversion module mainly includes voltage conversion and current conversion.
- User-defined modules: phase resistance (R), moment of inertia (J), polar logarithm (P), etc.

The meaning of each quantity in the dynamic structure block diagram of closed-loop DC speed regulation system is shown in Tab. 1:

Table 1 Control parameters of closed-loop DC speed regulation system

Symbol	Explain
U_n^*	Given voltage
U_i^*	Output voltage of ASR
U_{ct}	Control voltage of thyristor rectifier
U_d	Output voltage of thyristor rectifier
i_{dL}	Load current
α	Speed feedback coefficient
β	Current feedback coefficient

The rectifier is caused by the runaway of thyristor rectifier between two natural commutation points. In practical engineering calculation, it is generally calculated according to the first-order inertia link, and its transfer function is [15]:

$$F(s) = \frac{K_s}{T_s \cdot s + 1} \tag{1}$$

K_s - amplification coefficient of thyristor rectifier
T_s - delay time caused by thyristor commutation.

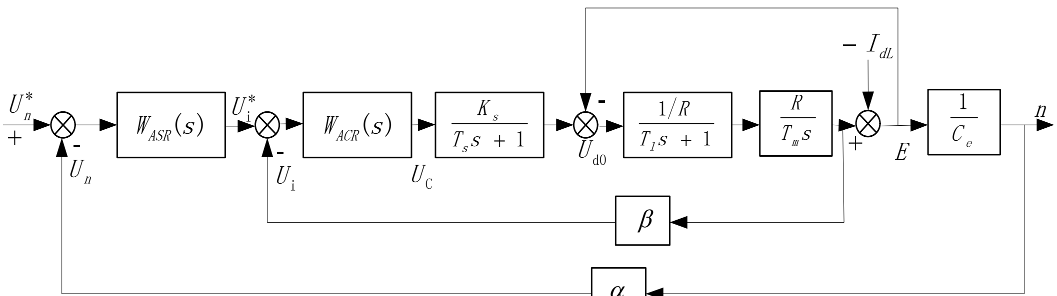

Figure 5 Dynamic structure diagram of closed loop DC speed regulation system

The transfer function of armature part of DC motor can be equivalent to:

$$F_a(s) = \frac{I_a(s)}{U_M(s) - E_M(s)} = \frac{K_a}{1 + t_s \cdot s} \tag{2}$$

$$F_M(s) = \frac{n(s)}{T_M(s) - T_L(s)} = \frac{1}{t_M \cdot s} \tag{3}$$

K_a - Magnification factor of armature circuit.

3.2 Simulation of Running State of Sliding Mode Variable Structure Control System for Brushless DC Motor

Use Matlb/Simulink software to establish a brushless DC motor sliding mode variable structure control system simulation diagram, as shown in Fig. 6. Simulation system modules mainly include motor system modules, sliding mode observer modules, speed control modules, current control modules and other auxiliary modules.

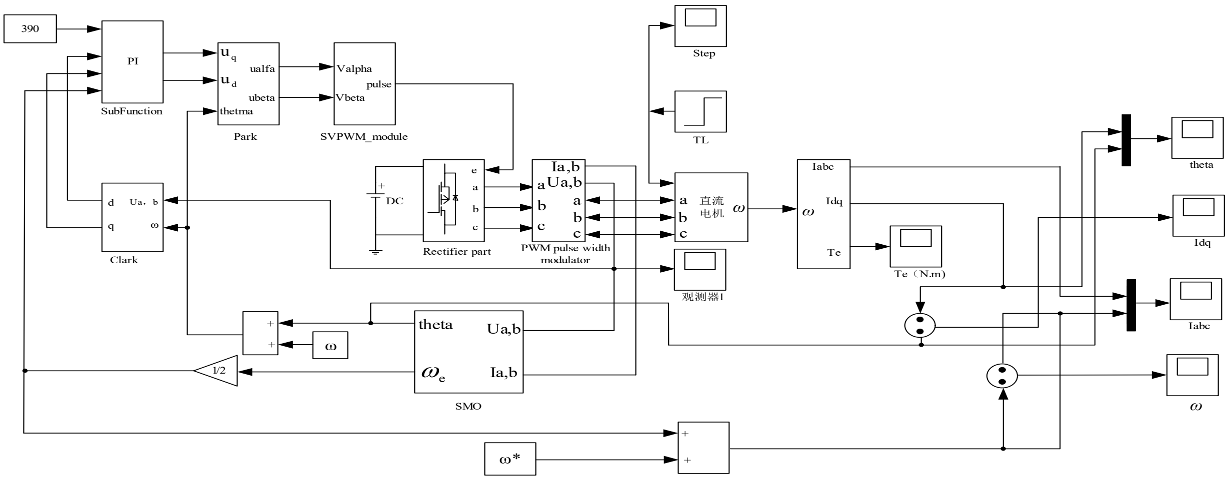

Figure 6 Simulation model of the position sensorless control system for permanent magnet brushless DC motor based on sliding mode observer

The stability and effectiveness of the sliding film variable structure control system of the seed metering drive motor are analyzed, and the running effect of the system is observed. The measured parameters of TS37GB3625 permanent magnet brushless DC motor selected in this study are shown in Tab. 2.

Table 2 Motor simulation parameter table

Parameters of TS37GB3625 motor	Value
Switching frequency	10 kHz
Magnetic linkage ψ_f	0.17 Wb
Stator resistance R	2.62 Ω
Stator inductance L	8.0 mH
Number of pole-pairs p	4
Rotary inertia J	0.001 kg·m^2

Test the startup time and anti-disturbance performance of the control system. The simulated seeder runs at the maximum speed of 16 km/h, with the minimum distance of 15 cm and the maximum torque of 2 N·m. According to the gear ratio between the driving motor gear and the seed tray, it is calculated that the theoretical maximum speed of the brushless DC motor used in the electric driven seed metering device is 390 r/min. The response time and change curve of the control system when the load torque changes and the speed changes are simulated in MATLAB. At t = 0, the system starts the motor and adds a disturbance of 1 Nm in 0.06 s, and observes the change of the system speed, as shown in Fig. 7.

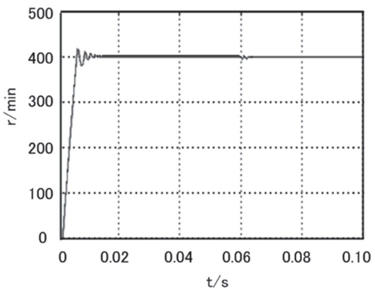

Figure 7 Simulation curve of start-up response time and anti-disturbance characteristics of brushless motor control system

It can be seen from Fig. 7 that after the system starts at t = 0, the motor speed reaches 400 r/min in 0.016 s and keeps stable operation. At 0.06 s, a disturbance of 1 N·m was added, and the rotating speed fluctuated at 4003 r/min for 0.004 s, and the rotating speed of the motor was stable at 400 r/min. It shows that the system has strong anti-interference.

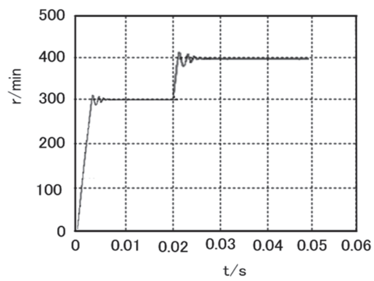

Figure 8 The simulation diagram of the motor in the state of acceleration and deceleration

Observe the response of the motor after the control system sends out the shift command, as shown in Fig. 8. The motor reaches a stable speed 0.005 s after starting, and it is observed that the motor speed increases from 300 r/min to 400 r/min, and the system response time is 0.005 s; The motor decelerates from 400 r/min to 300 r/min, and the system response time is 0.005 s; It can be seen from the simulation diagram that the sliding-film variable-structure motor control system controlled by saturation function has short response time and good anti-interference ability to external disturbances. The values of current and voltage observed by the system meet the design requirements, and the system has strong robustness.

4 FIELD SEEDING PERFORMANCE TEST OF ELECTRICALLY DRIVEN SEED METERING DEVICE

4.1 Test Materials and Equipment

In order to verify the reliability of the air-suction electric-driven seed metering device designed in this paper, a comparative test was conducted between the common mechanical transmission air-suction seed metering device and the electric-driven air-suction seed metering device, focusing on the qualification rate of the two seed metering devices at different operating speeds and different operating plant distances. The field seeding performance test of the electrically driven seed metering device is arranged as follows:

- Test time: April 28 to May 4, 2018.
- Test site: Agricultural machinery test field of Wodi Machinery Co., Ltd., Yanjiang Township, Jiamusi, Heilongjiang Province (Fig. 9).
- Test equipment: DebonDawei 2BGM-2 2-row air suction no-tillage corn seeder (Fig. 10). The tractor is John Deere 6B-1404 agricultural tractor, and the seeder runs at a speed of 3.0 km/h - 12.0 km/h.
- Experimental materials: Tiannong No.9 corn seeds, with the size of 6000 seeds/bag, moisture content of 12.8%, and the seed size range: long axis is 11.00 - 12.50 mm, short axis is 6.00 - 7.50 mm, seed repose angle is 23.2, and it can be used at atmospheric temperature 19 - 23 °C and soil temperature 17 - 22 °C.

4.2 Test Data and Result Analysis

According to GB/T6973-2005 "Test Methods of Single-grain (Precision) Seeder" (National Bureau of Standards, 2005), the qualified index of grain distance, standard deviation and coefficient of variation were selected as the test indexes to carry out the field test of electric drive seed metering device.

Figure 9 Test site

According to the requirements of "Tiannongjiu" corn seed sowing, the planting distance was selected as cm in the experiment, and the sowing distance of two rows of planters was tested at 4 km/h (low speed), 8 km/h (medium speed) and 12 km/h (high speed), and the sowing distance of 30 seeds was selected as the measured value in each experiment. The sowing distance of 30 seeds between the electrically driven seed metering device and the mechanically driven seed metering device was measured and recorded in Tab. 3.

Figure 10 Field Test of Electric Drive Seed-metering Device

According to the measured data in Tab. 3, analyze the qualified rate of sowing distance between mechanically driven air-suction seed metering device and electrically driven air-suction seed metering device at different operation speeds:

- Under the condition of running at a constant speed of 4 km/h, the distribution of sowing distance is shown in Fig. 11 when the preset sowing distance is 25 cm. Electrically driven seed metering device: the average sowing distance is 25.0 cm, the average standard deviation is 0.39 cm, and the average coefficient of variation is 1.571%. There is no replay or missing sowing phenomenon. Mechanically driven seed metering device: the average sowing distance is 24.7 cm, the average standard deviation is 2.84 cm, and the average coefficient of variation is 11.50%. And the position of the mechanically driven seed metering device at the eighth seed and the previous seed is 11.8 cm, which is less than 50% of the standard sowing distance of 25 cm, which is regarded as one replay.

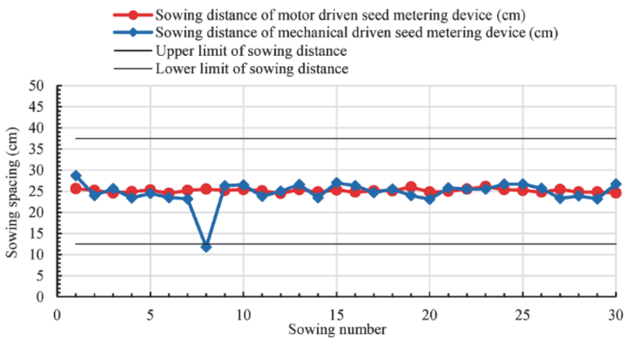

Figure 11 Comparison of sowing distance at 4 km/h

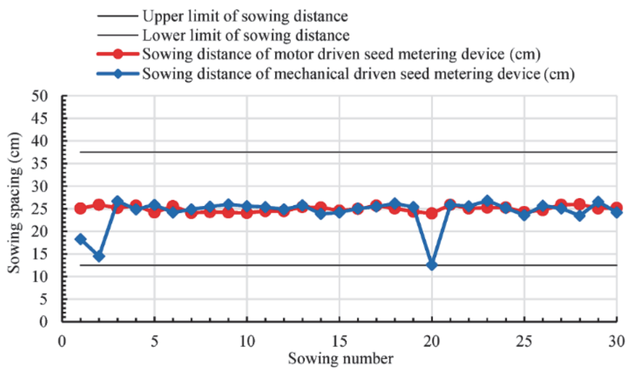

Figure 12 Comparison of sowing distance at 8 km/h

Table 3 Comparison data table of seeding spacing at different speeds of seeder

Speed of a motor vehicle --- Sowing serial number	4 km/h		8 km/h		12 km/h	
	Seed spacing of seed metering device driven by motor / cm	Seed spacing of mechanically driven seed metering device / cm	Seed spacing of seed metering device driven by motor / cm	Seed spacing of mechanically driven seed metering device / cm	Seed spacing of seed metering device driven by motor / cm	Seed spacing of mechanically driven seed metering device / cm
1	25.6	28.7	25.1	18.3	24.9	29.1
2	25.2	24.0	25.9	14.5	25.8	26.8
3	24.6	25.6	25.2	26.7	24.5	25.4
4	24.9	23.4	25.7	24.9	25.6	23.1
5	25.3	24.5	24.2	25.9	24.5	26.0
6	24.5	23.5	25.6	24.2	24.4	25.3
7	25.2	23.2	24.1	24.9	25.3	25.0
8	25.5	11.8	24.3	25.5	24.7	24.4
9	25.2	26.3	24.2	26.0	24.2	40.0
10	25.4	26.5	24.1	25.6	25.5	39.2
11	25.1	23.8	24.5	25.4	24.7	23.2
12	24.5	25.0	24.5	24.9	25.1	25.0
13	25.4	26.6	25.4	25.8	24.2	23.1
14	24.8	23.5	25.3	23.9	25.1	26.3
15	25.3	27.0	24.6	24.2	24.4	23.9
16	24.8	26.3	25.0	25.1	25.1	24.6
17	25.1	24.7	25.7	25.5	25.8	26.1
18	25.1	25.5	25.1	26.2	24.7	23.5
19	26.0	24.0	24.4	25.4	24.6	24.5
20	24.8	23.1	24.0	12.6	25.3	24.7
21	25.0	25.8	25.9	25.9	25.4	23.9
22	25.5	25.5	25.1	25.6	24.4	26.5
23	26.1	25.5	25.3	26.8	24.1	24.3
24	25.4	26.7	25.3	25.2	25.9	23.9
25	25.2	26.7	24.3	23.6	25.8	23.6
26	24.8	25.7	24.7	25.7	25.3	25.8
27	25.4	23.3	25.9	25.1	25.5	23.4
28	24.8	23.9	26.0	23.5	24.8	25.8
29	24.8	23.2	25.1	26.6	24.2	24.2
30	24.6	26.7	25.2	24.2	25.0	26.5
$\overline{L}$ / cm	25.1	24.7	25.0	24.3	25.0	25.9
S / cm	0.39	2.84	0.62	3.30	0.54	3.96
V	1.57%	11.50%	2.49%	13.59%	2.18%	15.29%

- Under the condition of running at a constant speed of 8km/h, the distribution of sowing distance is shown in Fig. 12 when the preset sowing distance is 25 cm. Electrically driven seed metering device: the average sowing distance is 25.0 cm, the average standard deviation is 0.62 cm, and the average coefficient of variation is 2.49%. There is no replay or missing sowing phenomenon; Mechanically driven seed metering device: the average sowing distance is 24.3 cm, the average standard deviation is 3.30 cm, and the average coefficient of variation is 13.59%. There is no phenomenon of repeated sowing and missed sowing.
- Under the condition of constant running speed of 12 km/h, the distribution of sowing distance is shown in Fig. 13 when the preset sowing distance is 25 cm. The average sowing distance is 25.0 cm, the average standard deviation is 0.54 cm, and the average coefficient of variation is 2.18%. There is no repeat or miss sowing. Mechanically driven seed metering device: the average sowing distance is 25.9 cm, the average standard deviation is 3.96 cm, and the average coefficient of variation is 15.29%. In addition, the distance between the 9th seed and the previous seed is 40 cm, and the position between the 10th seed and the previous seed is 39.2 cm, which is 50% greater than the standard sowing distance of 25 cm, and there are two missed sowings.

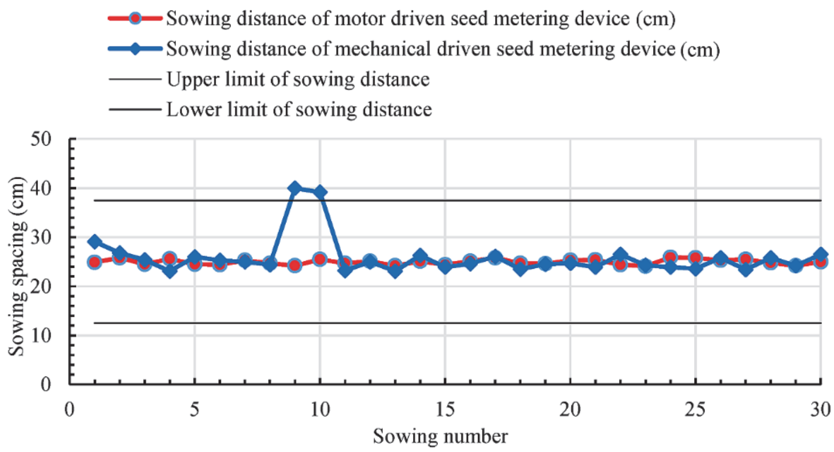

Figure 13 Comparison of sowing distance at 12 km/h

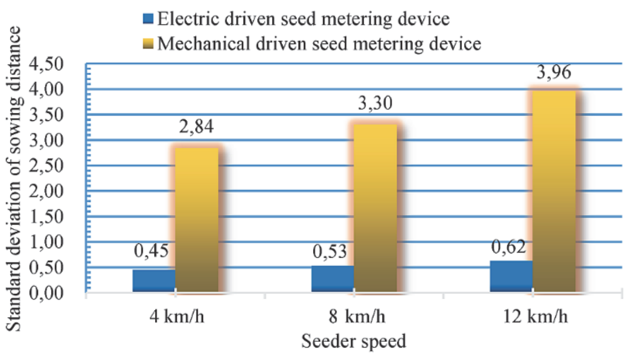

Figure 14 Distribution of standard deviation at different speeds

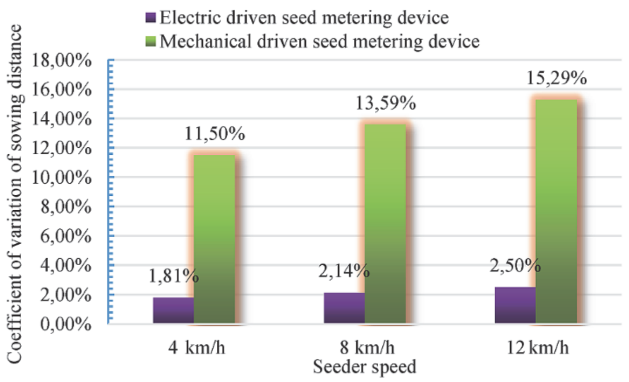

Figure 15 Distribution of coefficient of variation at different speeds

Fig. 14 and Fig. 15 show the standard deviation and coefficient of variation of the two control methods at different sowing speeds. It can be seen that the standard deviation of electric seeding device is between 0.45 - 0.62 and the average standard deviation is 0.53cm, while that of mechanical seeding device is between 2.84 - 3.96 and the average standard deviation is 3.37 cm, which indicates that the electric seeding device is obviously superior to the mechanical seeding device in the standard deviation of seeding distance. The variation coefficient of electric seeding device at different speeds is between 1.81 - 2.50%, and the average variation coefficient is 2.15%. The variation coefficient of mechanical seeding device is between 11.50 - 15.29%, and the average variation coefficient is 13.46%, and the variation coefficient increases with the increase of vehicle speed. From the data distribution range, the coefficient of variation of the electric seeding device is obviously smaller than that of the mechanical seeding device, and the seeding effect is better. The coefficient of variation increases with the increase of the running speed of the seeder, but the whole coefficient is within the qualified range.

5 CONCLUSION

The control system of air-suction electrically driven seed metering device based on sliding mode variable structure control algorithm is designed. The simulation results show that the system has short response time, strong robustness and anti-interference, and meets the design requirements. By establishing the sliding mode variable structure control model of the driving motor of the seed metering device, the influence of the slip of the ground wheel on the sowing operation is avoided, the potential of the high-speed operation of the seed metering device is further exerted, and the sowing operation quality is improved. By studying the requirements of corn field sowing, combining with relevant national standards and corn sowing specifications, referring to GB/T6973-2005 "Test Method of Single Seed (Precision) Seeder" as the basis, selecting the qualified index of grain spacing, standard deviation and coefficient of variation as test indexes, measuring the spacing distance of 30 seeds of the seeder at different forward speeds of 4 km/h, 8 km/h and 12 km/h. The experimental results show that when the plant spacing is 25 cm, and the operating speed is 4 km/h, 8 km/h and 12 km/h, the measured sowing distance of the electrically driven air-suction seed metering device is between 24.1 cm and 25.9 cm, and there is no replay or missing sowing. The measured sowing distance of the mechanical seed metering device is between 11.8 cm and 40.0 cm, with one repeat and two missed sowing. The qualified rate, average spacing, standard deviation distribution and coefficient of variation of electric seed metering device are better than those of mechanical seed metering device.

The system improves the operation efficiency of the seeder, and is of great significance to improve the agricultural modernization level and crop yield in China. However, the system needs to be further improved in servo control and false alarm rate.

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Contact information:

Shouhua REN
College of Engineering,
Heilongjiang Bayi Agricultural University,
5 Xin Feng Street Gao Xin District,
163319 Daqing Heilongjiang, China

Shujuan YI
(Corresponding author)
College of Engineering,
Heilongjiang Bayi Agricultural University,
5 Xin Feng Street Gao Xin District,
163319 Daqing Heilongjiang, China
E-mail: yishujuan_2005@yeah.net