DESIGN OF CONTROL SYSTEM OF SEED METERING DEVICE TEST-BED BASED ON FUZZY PID
/
基于模糊 PID 的排种器试验台控制系统设计

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ABSTRACT

In order to better detect the working parameters of the seed metering device and further improve the performance of the seed metering device, a set of test-bed control system of seed metering device based on fuzzy PID was designed. The PID parameters are mainly used for on-line fuzzy self-tuning to realize the dynamic adjustment of the speed of the seed metering shaft, so as to ensure the fast adjustment of the speed of the seed metering device. Through the simulation of conventional PID control and fuzzy PID control by MATLAB, the response curve of the control system is obtained. From the response curve, it can be seen that the step response time of fuzzy PID control is about 0.15 s, which is much higher than that of conventional PID control, and the work is stable and there is no overshoot. The bench test is carried out in the laboratory and the fuzzy PID control system is applied to the test-bed, and the actual speed regulation effect of the motor and the performance indexes of the seed metering device test-bed are obtained. The bench test shows that when the fuzzy control system is used to carry out the seed metering device test on the test bench, the qualified grain distance index of the seed metering device is maintained above 91%, the coefficient of variation of the qualified grain distance is less than 4%, the missing sowing index is less than 7%, and the replay index is less than 5%. All meet the national standard requirements of single-grain precision seed metering device.

摘 要

为了更好地实现对排种器的工作参数进行检测，进一步提高排种器性能，设计了一套基于模糊 PID 的排种器试验台控制系统。主要应用 PID 参数进行在线模糊自整定实现排种轴转速的动态调节，从而保证排种器转速的快速调节。通过 matlab 对常规 PID 控制与模糊 PID 控制进行仿真，得到控制系统的响应曲线，由响应曲线可以看出，模糊 PID 控制的阶跃响应时间约为 0.15s，较常规 PID 控制有较大幅度提升，且工作稳定，无超调量。在室内进行台架试验并将模糊 PID 控制系统应用在试验台上，得到电机实际调速效果以及排种器试验台的各项性能指标。台架试验表明，应用模糊控制系统在试验台上进行排种器试验时，排种器的合格粒距指数均维持在 91%以上，合格粒距变异系数在 4%以下，漏播指数在 7%以下，重播指数在 5%以下，均符合单粒精密排种器的国标要求。

INTRODUCTION

The seed metering device is the core component of the planter, and its performance testing is very important to improve the manufacturing, use, scientific research and development level of the planter *(Li M.S., et al, 2018)*. As an important platform for the research and development of high-performance seeder, the seed metering performance test-bed can simulate different speeds without the restrictions of location, environment and season, improve the efficiency and economy of the test, and shorten the research and development cycle. In the process of actual operation, the qualified grain distance of the seeder cannot be guaranteed in the process of starting and changing speed, and the waste of seeds is serious, so the time of starting process should be shortened as far as possible to reduce the waste of seeds. Therefore, it is very necessary to develop a set of control system of seed metering test-bed with fast response, small overshoot and stable operation.

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Many Chinese scholars have done a lot of research on the application of PID control in agricultural machinery *(Chen M. et al, 2016; Chen M. et al. 2016; Ren L. et al. 2020; Lv H.T. et al, 2021; Hao X.Z., 2017; Wang Q. et al. 2013)*. In order to solve the problem of the decline of sowing quality caused by the skidding of ground wheel, Zhao Xiaoshun designed an electronically controlled precision sowing system, which shortened the response time of the system and improved the control precision *(Zhao X.S. et al, 2021)*.

Zhang Chunling designed the electronically controlled corn metering system, established the corresponding transfer function and Simulink model, and designed the PID parameters and controller based on genetic algorithm, which improved the seeding quality *(Zhang C.L. et al,2017)*. In order to realize winter wheat real-time variable topdressing, Chen Man studied the real-time adjustment algorithm of variable topdressing machine based on fuzzy PID, and realized the optimal control of topdressing amount *(Chen M., et al, 2016)*. Ding Youchun designed a small tracked rape seeder navigation controller based on immune PID, which uses Beidou positioning module and electronic compass to realize the navigation control of the seeder. The conventional PID control and immune PID control are compared by MATLAB simulation and field experiments *(Ding Y.C. et al,2019)*. Shao Ruina analyzed and studied the STB-700 seed metering device test-bed, established its mathematical model by MATLAB/Simulink, carried out modeling and simulation analysis by using PID control, and obtained the best parameter index of the test-bed *(Shao R.N., 2013)*.

Scholars outside China have also done a lot of research *(Cay Anil et al, 2018; Mander Guneet et al, 2014; Nielsen S.Ã. et al, 2016)*. Zhang Shuai aiming at the deficiency of traditional PID control, a fuzzy adaptive PID controller is established on the basis of traditional PID controller. The design of fuzzy PID controller is discussed in detail, and the dynamic response curves of traditional PID controller and fuzzy PID controller are given *(Zhang S. et al, 2017)*.

Satyam Paul applied the fuzzy PID controller to the vibration control of agricultural manipulators to improve the effect of vibration suppression *(Satyam Paul, et al, 2020)*. Anil Cay and others use Arduino as the controller, use photoelectric sensors to detect the seed spacing, and carry out experiments on seeds with different physical characteristics in the laboratory to verify the success of the system *(Cay Anil et al, 2017)*. Wen Yan et al. combines fuzzy reasoning with neural network analysis and training, and designs an automatic control algorithm based on fuzzy neural network. The algorithm has good versatility and expansibility *(Wen Y. et al, 2022)*.

Mohammed Rabah applies fuzzy PID control algorithm to the trajectory tracking of quad vehicle, and compares it with PD controller and fuzzy logic controller by MATLAB/Simulink *(Mohammed Rabah et al, 2018)*.

In a word, scholars at home and abroad have done more research on PID control, and applied it to the field of agricultural machinery production, but most of them focus on specific machines and tools, and there are few applications in the control of indoor test-bed. In view of the above problems, a fuzzy PID control system of the seed metering performance test-bed is designed to ensure the speed and stability of the motor speed regulation, reduce the deviation of the motor speed regulation, and improve the control accuracy of the test-bed.

MATERIALS AND METHODS

The overall design of the control system of the seed metering device test-bed

- **System structure and working principle**

The test-bed is mainly composed of conveyor belt conveying device, seed metering device driving device, sensor detection device, hydraulic oil coating system and core controller. The photoelectric sensor and the speed sensor transmit the signal to the single-chip microcomputer, which displays the data on the monitoring interface, and the operator sends out instructions through the monitoring interface to control the seeding shaft, conveyor belt, fan and solenoid valve to work.

The conveyor belt conveyor is located at the bottom of the test-bed and is mainly used for fixing and observing under the seeds. The sensor detection device is mainly realized by encoder, flow sensor and photoelectric sensor, which is used to detect the speed of seed metering device, conveyor belt speed, fan speed and hydraulic oil flow. The driving device of the seed metering device is installed above the conveying device of the conveyor belt. The hydraulic oil coating system is realized by the hydraulic valve, the hydraulic oil is transported to the conveyor belt through the oil discharge hole, and the gap between the oil scraper and the conveyor belt is adjusted by the screw to control the thickness of the hydraulic oil film.

The overall structure of the test-bed is shown in figure 1.

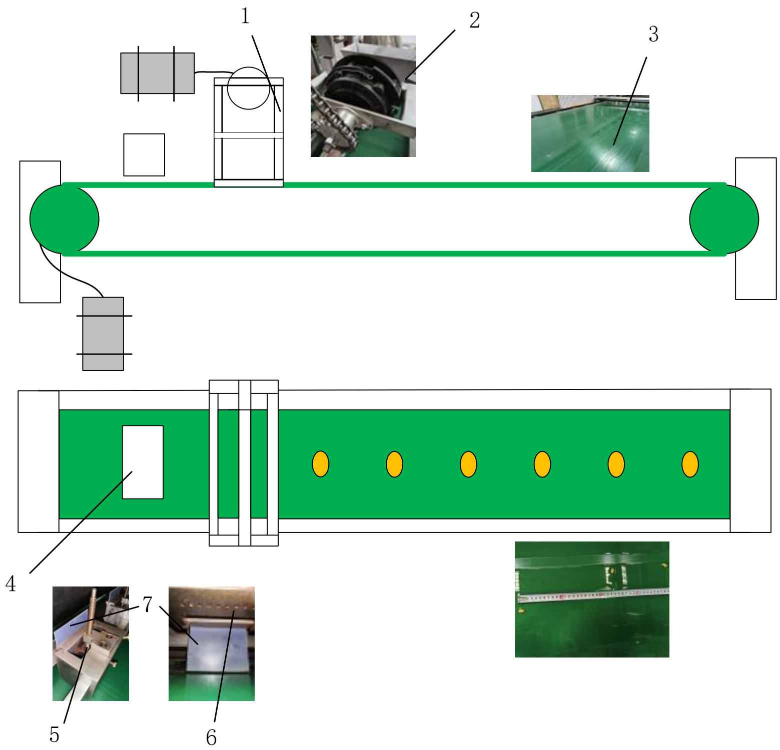

Fig. 1 - Schematic diagram of the whole machine structure

1. Seed metering device fixing device 2. Air suction seed metering device 3. Conveyor belt conveyor 4. Oiling device 5. Screw adjusting mechanism 6. Oil discharge hole 7. Oil scraper

- **Selection of seed metering device**

Due to the diversity of topography in China, in order to adapt to different terrain characteristics, experts and scholars have developed various types of seed metering devices. At present, the most widely used are outer groove wheel type, finger clip type and pneumatic type, but the first two are mainly used in medium and low speed operation, the seed metering device of outer groove wheel type is seriously missed in high speed operation, and the structure of finger clip type seed metering device is complex. It is very limited in high-speed operation. As the high-speed and precision sowing is the development direction in the future, the pneumatic seed metering device is mainly used for the experiment. The pneumatic seed metering device mainly uses the fan to generate negative pressure to absorb the seeds on the seed metering plate. When the seeds move to the seed feeding position, the seed scraping plate is used to block the air flow and then throw the seeds out.

At present, the best working quality of the Chinse precision seed metering device is 60r/min, and the debugging speed of the seed metering shaft of this test-bed is 30~150r/min.

The seeding rate of the seed metering device per second is

$$a = \frac{n}{60} \times k \tag{1}$$

where:

n —the rotation of the seed metering device in the formula, r/min,

a —seeding quantity of seed metering device per second, grain,

k —the number of holes in the seed platter,

The moving speed of the conveyor belt is.

$$v = 3.6 \times (a-1) \times L \tag{2}$$

L —plant distance, m.

v —seeder operating speed, km/h.

By substituting Eq.(2) into Eq.(1), the conversion relationship between the rotational speed of the pneumatic seed metering device and the working speed of the planter is:

$$v = 3.6L \times (\frac{n}{60} * k - 1) \tag{3}$$

- **Mathematical model of brushless DC motor**

Brushless DC motor (BLDC: Brushless Direct Current Motor), also known as electronic commutation motor, is a kind of synchronous motor using DC power supply. Brushless DC motor is mainly composed of rotor made of permanent magnet material, stator with coil winding, inverter and position sensor. In order to facilitate the analysis of the mathematical model of the motor *(Wang W., et al, 2012)*, it is assumed that the stator current and rotor magnetic field are symmetrically distributed, the installation errors of the stator and winding of the brushless DC motor are ignored, and the losses of hysteresis and eddy current are not taken into account. First, the balance equation of voltage in the circuit is established *(Ruan Y., et al, 2006)*:

$$U_s = Ri_d + L\frac{\mathrm{d}i_d}{\mathrm{d}t} + E \tag{4}$$

$$E = C_e \mathrm{n} \tag{5}$$

In the formula, U_s is the armature voltage, R is the winding resistance, i_d is the armature current, L is the winding inductance, E is the back EMF under the rated excitation motor, C_e is the motor back EMF coefficient and n is the motor angular speed.

Then the mechanical balance equation of motor operation is established *(Wang Y.Y., et al, 2008)*:

$$J_a \frac{d\omega}{dt} = M_a - M_L \tag{6}$$

In the formula, J_a is the moment of inertia of the motor rotor, M_a is the electromagnetic torque of the motor, and M_L is the reduced resistance torque.

The differential equations of the motor can be obtained by combining (4), (5) and (6) *(Du R.H, et al, 2014)*:

$$T_d T_m \frac{d^2 n}{dt^2} + T_m \frac{dn}{dt} + n = \frac{1}{C_e} U_s \tag{7}$$

In the formula, T_d is the electromagnetic time constant and T_m is the electromechanical time constant.

By Laplace transformation of formula (7), the transfer function of the motor can be obtained.

$$G(\mathrm{s}) = \frac{1/C_e}{T_m T_d s^2 + T_m s + 1} \tag{8}$$

$$T_m = \frac{RJ}{K_E K_T} \tag{9}$$

$$T_d = \frac{L}{R} \tag{10}$$

In the formula (9), K_E is the induced voltage constant and K_T is the torque constant of the motor. The standard requires that the torque of the seed metering shaft is not more than 10 N.mm, so the motor power of the seed metering shaft is:

$$P = \frac{T \cdot n_{电}}{9550} = \frac{10 \times 150}{9550} = 157.1W \tag{11}$$

Table 1

Parameter table of brushless DC motor

Model	**57BL04**
Rated voltage U	36 V
Rated power P	200 W
Winding resistance R	0.3 Ω
Winding inductor L	0.7 mH

Moment of inertia J	$230\ \mathrm{g \cdot cm^2}$
Torque constant K_T	72 mNm/A
Induced electromotive force constant K_E	5.3 Vrms/krpm

The motor chooses 57BL brushless DC motor and the model is 57BL04. The specific parameters are shown in Table 1.

By substituting it into equations (9) and (10), get T_d = 2.3ms, T_m = 0.422s, C_e = 0.088V * (r*s^{-1})$^{-1}$, then the transfer function of the brushless DC motor is obtained as follows:

$$G(s) = \frac{11.36}{0.00097s^2 + 0.422s + 1} \tag{12}$$

Principle and simulation of conventional PID control

- **Conventional PID control principle**

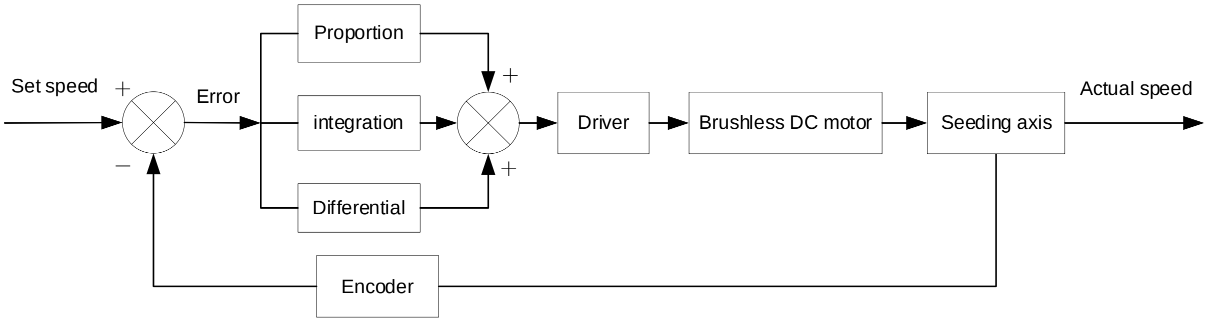

Fig. 2 - General PID control block diagram

The control with proportional + integral + differential control law is called proportional integral differential control (PID control, control block diagram as shown in figure 2), and its expression is as follows:

$$u(t) = K_p \left[e(t) + \frac{1}{T_I} \int_0^t e(t)\mathrm{d}t + T_D \frac{\mathrm{d}e(t)}{\mathrm{d}t} \right] \tag{13}$$

In the formula, $u(t)$ is the output signal of the regulator, $e(t)$ is the deviation signal, K_p is the proportional coefficient, T_I is the integral time constant and T_D is the differential time constant.

Because the single chip microcomputer is a kind of sampling control system, the control quantity can only be calculated according to the deviation during sampling, so it must be discretized. The PID expression after discretization is:

$$u(k) = K_p \left\{ e(k) + \frac{T}{T_I} \sum_{j=0}^{k} e(j) + \frac{T_D}{T} \left[e(k) - e(k-1) \right] \right\} \tag{14}$$

In the formula, $u(k)$ is the output of the controller during the k-th sampling of the system, $e(k)$ is the deviation value of the k -th sampling time, $e(k-1)$ is the deviation value of the k-1st sampling time, k is the sampling sequence number, T is the sampling period.

The key to the design of the control system is to control the motor, so the transfer function of the motor is the transfer function of the system. Use the Simulink plug-in in MATLAB to simulate the control system, and the simulation program block diagram is shown in the figure 3.

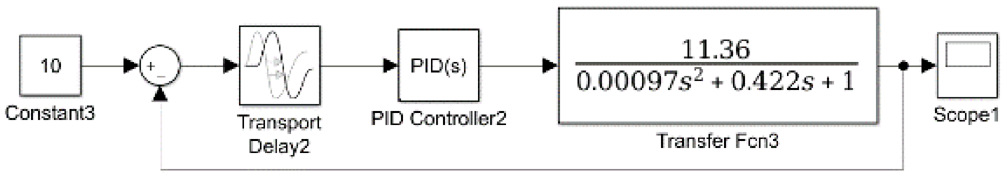

Fig. 3 - General PID program diagram

- **Parameter tuning of PID based on Z-N.**

The Ziegler-Nichols method was invented by John Ziegler and Nathaniel Nichols in 1942 and is still widely used up to now. The Ziegler-Nichols method is divided into two steps: 1. Build a closed-loop control loop to determine the stability limit. 2. The parameters of the controller are calculated according to the formula. The stability limit is determined by the P element. When the stability limit is reached, the constant amplitude oscillation will occur. When the constant amplitude oscillation is reached, P is the critical coefficient, and the period of the constant amplitude oscillation is the critical oscillation period.

The Ziegler-Nichols method is used to set the PID parameter, and the delay is set to 1 s. First, the I-score D parameter is set to 0, and then the P parameter is adjusted. When the P parameter is adjusted to 0.124, the constant amplitude oscillation occurs. The oscillation curve is shown in figure 4. According to the response curve, the oscillation period is 2.5s.

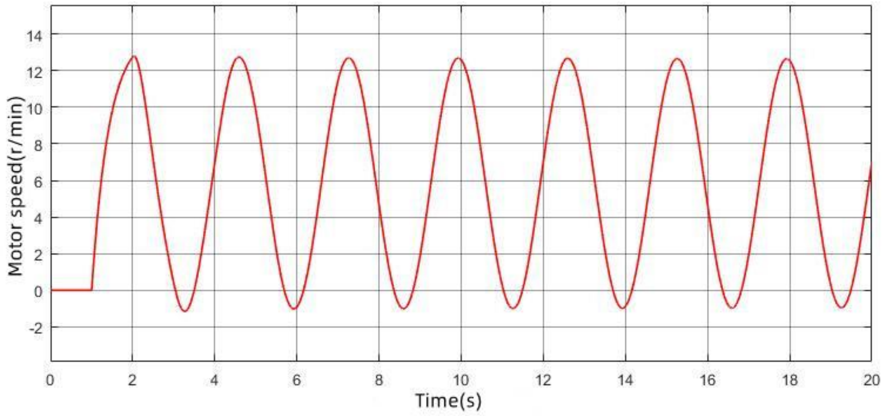

Fig. 4 - Constant amplitude oscillation response curve

Table 2

PID setting formula table

Controller type	K_p	T_i	T_d	K_i	K_d
P	0.5 K_{pcr}				
PD	0.8 K_{pcr}		0.12 T_{cr}		$K_p * T_d$
PI	0.45 K_{pcr}	0.85 T_{cr}		$K_p * T_i$	
PID	0.6 K_{pcr}	0.5 T_{cr}	0.12 T_{cr}	$K_p * T_i$	$K_p * T_d$

According to the PID setting formula (as shown in Table 2), p is 0.062, I is 0.06, and d is 0.0089. Input the calculated parameters into the simulation program, and the response curve is shown in figure 5.

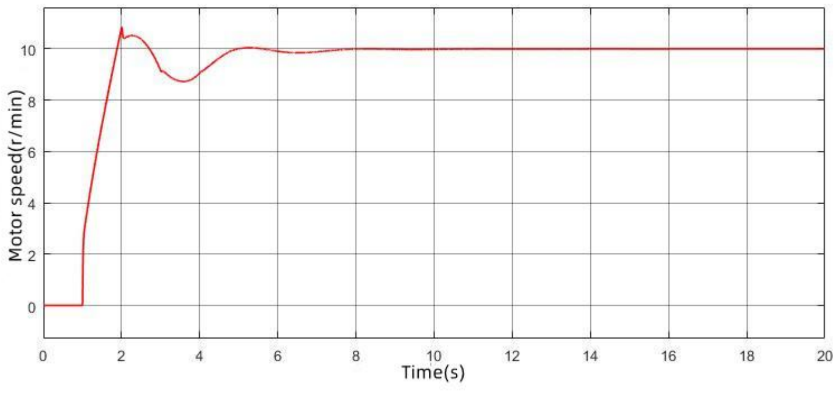

Fig. 5 - Response curve of PID formula after adjustment

However, the PID parameters calculated by the formula can only be used as a reference, and the PID parameters need to be adjusted on-line. Through the on-line tuning of the parameters, p is 0.05, I is 0.06, d is 0.007, and the simulation effect is shown in figure 6.

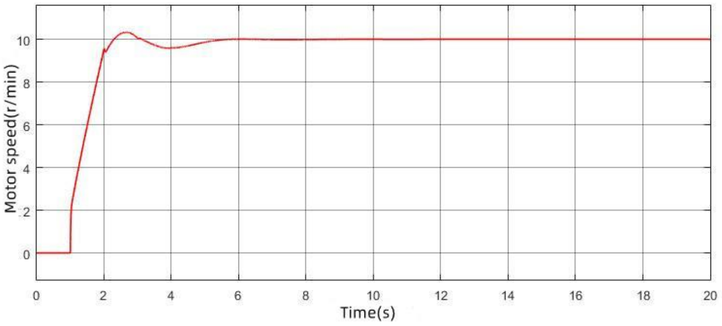

Fig. 6 - Response curve of PID on-line setting

The results show that the conventional PID control can better complete the speed regulation function without steady-state error, but the overshoot of the system is larger and the adjustment time is longer. The long response time of the motor will affect the seeding performance during the working process of the seed metering device. Therefore, the fuzzy self-tuning of PID parameters is carried out by using the fuzzy control algorithm in modern control theory to improve the overall performance of the control system.

Principle and simulation of conventional PID control

- **Fuzzy PID control principle**

For traditional PID, its parameters are a group of near-optimal parameters obtained by developers after a large number of debugging according to the formula or personal experience under certain circumstances, but for some nonlinear time-varying systems, the working environment changes all the time and has a strong uncertainty. Fuzzy PID can solve this problem to a certain extent, using fuzzy logic and fuzzy rules to optimize PID parameters in real time, so as to overcome the disadvantage that traditional PID cannot adjust parameters in real time.

Fuzzy PID control uses fuzzy logic and some fuzzy rules to optimize PID parameters in real time to overcome the disadvantage that traditional PID parameters cannot adjust PID parameters in real time. Fuzzy PID generally includes several steps, such as quantification of input, fuzzification, fuzzy reasoning, defuzzification and so on.

The block diagram of fuzzy PID control is shown in figure 7.

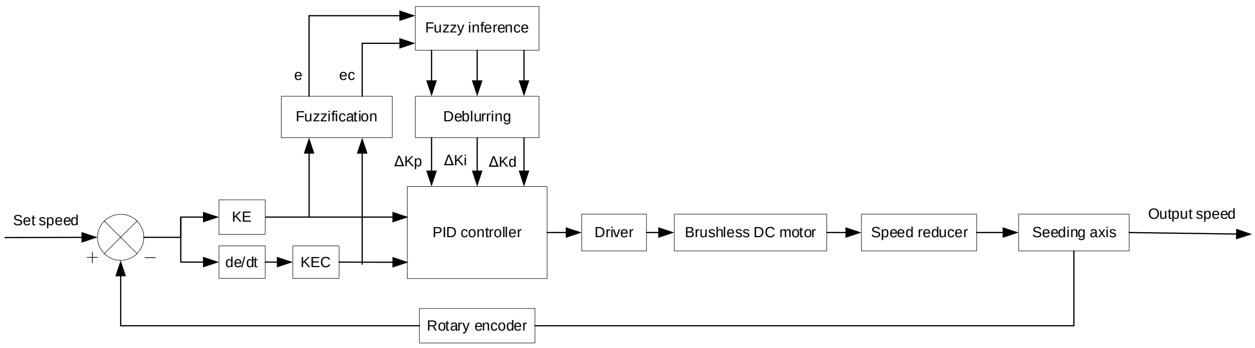

Fig. 7 - Fuzzy PID control block diagram

- **Fuzzy controller design**

The design of fuzzy controller should first determine the fuzzy set, and then determine the domain of variables. The input variables of the fuzzy controller are the error e and the error change rate e_c, the on-line correction ΔK_p of proportional coefficient K_p, the on-line correction ΔK_i of integral coefficient K_i and the on-line correction ΔK_d of differential coefficient K_d, which are used as the output variables of the fuzzy controller.

In order to enable the control system of the test-bed to adjust the motor speed smoothly and quickly, it is necessary to design the fuzzy control rules of the system reasonably. Fuzzy control rule is the most important part in the design process of fuzzy controller, which directly affects the actual performance of the controller.

In the initial stage of regulation, because of the large deviation, larger proportional coefficient, smaller integral coefficient, larger differential coefficient should be selected, and in the middle of the regulation process, in order to make the system have smaller overshoot, smaller proportional coefficient, moderate integral coefficient, smaller differential coefficient, and in the later stage of the adjustment process, larger proportional coefficient should be selected to reduce the static error, and larger integral should be selected to adjust the static error. A smaller differential coefficient is selected to reduce the braking effect in the controlled process. As a result, the fuzzy rule tables of proportional integral and differential coefficients are determined, as shown in Table 3, Table 4 and Table 5.

ΔK_p Fuzzy rule table **Table 3**

ΔK_p		e_c						
		NB	NM	NS	ZO	PS	PM	PB
e	NB	PB	PB	PM	PM	PS	ZO	ZO
	NM	PB	PB	PM	PS	PS	ZO	NS
	NS	PM	PM	PM	PS	ZO	NS	NS
	ZO	PM	PM	PS	ZO	NS	NM	NM
	PS	PS	PS	ZO	NS	NS	NM	NM
	PM	PS	ZO	NS	NM	NM	NM	NB
	PB	ZO	ZO	NM	NM	NM	NB	NB

ΔK_i Fuzzy rule table **Table 4**

ΔK_i		e_c						
		NB	NM	NS	ZO	PS	PM	PB
e	NB	NB	NB	NM	NM	NS	ZO	ZO
	NM	NB	NB	NM	NS	NS	ZO	ZO
	NS	NB	NM	NS	NS	ZO	PS	PS
	ZO	NM	NM	NS	ZO	PS	PM	PM
	PS	NM	NS	ZO	PS	PS	PM	PB
	PM	ZO	ZO	PS	PS	PM	PB	PB
	PB	ZO	ZO	PS	PM	PM	PB	PB

ΔK_d Fuzzy rule table **Table 5**

ΔK_d		e_c						
		NB	NM	NS	ZO	PS	PM	PB
e	NB	PS	NS	NB	NB	NB	NM	PS
	NM	PS	NS	NB	NM	NM	NS	ZO
	NS	ZO	NS	NM	NM	NS	NS	ZO
	ZO	ZO	NS	NS	NS	NS	NS	ZO
	PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
	PM	PB	NS	PS	PS	PS	PS	PB
	PB	PB	PM	PM	PM	PS	PS	PB

Because the maximum speed of the speed regulation of the control system is set to 120 r/min, and the input speed range is 0~120 r/min, the basic domain of deviation e is set to [-120, 120], the basic domain e_c of deviation change rate is set to [-20, 20], and the output variable K_p, K_i, K_d is set to [-0.05, 0.05], [-0.05, 0.05], [-0.5, 0.5], respectively. The fuzzy set domain of the input variable e and e_c is set to [-6, 6], and the fuzzy set domain of the output variable is also set to [-6, 6].

In order to carry out fuzzy inference, it is necessary to discretize the basic domain and transform the quantization factor into the fuzzy domain. The calculation formula of the quantization factor is as follows:

$$K_e = \frac{n_e}{x_e} = 0.05 \tag{15}$$

$$K_{ec} = \frac{n_{ec}}{x_{ec}} = 0.3 \tag{16}$$

In the formula, K_e is the error quantization factor, K_{ec} is the error deviation quantization factor, n_e is the fuzzy set domain of deviation e, x_e is the basic domain of deviation e, n_{ec} is the fuzzy set domain of deviation change rate e_c, and x_{ec} is the basic domain of deviation change rate e_c.

The formula for calculating the proportional factor of the output is *(Chen X. et al, 2006):*

$$\Delta K_{Kp} = \frac{n_p}{x_p} = 0.008 \tag{17}$$

$$\Delta K_{Ki} = \frac{n_i}{x_i} = 0.008 \tag{18}$$

$$\Delta K_{Kd} = \frac{n_d}{x_d} = 0.08 \tag{19}$$

Where, ΔK_{Kp} is the basic domain of proportional coefficient, n_p is the basic domain of proportional coefficient K_p, x_p is the fuzzy set domain of proportional coefficient K_p, ΔK_{Ki} is the basic domain of proportional coefficient, n_i is the basic domain of Integral coefficient K_i, x_i is the fuzzy set domain of Integral coefficient K_i, ΔK_{Kd} is the basic domain of proportional coefficient, n_d is the basic domain of differential coefficient K_d, x_d is the fuzzy set domain of differential coefficient K_d.

According to experience, the fuzzy subset of input, output variables and fuzzy PID parameters is defined as {PB, PM, PS, ZO, NS, NM, NB}, that is, positive large, positive median, positive small, zero, negative small, negative median, negative large.

- **Membership function design**

Because of the high reaction time of the system in the experiment, the motor needs to adjust the speed in time, so the deviation e, the deviation change rate e_c and the correction value ΔK_p, ΔK_i, ΔK_d of PID parameters all choose the triangular membership function with less calculation and less memory, and the structure of the membership function is shown in figure 8.

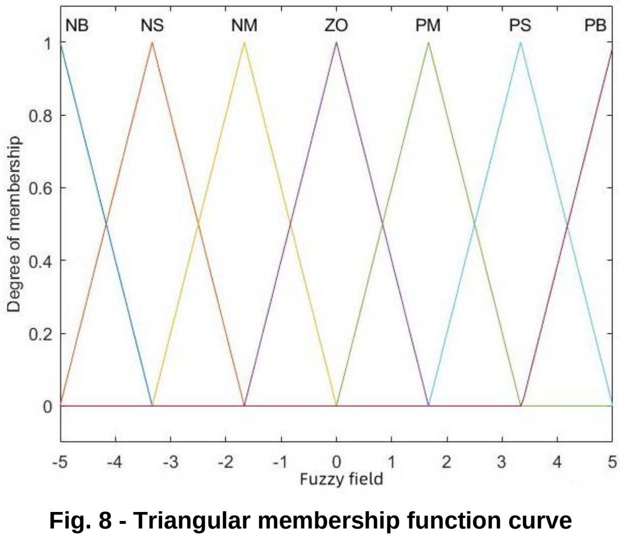

Fig. 8 - Triangular membership function curve

- **Clarity**

The adjustment and variation of PID parameters can be obtained by fuzzy reasoning according to fuzzy rules. Because the fuzzy control quantity is a combination in the fuzzy domain, it needs to be clarified before it can be recognized by the controller.

At present, the main methods of clarity are area center method (center of gravity method), area bisection method, maximum membership method and so on *(Shi X.M. et al, 2018)*. Considering that the system requires high reaction time and the area bisection method is intuitive and reasonable, the area center method is selected to clarify the fuzzy quantity. The area center method is to find out the center of gravity of the area surrounded by the membership function curve and the horizontal axis, and the coordinate value corresponding to the center of gravity point is used as the output value of fuzzy reasoning. The calculation formula is as follows:

$$\Delta K_p = \frac{\int_{U_1} A_1(u_1)u_1 du_1}{\int_{U_1} A_1(u_1)du_1} \tag{20}$$

$$\Delta K_i = \frac{\int_{U_2} A_2(u_2)u_2 du_2}{\int_{U_2} A_2(u_2)du_2} \tag{21}$$

$$\Delta K_d = \frac{\int_{U_3} A_3(u_3)u_3 du_3}{\int_{U_3} A_3(u_3)du_3} \tag{22}$$

Among them, ΔK_p, ΔK_i, ΔK_d are the amount of change of K_p, K_i, K_d. The adjustment value of PID parameter can be obtained from the above formula, and the final calculation formula of fuzzy PID is:

$$K_p = K_{p0} + \partial * \Delta K_p \tag{23}$$

$$K_i = K_{i0} + \partial * \Delta K_i \tag{24}$$

$$K_d = K_{d0} + \partial * \Delta K_d \tag{25}$$

In the equation, K_{p0}, K_{i0}, K_{d0} are the initial values of K_p, K_i, K_d, ∂ is the proportional coefficient, which can magnify and reduce ΔK_p, ΔK_i and ΔK_d according to the actual situation.

- **Simulation experiment of Fuzzy PID Control system**

In order to verify the superiority of fuzzy PID control system, the program of fuzzy PID control is designed through the Simulink plug-in in MATLAB. The control program module diagram is shown in figure 9.

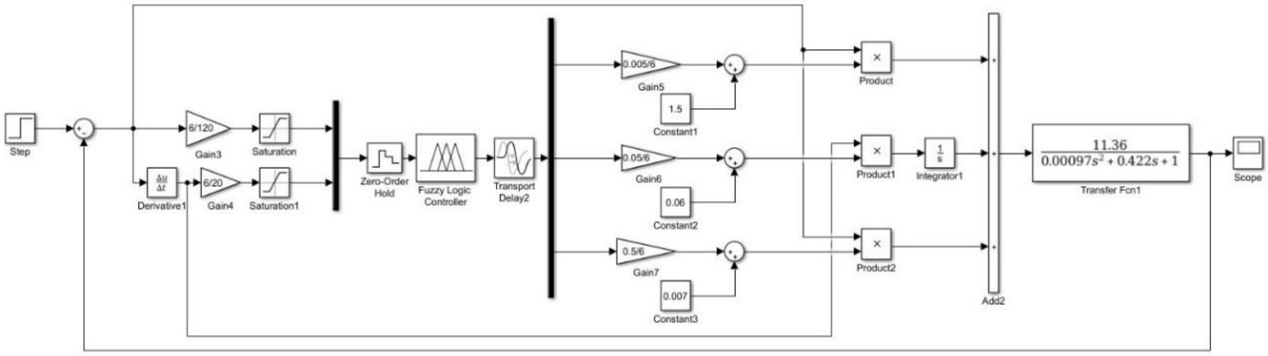

Fig. 9 - Fuzzy PID control program module diagram

The simulation effect is shown in figure 10. From the response curve of the control system, the response time of the fuzzy PID control system is about 0.15 s, which is greatly improved compared with the conventional PID control performance, there is no steady-state error, the system has no overshoot, and the control effect is good.

Comparing the system response curve of the fuzzy PID controller and the conventional PID controller, we can see that the fuzzy PID controller can quickly adjust the speed, and the control effect is better than the conventional PID controller.

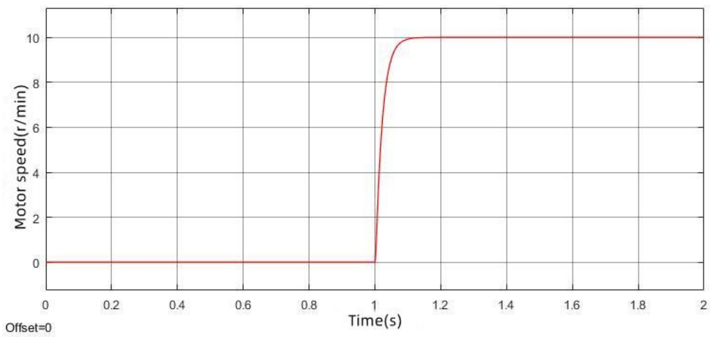

Fig. 10 - Fuzzy PID response curve

Design of control system

- **Hardware design of control system**

The main controller is the core part of the control system of the seed metering test-bed, which not only receives the signal of the speed sensor, but also outputs the control instructions issued by the man-machine interface. During the operation of the system, because the main controller needs to respond to the received signal in a short time, the computing performance of the main control chip is required. Considering the advantages and disadvantages of various main controllers, the STM32F103C8T6 single chip microcomputer based on Cortex-M3 architecture is selected. The parameters of the single chip microcomputer are shown in Table 6.

Parameters of single chip microcomputer controller **Table 6**

Type	parameter
Kernel	Cortex-M3
SRAM	20K×8bit
GPIO	37 GPIO
ADC	2*12bit ADC total 12 channels.
timers	7
Operating voltage, temperature	2V~3.6V、-40°C~85°C
Communication serial port	2*IIC，2*SPI，3*USART，1*CAN
Debug mode	Both SWD and JTA debugging are supported

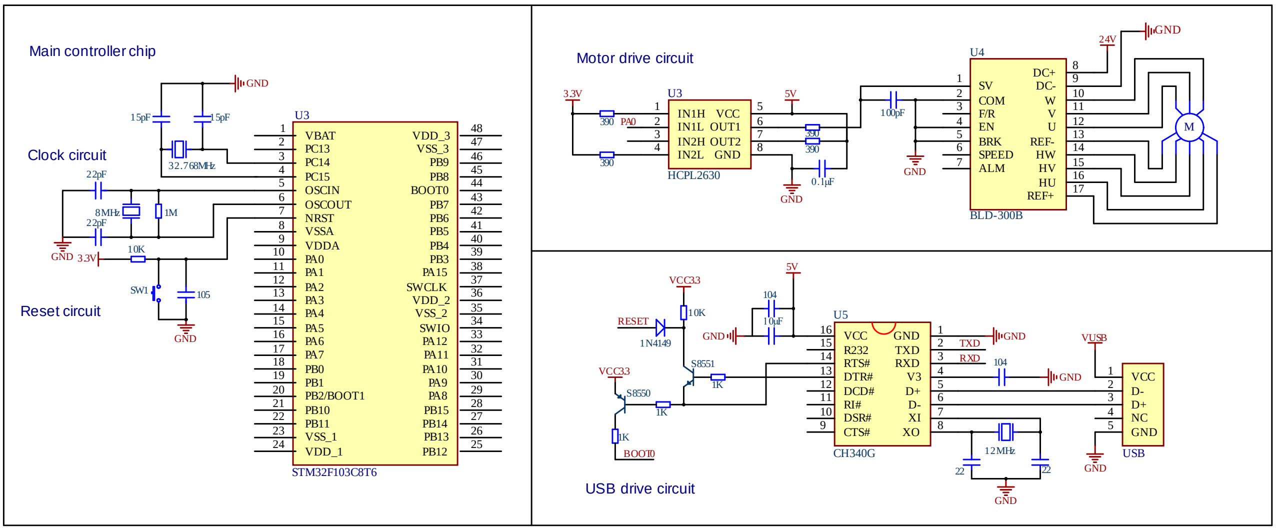

Fig. 11 - Motor drive circuit diagram

The hardware circuit diagram of the control system of the seed metering device test-bed is shown in figure 11. The whole circuit is communicated by USB, the circuit is protected by HCLP-2630 optocoupler isolation module, and the motor is driven by BLD-300. The encoder is used to detect the speed of the seed metering device and the conveyor belt. The type is OMRON E6B2-CWZ6C (the parameter table is shown in Table 7), the outer diameter is 40 mm, the maximum output pulse per turn is 3600 pulses, and the DC power supply is 24V. It can convert the displacement into periodic electrical signals, and then convert the electrical signals into counting pulses. In the speed detection of the conveyor belt, the meter wheel is in contact with the conveyor belt to make it rotate synchronously. Then the actual rotational speed of the conveyor belt is obtained (the installation location of the encoder is shown in figure 12).

Rotary encoder parameter table **Table 7**

Model.	57BL04
Rated voltage U	36 V
Rated power P	200 W
Winding resistance R	0.3 Ω
Winding inductor L	0.7 mH
Moment of inertia J	230 g·cm2
Torque constant KT	72 mNm/A
Inductive electromotive force constant KE	5.3 Vrms/krpm

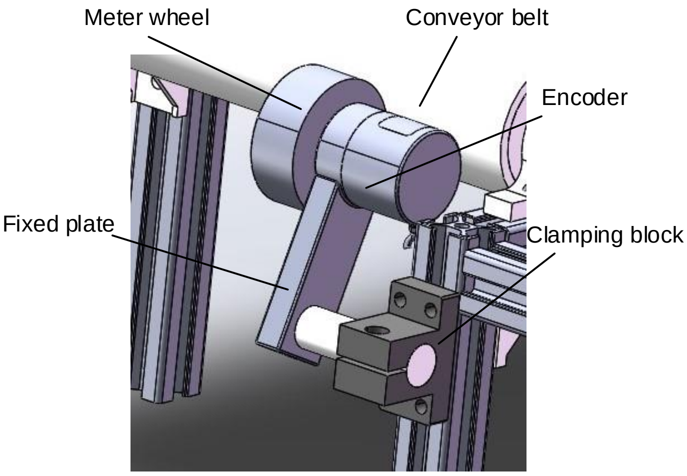

Fig. 12 - Encoder fixing device

- **Software design of control system**

The software system uses Keil5 MDK produced by American Keil Software company as the development environment, and the programming language is C language. When the system starts to work, the speed of the motor and the set grain distance are inputted through the man-machine interface, the theoretical speed of the conveyor belt is calculated by the main controller, and then the PWM value of the corresponding duty cycle is output, and the driver drives the motor to run. The encoder detects the speed of the motor and the conveyor belt, and displays the actual speed on the man-machine interface. The software control flow chart of the system is shown in figure 13.

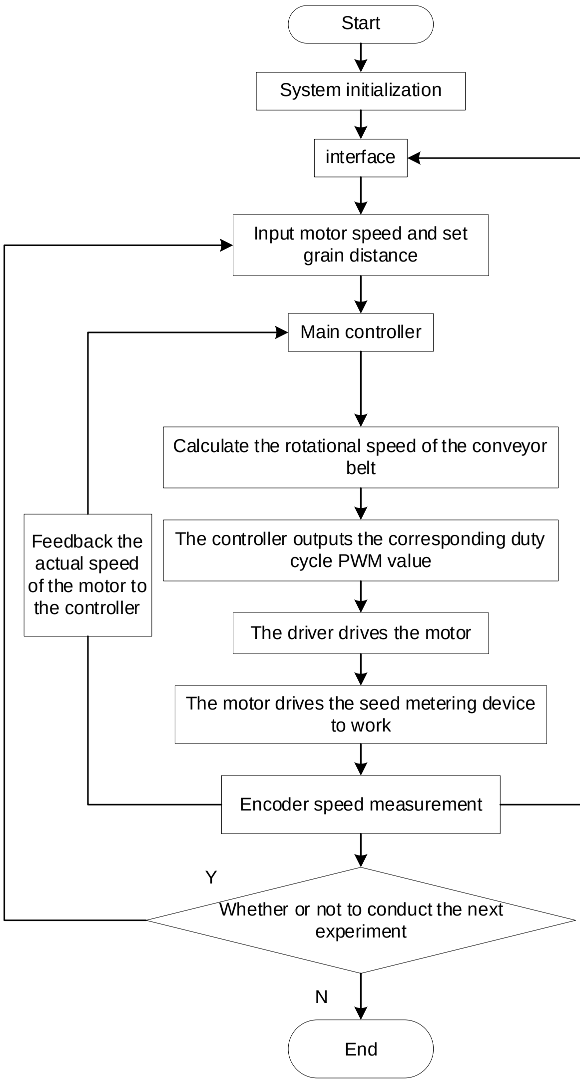

Fig. 13 - Force analysis of prawn

RESULTS

Bench test

Taking maize seed as the experimental object, the indoor experiment was carried out in the State key Laboratory of soil Plant Machine system Technology of Chinese Academy of Agricultural Mechanization on April 24, 2022. The rotation speed test of seed metering device and the precision sowing experiment of single grain of corn were carried out. The working picture of the seed metering device is shown in the figure. The experimental equipment includes: a set of seed metering performance testing system, a 57BL04 brushless DC motor, a BLD-300B motor driver, an OMRON rotary encoder, a step-down power module, an air suction seed metering device, and a seed metering tube.

- **Rotation speed test of seed metering device**

The total length of the conveyor belt is 5 m. Each experiment collects 20 data from the beginning to the smooth operation of the seed metering device, is repeated 3 times, it takes the average value, takes the different theoretical rotational speed and real-time rotational speed of the seed metering device as the testing object, and compares the difference between them. Take this as the evaluation criterion of control accuracy. The rotational speed of the seed metering device is set as 30 rpm, 50 rpm, 70 rpm, 90 rpm, respectively. The actual rotational speed of the seed metering device is detected in real time through the encoder, and the speed error of the seed metering device is analyzed.

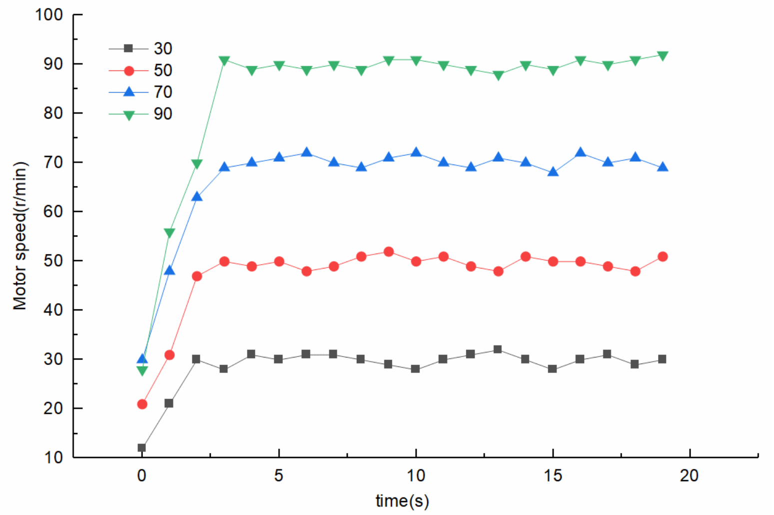

Fig. 14 - Detection diagram of rotation speed of seed-metering shaft

The speed test result of the seed metering device is shown in figure 14. When the seed metering device starts to work, there is a big difference between the theoretical speed and the actual speed. When the seed metering device works smoothly, the real-time speed of the seed metering device is relatively stable, the control error of the control system is small, and the relative error is small, which meets the needs of use.

- **Performance test of seed metering device**

A qualified seed metering device was selected to test the accuracy of the test-bed, the experimental device is shown in figure 15.

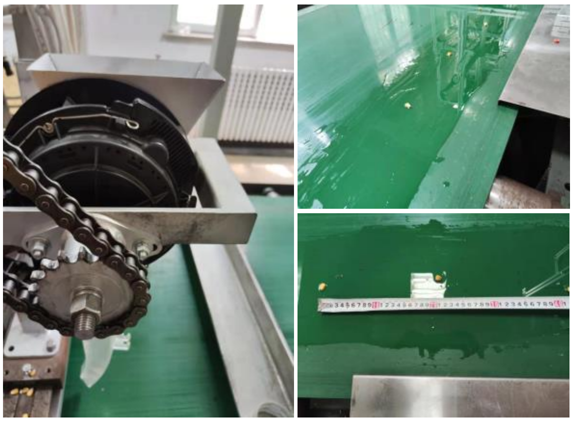

Fig. 15 - Performance test of seed metering device

According to GB/T6973-2005 Experimental method of single-grain precision seeder, qualified index, replay index, missed sowing index and coefficient of variation of qualified grain distance were selected as evaluation indexes.

250 seeds after stable operation were selected to test the performance of the seed metering device on the test bench, and the grain distance was set to 20 cm, 25 cm, 25 cm, 30 cm, 35 cm, respectively, to determine the accuracy of the control system of the test-bed. When the seed metering device is used for precision sowing of single grain, if t is the average grain distance, then 1.5t grain spacing > 0.5t will be qualified. The rotation speed of the seed metering device is 11 rpm, 18 rpm, 25 rpm, 33 rpm, respectively, corresponding to low speed operation, medium speed operation and high speed operation. The experimental results are shown in Table 8.

Working results of seed metering device under different grain distance and rotational speed Table 8

Set the evaluation	index of grain distance	Rotation speed of seeding shaft			
		11 rpm	18 rpm	25 rpm	33 rpm
20 cm	qualified grain distance index	91.1	92.2	93.3	93.3
	qualified grain distance variation index.	5.8	5.5	3.3	5.1
	replay index	3.3	3.3	3.3	3.3
	missed seeding index	5.5	4.4	5.1	3.3
25 cm	qualified grain distance index	94.4	92.2	92.2	92.2
	qualified grain distance variation index.	6.7	6.8	6.7	6.3
	replay index	1.1	4.4	3.3	3.3
	missed seeding index	3.3	3.3	4.4	4.4
30 cm	qualified grain distance index	92.2	93.3	95.5	96.6
	qualified grain distance variation index.	7.1	7.7	7.0	6.8
	replay index	5.2	3.3	1.1	0
	missed seeding index	2.2	4.4	4.4	3.3
35 cm	qualified grain distance index	91.1	90.0	93.3	92.2
	qualified grain distance variation index	7.9	7.7	7.3	7.8
	replay index	4.4	4.4	3.3	6.6
	missed seeding index	4.4	4.4	3.3	3.3

It can be obtained from Table 8 that the working performance of the seed metering device is very stable under different grain spacing and different rotational speeds. When the electronically controlled seed metering system is used to test the performance of the seed metering device, the qualified grain distance index of the seed metering device is maintained above 91%. The coefficient of variation of qualified grain spacing is less than 4%, the missing sowing index is less than 7%, and the replay index is less than 5%, all of which meet the national standard requirements of single-grain precision seed metering device.

CONCLUSIONS

(1) According to the rotational speed requirements of seed metering device and conveyor belt, a fuzzy PID speed control system is designed, and the whole structure of the test-bed, the relationship between seed metering speed and grain distance and the selection of sensors are determined, and the purpose of motor control and normal operation of seed metering device test-bed is realized.

(2) Through Simulink simulation and prototype experiment, it is proved that the fuzzy PID motor control strategy can better realize the speed control of the test-bed motor. The simulation results show that the fuzzy PID self-tuning control algorithm designed in this paper has faster response speed, smaller overshoot and better stability than the conventional PID control algorithm, which greatly improves the dynamic performance of motor control in the test-bed.

(3) In the prototype test, the performance test of the seed metering device is carried out on the test-bed. Through the calculation of the qualified grain distance index, miss sowing index, replay index, qualified grain distance variation index and other parameters, it shows that the design of the control system meets the pre-design requirement.

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