DESIGN AND EXPERIMENT OF A NEW ROTARY COATING MACHINE BASED ON LabVIEW
/
基于 LabVIEW 控制的新型旋转式包衣机的设计与试验

Xiwen Zhang, Zhanfeng Hou*), Nianzu Dai
Inner Mongolia Agricultural University, College of Mechanical and Electrical Engineering, Inner Mongolia, China
Tel: 04714309215; Corresponding author E-mail: njau-hzf@163.com
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ABSTRACT
In view of the problems of long coating time, complicated manual operation, high multi-seed rate of coated seeds, low qualified rate, and low degree of automation of control equipment in traditional rotary coating machine, a new type of rotary coating machine was designed while using LabVIEW with a complete electric control system, which can effectively improve the speed and quality of coating. The system uses single-chip microcomputer as the lower computer, LabVIEW as the upper computer, and uses programming electronic control technology to set seed coating parameters in advance, precisely control each part and achieve precise supply. Batch supply of powder and liquid greatly improves the automation and intelligence of the operating system, improves the coating efficiency, reduces the multi-seed rate and the seedless rate, and increases the coating pass rate. In order to improve the coating quality and the supply accuracy of the coating machine, the error analysis and calibration test of the seed supply system, powder supply system and liquid supply system were carried out. After the test verification, the supply error was controlled within 2% to meet the demand for precise supply. The test results show that the pass rate of the seeds coated by the new rotary coating machine is increased by 15% to 20% compared with the seeds coated by the traditional manual coating.

摘要
针对传统旋转式包衣机存在包衣时间长、人工操作复杂、包衣种子多籽率高合格率低、控制设备自动化程度低等问题，设计了一套新型旋转式包衣机的同时，运用 LabVIEW 设计了一套完整的电控系统，*可有效提高包衣的速度和质量。该系统以单片机作为下位机，* LabVIEW *做上位机，运用编程电控等技术，可提前设置种子包衣参数，精准控制各部分，对供种量、供粉量以及供液量实现精准供给。分批次供给极大提高了操作系统的自动化和智能化，提高了包衣效率的同时，降低了多籽率和无籽率，提高了包衣合格率。为提高包衣品质和包衣机的供给精度，分别对供种系统、供粉系统以及供液系统进行误差分析以及校准试验，经试验验证，供给误差控制在 2%以内，满足精准供给的需求。试验结果表明：通过新型旋转式包衣机包衣的种子相比于传统人工添料包衣的种子包衣合格率提升 15%到 20%。*

INTRODUCTION
Seed coating technology is to use a specific coating process to make the surface of the seed and the coating agent evenly contact, and wrap it to form a smooth and firm film. Through mechanical processing, small spheres of uniform size and regular shape (including circle, ellipse, oblate, etc.) are made. The coating agent can contain a variety of components (*Shao, 2018; Wu, 2017*). According to specific environmental factors, proper adjustment of the dosage components can improve the ability of seeds to tolerate drought, cold, salt and alkali, and prevent soil-borne diseases. In addition, the coating technology achieves a uniform increase in seed particle size. The increase in particle size not only improves the fluidity of seeds in terms of physical properties, but also facilitates mechanized and precise seeding, thereby achieving the purpose of improving seeding efficiency and reducing seed waste. Therefore, how to use high-quality coating technology to achieve the diversity and functional specificity of coated seeds is an urgent and realistic demand (*Qiu, 2017; Bai, 2020*). Seed coating technology in China started in the 1980s, which is relatively late compared to some countries in the West. At present, the coating machine independently designed and produced in China has a low degree of intelligence and a relatively simple control system. The coating experience and operating proficiency of the operator directly affect the quality of the seed coating.

Considering how to optimize the coating process, select coating parameters, enrich the operating system to reduce the multi-seed rate and the seedless rate, and to increase the single-seed rate and the coating pass rate are the current mainstream research directions (*Wang, 2021*).

Aiming at the problems of uneven supply of powder and liquid in current seed coating technology, sticking pan, inconsistent coating formula, insufficient theoretical research of coating machine, low degree of automation, poor coating quality, etc., a new type of rotary type was researched and designed (*Shu, 2017*). The seed coating machine uses STM32 single-chip microcomputer as the lower computer, and the LabVIEW control system is designed as the upper computer to intelligently control the seed coating part, the powder supply part and the spray part. The automation of the coating machine is improved, and at the same time the precise supply of seeds, powders, and sprays is realized (*P.T, 2016; Zhu, 2012*). The modules operate in a coordinated and orderly manner to reduce the multi-seed rate and the seedless rate, increase the single-seed rate and the coating pass rate, and improve forming quality of coated seeds.

MATERIALS AND METHODS

OVERALL STRUCTURE

The seed coating machine designed this time consists of a seed supply system, a powder supply system, a liquid medicine supply system, a coating pot adjustment system and a host computer control system. The three-dimensional and two-dimensional diagrams of the overall structure are shown in Fig.1.

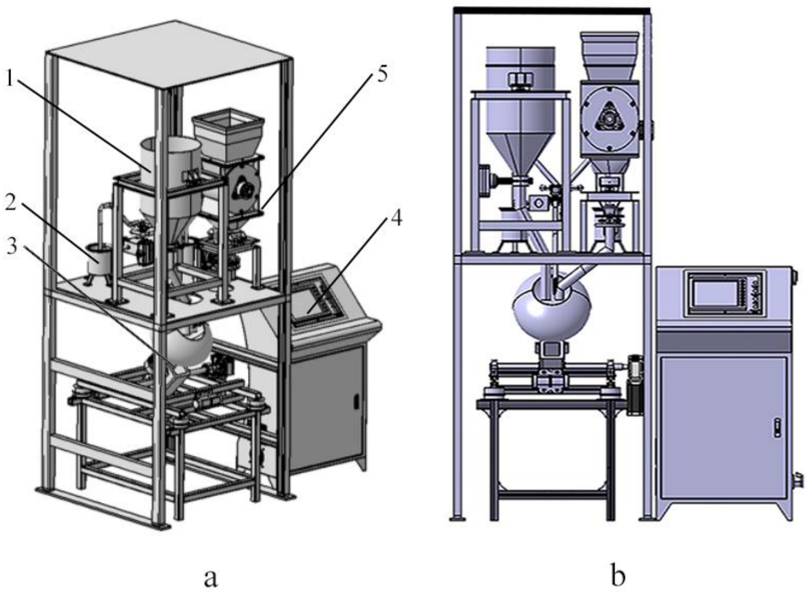

Fig. 1 - General structure

1-Seed supply system; 2-Liquid medicine supply system; 3-Coating pot adjustment system; 4-Host computer control system; 5-Powder supply system

Working principle of seed supply system

The seed supply system is mainly composed of seed charging barrel, load cell, pneumatic valve and solenoid valve. In this design, a high-precision piezoelectric weighing sensor with a range of 0-10 kg and an accuracy of less than 1 g is selected. After calibration, its combined error is <0.05%. It has the characteristics of high precision, easy operation, simple structure and strong anti-interference ability. Among them, the AD module uses HX711, which has 24-bit AD conversion and the accuracy level is C3. The specific seed supply process is as follows: fix two piezoelectric load cells on the tray of the seed hopper, real-time detection of the seed weight in the hopper, the weight information is converted from Digital-Analog Convert and transmitted to the single-chip microcomputer, then transmitted from the single-chip microcomputer to the upper computer. The weight is real-time display in the control system. First select the seed drop value in the control system, and then the system records the initial weight in the hopper. After starting to run, the single-chip microcomputer controls the relay to pull in, the solenoid valve opens, the pneumatic valve opens under the action of air, and the seeds begin to fall. During the falling process, the load cell detects the weight change in real time, and the control system calculates the weight loss in the hopper.

When the loss reaches the initial selected drop value, the microcontroller control relay will be disconnected, the solenoid valve will be closed, and the pneumatic valve will be closed to complete the entire drop. During the seed supply process, the seeds will fall into the coating pan and wait for coating. When the initially selected planting value is less than the weight value in the hopper, it prompts to add seeds. The system realizes accurate seed supply and continuous multi-batch operation. The three-dimensional and two-dimensional diagrams of the seed supply system is shown in Fig.2.

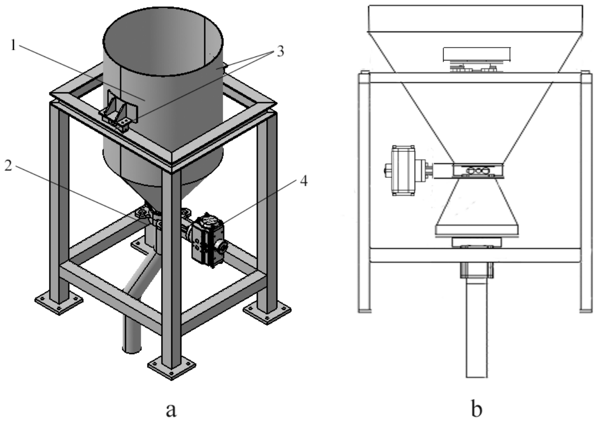

Fig. 2 - The three-dimensional diagram of the seed supply system
1- Seed charging barrel; 2- Load cell; 3- Pneumatic valve; 4- Solenoid valve

Working principle of the powder supply system

The powder supply system is mainly composed of charging barrel of powder, a stepping motor and an impeller metering disc. In order to realize the synchronous supply of powder and the precise amount of falling, a 42-line geared motor with a reduction ratio of 30 is selected to drive the impeller metering disc. This device can effectively improve the metering accuracy. The impeller metering disc is composed of 4 blades, and each blade has an angle of 90°. The volumetric method is used to control the powder supply weight. The right-angle volume between the two blades is calculated as 100 g by design. During the coating process, initially select the parameters in the control system, and set an appropriate seed-powder ratio according to the weight of the seed dropping. After starting and running, the stepping motor starts to rotate under the control of single chip microcomputer, and the impeller metering plate starts to rotate. The supply is completed every 90° rotation. The powder falls into the coating pan through the pipe under its own weight. The number of powder supply is calculated in the control system, and the cycle runs until the end of the powder supply. In order to prevent the powder from sticking and causing supply errors, the powder box is made of acrylic material, and the blade and shell of the impeller metering disc are 3D printed with PLA (Polylactic acid) material. When the shell and the impeller rotate, a large torque will be generated. The joint is designed with a fixed bearing to reduce the friction caused by rotation and reduce the error caused by the angle deviation. The three-dimensional and two-dimensional diagrams of the powder supply system is shown in Fig.3.

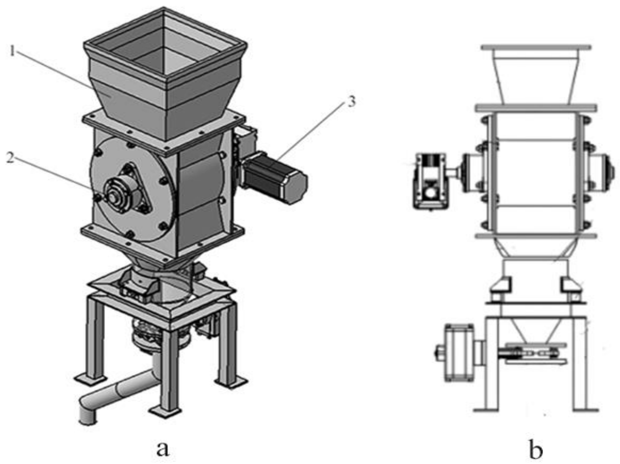

Fig. 3 - The three-dimensional diagram of the powder supply system
1- Charging barrel of powder; 2- Stepping motor; 3- Impeller metering disc

Working principle of the liquid supply system

The liquid supply system consists of a clear water barrel, a liquid medicine barrel, a peristaltic pump, a nozzle and pipeline. The working process of the liquid supply system is as follows: initially select the appropriate seed-liquid ratio in the control system, and according to the seed weight provided, the ratio 1g corresponds to 1 ml. After selecting the parameters, it starts to run, and the single-chip microcomputer controls the peristaltic pump to start working. The clean water and the liquid medicine are mixed through the water pipe and sprayed from the nozzle under the action of pneumatic force. The system calculates the required amount of liquid medicine through the seed weight provided and the selected seed-liquid ratio, and obtains the working time of the peristaltic pump through calculation, and performs timing in the system until the peristaltic pump stops running at the specified time. The liquid medicine is finally sprayed from the nozzle through the pipeline. The atomization nozzle chooses a gas-liquid two-phase flow nozzle, one end is connected to the air pump, one end is connected to the pipeline, and the nozzle position is aligned with the drop position of the seed in the pot. Under the action of air flow, the liquid medicine floats in the coating pan to form a moist mist environment, which is convenient for full contact with the seeds at the bottom and effective mixing to achieve an ideal coating state. According to the query atomization nozzle parameter table, when the flow rate is 9 L/h, the air flow rate is 45 L/min, which meets the atomization requirements required by the experiment. The three-dimensional and two-dimensional diagrams of the liquid supply system is shown in Fig.4.

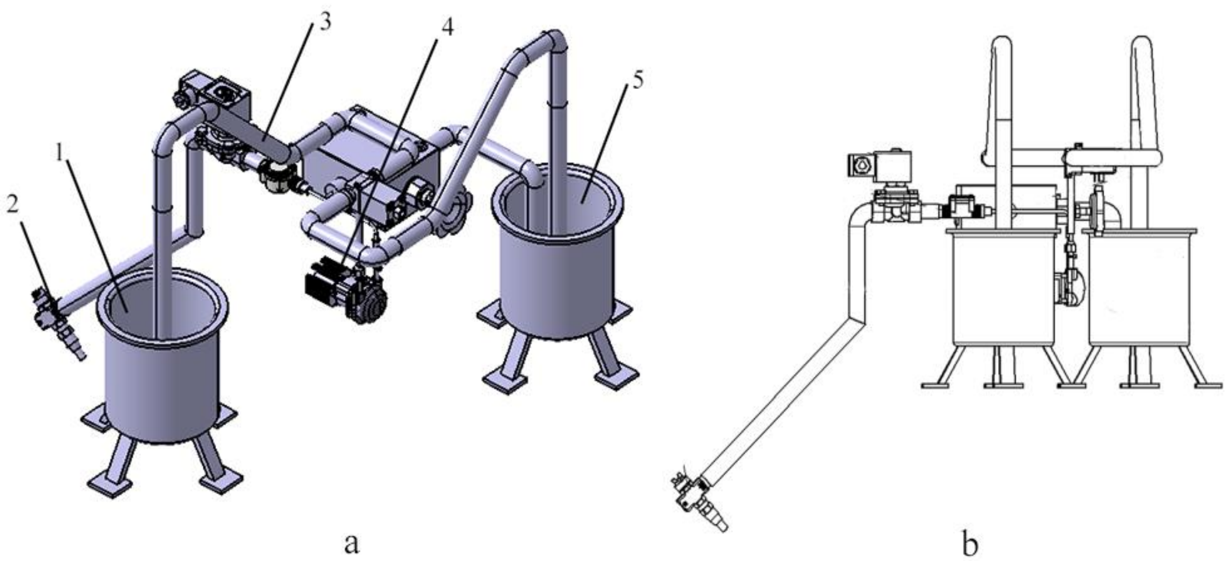

Fig. 4 - The three-dimensional diagram of the liquid supply system
1- Clear water barrel; 2- Nozzle; 3- Pipeline; 4- Peristaltic pump; 5- Liquid medicine barrel

Coating pot adjustment system

The coating pot adjustment system is composed of a coating pan, a frame, a driving motor and an inclination adjustment mechanism (*Rogovskii I.L., 2020*). Among them, the driving motor controls the rotating speed of the coating pan, and the rotating speed ranges from 0 r/min to 90 r/min, which meets the rotating speed requirements of normal rotary coating. The inclination adjuster is controlled by a NMRV turbo-worm gear stepper motor. The subdivision number is 3200.

The inclination angle is composed of the horizontal ground and the parallel line of the pot opening. When the pot opening is perpendicular to the ground, the inclination angle is 90°. The theoretical angle range is from 0° to 360°, but when the inclination angle exceeds 90° and is less than 180°, considering that the drive motor is placed above the rotating rod, long-term operation can easily cause the rotating rod to break and cause damage. When it exceeds 180°, the mouth of the pot is facing downwards, and coating cannot be carried out.

Usually, it is more appropriate to select a range between 20° and 60° for coating. The coating pan adjustment system satisfies the adjustment of the coating pan inclination and the coating pan rotation speed.

The three-dimensional and two-dimensional diagrams of the coating pan adjustment system is shown in Fig 5.

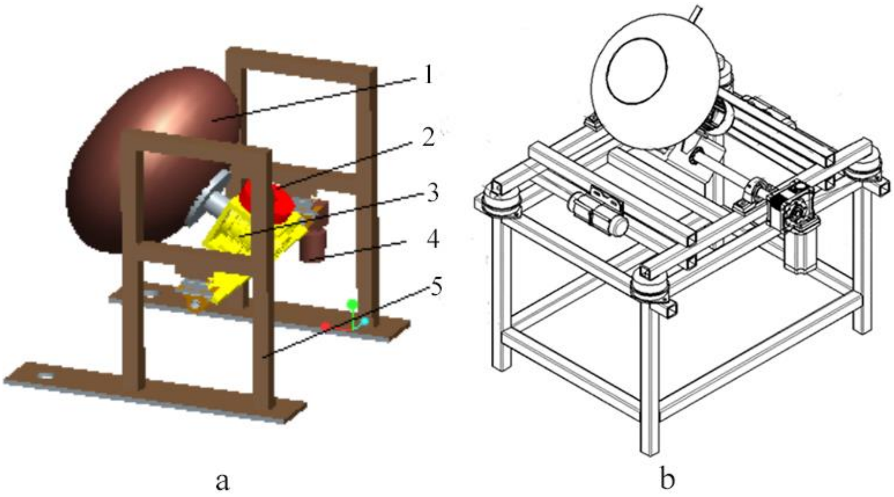

Fig. 5 - The coating pan adjustment system

1- Coating pan; 2- Driving motor; 3- Rotating rod; 4- Inclination adjustment mechanism; 5- Frame

Control System

Considering the low automation of domestic coating machine, a complete control system is designed by using LabVIEW. The control system is shown in Fig.6.

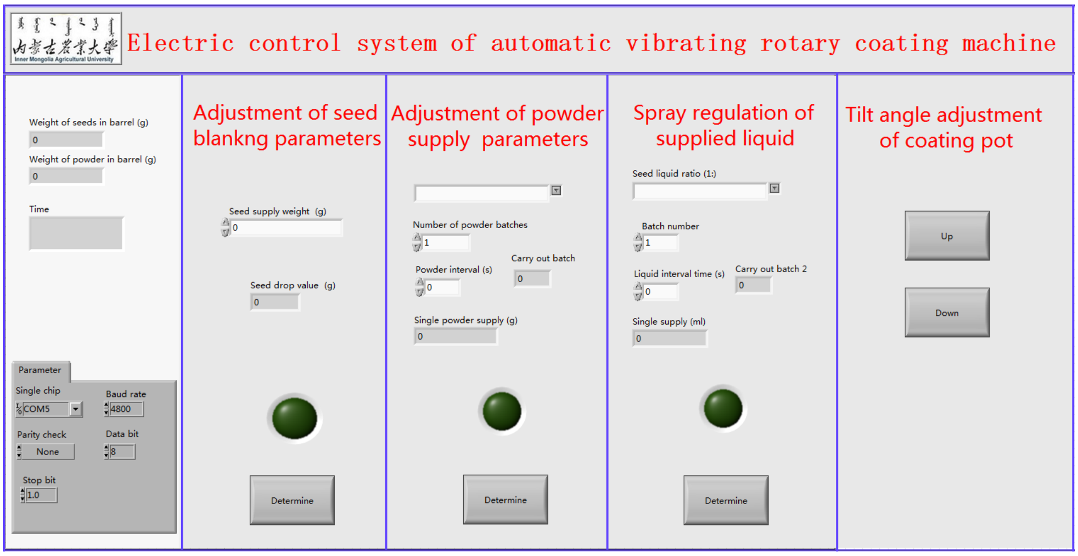

Fig. 6 - The control system

The control system consists of a front panel graphical user interface and a rear panel block diagram. The front panel is the control surface, which has functions such as sending operation instructions, parameter input, and data display. The block diagram of the rear panel uses graphical language to realize the logic control of the control system (*Gülden, 2020*).

The control system mainly realizes the precise control of the amount of seed supply, powder supply and liquid supply, as well as the adjustment of the inclination angle of the coating pan. At the same time, real-time detection of the weight change in the hopper to observe the margin.

Considering that the amount of coated seeds in a single time is too large, the function of supplying powder and liquid in batches is set up, which improves the intelligence of the system.

The specific control flow chart is shown in Fig.7.

First, the equipment is powered on, initialization adjustment and serial port selection are carried out. The appropriate single-chip serial port, baud rate, parity check, data bit and stop bit are adjusted. The default data can be adjusted to facilitate the next direct power on. During normal operation, the current seed and powder allowance will be displayed in real time, and the replenishment will be prompted if the allowance is insufficient. Before coating, select the parameters such as the ratio of seed to powder and the ratio of seed to powder liquid, adjust the dip angle of the coating pan, and adjust the rotary frequency converter to the appropriate speed of the coating pan.

If the supply is too much, batch supply can be selected. In the coating process, seed supply is carried out first, the valve of seed feeding system is opened, seeds in the seed charging barrel start to fall, and the weight information is transmitted by the load cell of seed feeding system to single chip computer in real time. After being converted by the Single Chip Microcomputer, the weight value is displayed in the upper computer control system in real time. Before operation, the system records the total weight of seeds in the seed charging barrel. During the seed feeding process, the system calculates the weight difference in real time. When the difference value reaches the set seed dropping value, the valve of seed feeding system closes, so as to complete the seed supply.

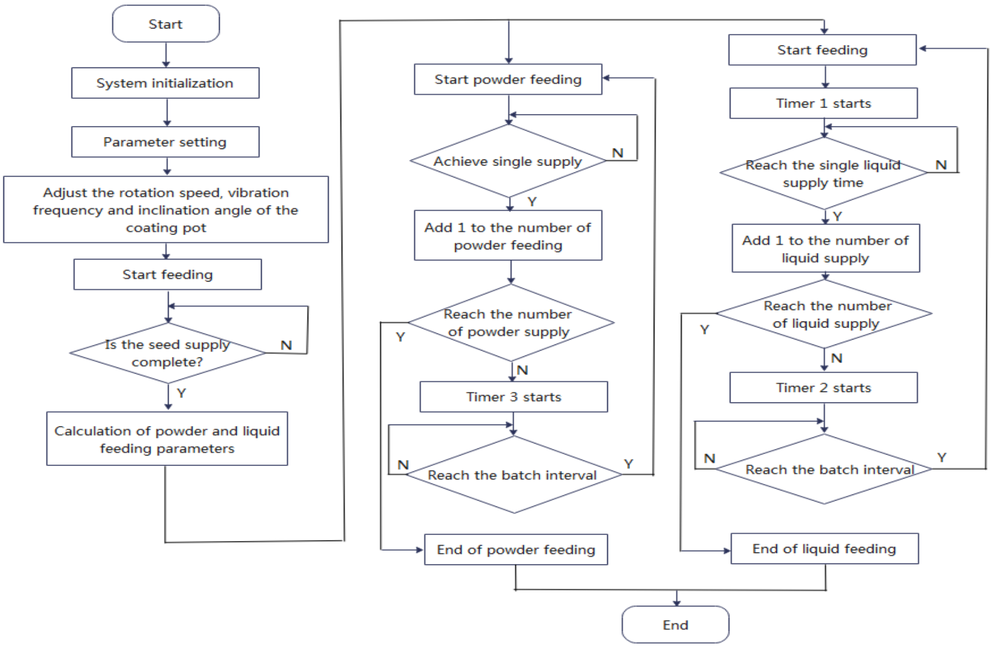

Fig. 7 - The specific control flow chart

After the seed supply is completed, the system records the supply amount, and calculates the single powder supply and single liquid supply by setting the seed powder ratio, seed liquid ratio, powder feeding batch, and liquid feeding batch. The single supply rotation angle of the stepping motor of the powder supply system is calculated through the calculation of a single supply of powder. After the calculation is completed, click Determine to start supplying. During the powder supply process, the indicator light will be on, indicating that the powder supply system is working. When the powder is supplied, the stepping motor of the powder supply system starts to rotate, and the powder in the powder container begins to fall. When the rotation angle of a single supply is reached, the number of powder supply increases by one. When the initial set powder supply batch is not reached, the powder supply system timer 3 starts to time, and when the set powder supply interval time is reached, the powder supply process is repeated. When the number of feeding times is equal to the initially set powder supply batch, the entire powder supply process is completed.

When supplying liquid, click Determine to start liquid supply, peristaltic pump starts to run, the liquid supply system timer 1 starts to time, during operation, indicator light is on, indicating that liquid supply is in progress. The system calculates the single working time by the spray amount per second of the nozzle and the single supply quantity of the setting. When the liquid supply system timer 1 reaches the single working time, the peristaltic pump stops running, and the number of liquid supply is added 1. At this time, the system compares the number of liquid supply and the initial set batch of liquid supply, and completes the whole liquid supply process when the batch reaches the liquid supply batch. When the batch of liquid supply is not reached, the liquid supply system timer 2 starts to time. When the liquid supply system timer 2 reaches the set liquid supply interval, the peristaltic pump starts to run and repeat the liquid supply process.

The upper computer communicates with the lower computer all the time to realize the functions of data transmission and module operation (*Xiong, 2019*). When the operation conditions are met, serial port communication is conducted through USB data line to control the high and low level of the CPU pin, so as to control the switch of relay and realize the switch control of specific modules. Finally, the whole coating process of rotary seed coating machine is completed. The circuit diagram of the system design is shown in Fig.8.

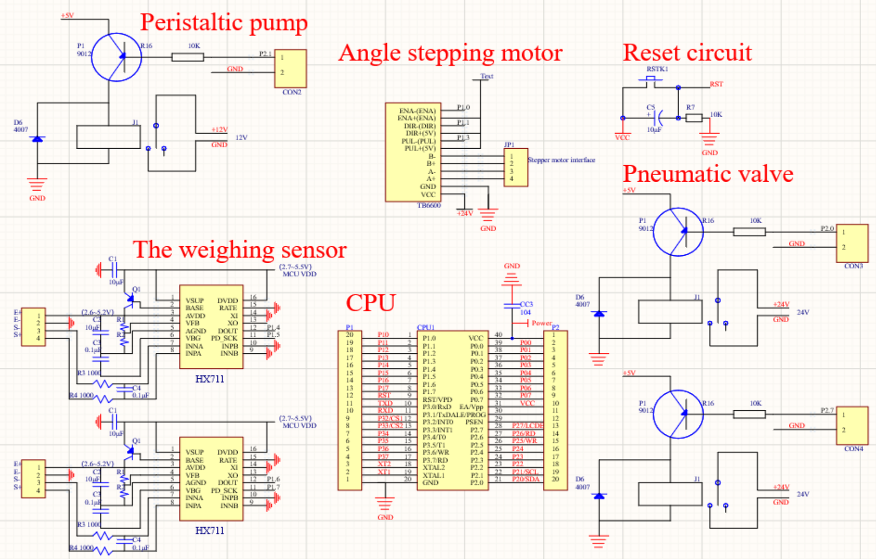

Fig. 8 - The circuit diagram of the system design

RESULTS AND DISCUSSIONS

ERROR ANALYSIS AND CALIBRATION TEST

In order to realize the precise supply of each module and meet the precision requirements during coating work, error analysis and calibration experiments were carried out on the seed supply system, powder supply system and liquid supply system. The physical picture of the coating machine is shown in Fig.9.

Fig. 9 - The physical picture of the coating machine

Calibration of seed supply error

The seed supply system uses a pneumatic valve to control the start and stop of the seed supply. The start and stop of the valve send instructions from the serial port to the microcontroller through the host computer. After the microcontroller receives it, the pin level is changed in real time, and the relay connected to the pin is used as a switch to control the pneumatic valve. The solenoid valve is turned on and off, and finally the valve opens and closes in real time. Considering that there is a time difference between the start and stop of the pneumatic valve, a small amount of excess seed drop is caused, which affects the precise supply of seeds and causes errors. In summary, choose the supply values of 100g, 500g, 1000g, 1500g and 2000g, and conduct multiple tests for comparison. The test results are shown in Table 1.

Table 1

Test value of feeding error

Supply values (g)	Number of tests	Average value of seed drop (g)	Standard deviation
100	20	128.3	1.26
500	20	528.9	1.32
1000	20	1027.8	1.28
1500	20	1527.9	1.30
2000	20	2028.1	1.28

The error is calculated from the data in the table, and the average of the results of five times can be obtained. According to the experimental data, the error caused by the difference between the start and stop time of the pneumatic valve is about 28g, which is independent of the seed supply weight. Before coating, the system initially records the weight of seeds in the hopper. During operation, when the weight loss value in the hopper is equal to the selected value, it sends an instruction to close the valve and stop the seed supply. Taking into account the error value brought by the valve, when the weight loss value is set equal to the selected value minus 28g, the control system will stop the seed supply. Several tests were performed to analyse the errors, and the test results are shown in Table 2.

Table 2

Calibration test value of seed supply

Supply values (g)	Number of tests	Average value of seed drop (g)	Standard deviation
100	20	101.1	1.26
500	20	500.0	1.08
1000	20	1000.8	1.22
1500	20	1500.9	1.26
2000	20	2001.3	1.28

According to the data in Table 2, the error value of the seed supply after calibration is stable within 2%, which meets the design requirements.

Powder supply calibration design

During the coating process, the upper computer calculates the required powder supply amount through the weight of seed supply and the seed-powder ratio, and sends instructions to the lower computer through the upper computer. Each instruction controls the stepping motor to rotate 90°. At this time, the impeller metering disc rotates 90°, 100g powder supply, complete one-time powder supply. Times of powder feeding is calculated in the upper computer control system, and the cycle runs until the powder supply ends. In order to detect the error of the powder supply system, a number of tests were performed to analyse the error. The test results are shown in Table 3.

Table 3

Powder supply system error

Supply values (g)	Number of tests	Average powder drop value (g)	Error rate (%)
100	20	100.56	0.56

According to the experimental data, the error of the powder supply system is within 1%, which meets the design requirements.

Liquid supply calibration design

The amount of liquid supply depends on the operating time of the peristaltic pump. In order to achieve the effect of accurate liquid supply, the peristaltic pump needs to be accurately sprayed. The working voltage of the peristaltic pump selected in this design is 12 V, the rated current is between 4 and 6.5 A, and the spray volume depends on the current, which is 7 to 9 litres per minute. In the actual running process, the timing function is set on the upper computer, and the duration is calculated according to the liquid supply amount, and the liquid supply is completed by the arrival time. In order to accurately calculate the amount of sprayed liquid, choose to electrify for 10 s, 30 s, 60 s and 120 s, and perform multiple tests. The test results are shown in the Table 4.

Calculated value of liquid supply flow **Table 4**

Liquid supply time (s)	Number of tests	Average value of liquid supply (ml)	Liquid supply per second (ml/s)
10	25	1063.2	106.3
30	25	3180.4	106.0
60	25	6390.6	106.5
120	25	12744.6	106.2

After calculation, the average value of multiple results can be obtained. The spray volume is 106 ml/s. When the actual liquid supply is 100 ml, it takes 0.94 s. In the control system, the cycle time is adjusted from 1000 ms to 940 ms, and 100 ml liquid is provided after one cycle.

Experimental results and analysis

In order to test the coating pass rate after the actual coating by the machine, the Agropyron seed are selected for the test. The powder is selected from soybean powder and diatomaceous earth mixed in a ratio of 4 to 6, and the pass rate of the coating after the traditional manual operation is used as the contrast, 50 sets of experiments were performed. Each group of seeds weighs 100g, choose the seed-powder ratio of 1:3 and the seed-liquid ratio of 1:2. When the seed coating agent is completely coated on the outer surface of the single seed is recognized as qualified as the coating, the qualified rate is calculated as the percentage of the number of qualified seeds in the total number of seeds tested. The test results are shown in Table 5.

Table 5

Coating qualification rate comparison table

Number	Traditional coating pass rate (%)	Instrument coating pass rate (%)	Difference	Number	Traditional coating pass rate (%)	Instrument coating pass rate (%)	Difference
1	71	89	18	26	69	88	19
2	69	88	19	27	72	89	17
3	70	89	19	28	70	90	20
4	70	86	16	29	68	86	18
5	68	85	17	30	66	85	19
6	68	86	18	31	71	89	18
7	71	89	18	32	72	87	15
8	68	85	17	33	69	88	17
9	70	88	18	34	70	88	18
10	72	87	15	35	73	88	15
11	71	90	19	36	71	86	15
12	67	86	19	37	67	83	16
13	69	84	15	38	66	84	18
14	70	87	17	39	69	86	17
15	67	85	18	40	70	85	15
16	71	86	15	41	71	87	16
17	74	90	16	42	73	90	17
18	66	83	17	43	69	84	15
19	65	82	17	44	66	86	20
20	69	85	16	45	68	87	19
21	71	89	18	46	70	88	18
22	68	83	15	47	68	85	17
23	72	89	17	48	69	84	15
24	73	90	17	49	66	82	16
25	70	88	18	50	71	86	15

The results show that the coating pass rate of the new type of rotary coating machine designed this time is 15%-20% higher than that of the traditional manual coating.

The difference of qualified rate of coating is shown in Fig.10.

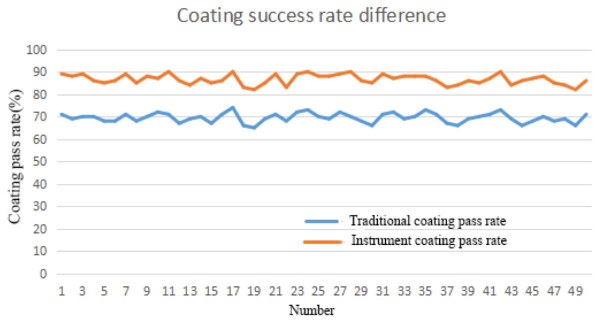

Fig. 10 - Contrast curve of coating success rate

CONCLUSIONS

This paper introduces the design structure of a new type of rotary coating machine, designs the electric control system of the coating machine by LabVIEW software, and controls it by MCU and other hardware modules. The automatic operation of coating process is realized, which can effectively improve the speed and quality of coating. On the premise of achieving the required function of coating process, the error calibration of each module was carried out, and the coating test of Agropyron seed was carried out.

The conclusion is as follows:

1) The error of seed feeding system, powder feeding system and liquid feeding system is controlled within 2% to meet the demand of precise supply.

2) Compared with the traditional manual coating, the qualified rate of the seeds coated by the new rotary coating machine increased by 15% to 20%.

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