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Design of the preparation system of nanofiber membrane

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ABSTRACT

Electro spinning as the main technology for preparation of nanofiber membranes still displays some shortcomings such as low control accuracy. Therefore, PLC is designed as the control center to carry out real-time detection and correction on the spinning process parameters through the sensors and AD/DA conversion module and display the results on the touch screen. Meanwhile, the combination of stepper motor and multi-axis motion control mode greatly improves the control accuracy of the preparation system. The experimental results show that the design achieves the purpose of precise preparation and dynamic monitoring of two-dimensional nanofiber membranes.

Keywords: Electro Spinning, Touch Screen, Nanofiber Membrane, PLC, Multi-Axis Motion Control.

1. INTRODUCTION

With the development of nano-technology, nano-materials are enabled to play an important role in many fields and become the most active part of nano-technology. And electrostatic spinning as an important method for preparation of continuous nanofibers is characterized by extensive applicable materials, controllable fiber dimension and structure and simple procedures, developing towards quantitative production[1-4]. However, the electrostatic spinning technology involves massive motion control, and the early motion control technology is single in control function and insufficient in control accuracy, greatly hindering the development of nano-fiber membrane manufacturing[5-7]. Hence, a preparation system with the multi-axis motion function and high control precision is designed in light of the above-mentioned defects, which adopts the S7-200 SMART PLC as the control core and the sensor, the stepping motor and the analog-digital conversion module as the auxiliary structure; and the introduction of the touch screen establishes a platform for the realization of human-computer interaction. The final experimental results show that the design can achieve the control effect of high precision and complex multi-axis motion.

2. OVERALL STRUCTURE OF THE SYSTEM

The electrostatic spinning preparation system usually consists of three parts: high voltage power supply, syringe pump and receiving devices. In the electrostatic spinning process, under the action of the electric field force in the presence of a high voltage electric field, electrostatic droplets move from the end of the capillary to the receiving devices in the form of jet flow, during which the accelerated movement is completed to stretch the jet-flow in the electric field and thus to obtain ultrafine fibers. This process is mainly completed under the operation of the feed pump, mobile spinneret needle, high voltage power supply and receiving shaft. The specifics are shown in Figure 1.

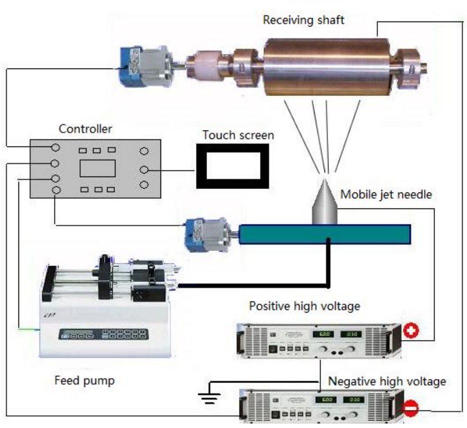


Figure 1. Structure diagram of the system

There are mainly three aspects of process parameters: solution parameters, process parameters and environmental parameters. The solution parameters are mainly the solution concentration, viscosity, surface tension, conductivity, etc., which are inconvenient to be controlled; so the system design is focused on the regulation control of process parameters and environment parameters. The process parameters include the magnitude of the voltage, the anode-to-cathode distance, the solution flow and the speed of the receiving shaft. The environmental parameters include the temperature, humidity and airflow speed of the spinning zone.

The feed pump mainly functions to push the syringe and control the solution flow rate, and the feeding speed is adjustable in the range of 0~1000um/min. The mobile spinneret needle can adjust the distance between the needle and the receiving shaft between 15 ~ 50cm and control the uniform distribution of the fiber through reciprocating movement. The high-voltage power supply provides electric field for the electrostatic spinning with the effective output value between 0~20kw. The speed of the receiving shaft is within the range of 0~500r/min. The controller can realize the intelligent control of the spinning process through centralized control on the feed pump, the mobile spinneret needle, the receiving shaft and the high voltage power supply, thus obtaining the required nanofibers.

In order to precisely control the movement of the feed pump and maintain its long-time low-speed operation, the stepper motor is selected as the motor of the feed pump and the screw mechanism is employed to convert the rotary motion of the motor into linear reciprocating motion in the meantime. Additionally, the controller is used to control the forward and reverse rotation and the speed of the stepper motor, which can satisfy the control requirements of the receiving shaft.

3. THE HARDWARE DESIGN OF ELECTROSTATIC SPINNING

3.1 The main controller PLC

PLC is adopted as the control core in this system. The electrostatic spinning system is required to meet the requirements of high precision, fast response, multi-axis complex movement and spinning environment control; and the spinning environment process is unstable, so the equipment needs to satisfy the optimization and modification of the different process requirements. The electrostatic spinning system also involves the control of many switch values and analog quantities, so the PLC should be equipped with the corresponding analog input and output modules, and the input module is required to realize simple computing and A/D conversion. The electrostatic spinning system has high control demands for motion modules because it needs to implement complex actions and frequent positioning control, which poses high requirements for the response speed; thus, the PLC selected should possess the high-speed pulse output and the motion control function module. The system is equipped with the host computer and touch screen, and the Ethernet communication is used to achieve data transmission, so the PLC should possess a standard Ethernet interface supporting various terminal connections; besides, the PLC should have the scalable I/O module function to facilitate future adjustment and optimization.

Based on the above-mentioned control selection requirements analysis and the comparison of market products, the Siemens PLC S7-200 SMART standard programmable controller is finally selected, which is characterized by explicit functional division consistent with the program and excellent external device communication, being able to adapt to the complex field conditions and facilitating the coordinate management and resource sharing.

3.2 Stepper motor

The stepper motor is characterized by low price, reliability, simplicity in start and stop, forward and reverse rotation and variable speed; and the PLC can also precisely control the stepper motor. Therefore, the stepper motor fully meets the control requirements of the moving shaft and the feed pump with its stability in control. But it cannot be used directly as an ordinary motor; the stepper motor must be equipped with the corresponding driver, and then the pulse signal is sent through the controller to control its positioning and speed variation. The connection diagram of the stepper motor and the driver is shown in Figure 2.

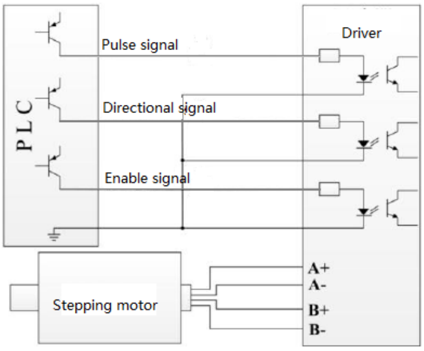


Figure 2. Connection diagram of stepper motor and the driver

3.3 Machine design

The system is mainly applied to the preparation of two-dimensional nanofiber membranes. Aimed at the control of the airflow velocity, the uniformity of the membrane and formation of the two-dimensional nanofiber membrane during the preparation process, the receiving device is designed as shaft model; the feed pump is mainly designed through the application of the screw mechanism to convert the rotational motion of the motor into a linear motion; and the design of the receiving shaft solves the problem of air flow during the spinning process. The uniformity of nano-film also affects the quality of nano-materials. Therefore, the mobile spinneret design is adopted to compensate the non-uniformity of single fixed spinneret through the single needle horizontal mobile spinneret. In addition, the TPC1061Ti Kunlun Tongtai touch screen is employed as the man-machine interaction process parameter input device of the system, and the man-machine interface is used to set the process parameters of the electrostatic spinning, thus achieving real-time adjustment of the parameters.

Based on the above-mentioned, the PLC control system structure is determined as shown in Figure 3.

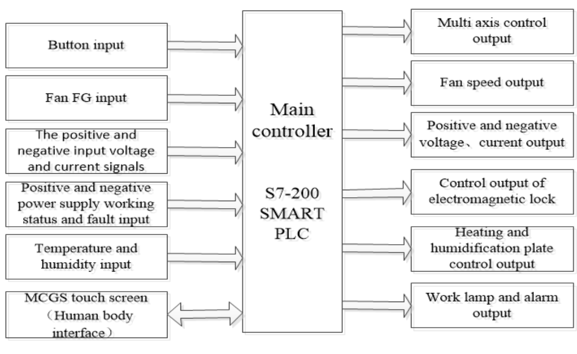


Figure 3. PLC hardware structure diagram

4. SOFTWARE DESIGN OF ELECTROSTATIC SPINNING

Software design is the precision and specification process of data structure, program structure and process steps. The software design of this system includes PLC software design and touch screen software design. The PLC control program mainly includes the main program, subprogram and digital-to-analog conversion program. The main program is applied to system initialization, parameter setting and data processing; the subroutine is responsible for signal output and signal execution; the digital-to-analog conversion program is designed to complete the conversion between analog quantity and digital quantity; the touch screen man-machine interface design mainly includes parameter settings screen and data display screen.

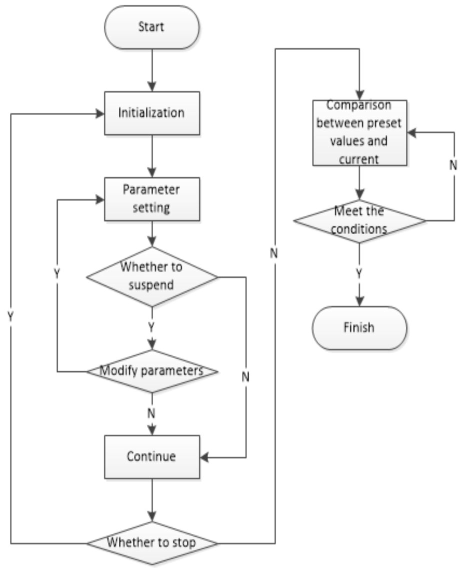
4.1 PLC software design

The overall program control: when the PLC is powered up, the program will initialize the data, reset the setup parameters of the motion axis, set the voltage and temperature, etc.; the subroutines are set to be always connected in the first scan cycle to define the parameters and determine whether the machine stops. If the detected machine works properly, the device will enter the normal working status. The specific design flow is shown in Figure 4 (a).

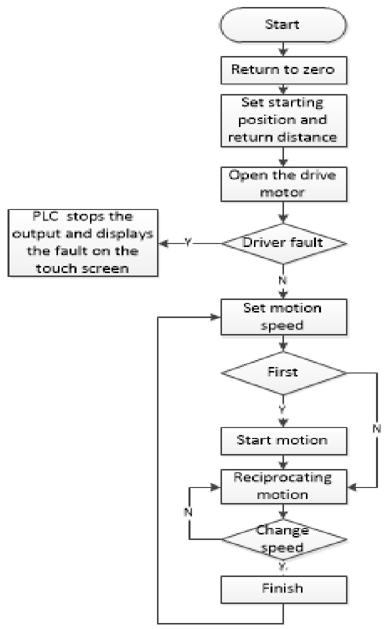
(1) The mobile axis control: the mobile axis mainly controls the two-phase subdivision stepper motor and regulates the forward and reverse rotation and speed of the motor; the mobile axis control mainly involves the combination of sensor and displacement control, rendering the spinneret needle to conduct reciprocating movement. Here the mobile axis rotation is required to produce 4mm displacement, and the specific design process is shown in Figure 4 (b).

(2) The feed pump unit: the power source of feed pump is the stepper motor, and the generation speed of pulse signal determines the speed of the feed pump propulsion device. On account of the control accuracy of the electrostatic spinning system, the advance speed is required to be extremely low with relatively long operation time. So the feed pump module contains speed control and time control, and the operation time is controlled by the total number of pulses and the number of pulses per second. Therefore, the PLC pulse frequency can be used to control the speed of the device.

(3) The positive and negative power control: the positive and negative power control and temperature and humidity control both involves the conversion of analog signals into digital signals or digital signals into analog signals. Taking positive voltage control as an example, the analog quantity of 0-50KV is required to be converted into the digital value of 0-27648, and their mutual conversion satisfies the linear proportional function.



(a)



(b)

Figure 4. PLC hardware structure diagram

4.2 Software design of touch screen

Configuration screen design is to achieve the establishment of man-machine interface, which is the operating environment for the users to operate computer systems, thus completing the interaction of user information and computing language. The users also send motion parameters and control instructions to the PLC system through the input unit of the touch screen display device, contributing to the efficiency and convenience of the work. Figure 5 is the main screen design of the touch screen.

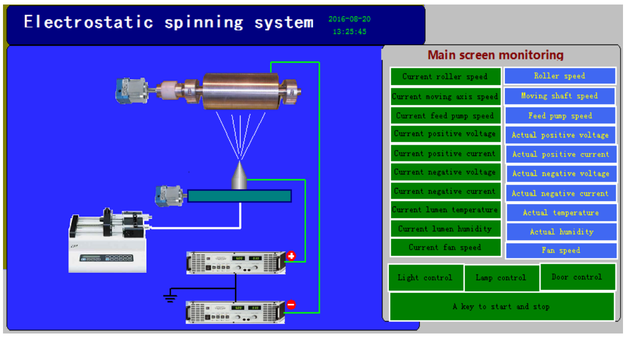


Figure 5. The main screen design of the touch screen

4.3 Experimental commissioning and operation

After completing the circuit connection and software programming, the program will be downloaded to the PLC and the touch screen when the hardware device is detected to be correct, and joint commissioning is carried out through the host computer and the touch screen.

The preparation of nano-fiber membrane can be conducted after determining that the control mechanism can operate stably and accurately for a long time; and the nano-fiber membrane can be obtained after the completion of parameter setting. Figure 6 shows the prepared nanofiber membrane.

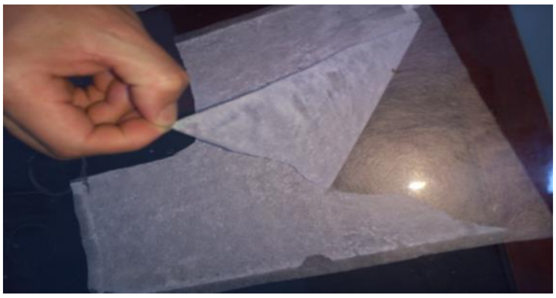


Figure 6. Two-dimensional nanofiber membrane

5. CONCLUSION

Based on the full understanding of the principle and research status of the two-dimensional nanofiber membrane preparation by electrostatic spinning, a preparation system of nanofiber membrane based on PLC is designed with distinctive layers and rigorous layout, which is convenient for postmaintenance. After debugging, the entire electrostatic spinning system has been able to carry out stable, accurate and reliable operation for a long time, showing excellent field application effect and possessing certain application and promotion value.

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