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Control system of automatic hot-melt welding machine based on servo motor

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Abstract

Polyethylene pipeline hot-melt welding machines widely used in natural gas, water supply, mining and other fields usually use hydraulic presses as power, while polyethylene pipeline welding environment is complex and often needs to work in urban, suburban, wild and other conditions. But the hydraulic press is not only bulky and unsuitable to carry, but also expensive. To solve the above problem. A fully automatic hot-melt welding machine based on servo motor was developed. The low-speed curve of the servo motor is smooth, and the torque output is stable, which can fully meet the requirements of the welding process, and the weight is lighter and the price is lower. The servo motor is used as the power, and the STM32 single-chip microcomputer is used as the core to drive the servo motor, perform timing, and collect data. RS485 communication reads the output torque of the motor, the LCD displays the relevant parameter data in real time, and the SD card stores the data to complete the development of the automatic heat fusion welding machine control system.

Keywords

Hot melt welding; servo motor; RS485 communication.

1. Introduction

Polyethylene plastic pipes are widely used in gas, water and other fields due to their advantages of light weight, corrosion resistance, smooth pipe wall, good windability, reliable interface, and convenient operation and maintenance [1]. There are many ways to connect plastic pipes, such as electrofusion welding, hot melt welding, socket butt joint, etc. The welding of polyethylene pipes with medium and large diameters such as natural gas, water supply and drainage, etc. is mainly based on hot melt welding, which is easy to operate, highly economical, and reliable in welding joints [2]. In order to obtain a reasonable hot melt welding process and efficient and reliable welding equipment, experts and scholars have done a lot of research [3,4,5]. According to the degree of automation, hot-melt welding machines are divided into manual hot-melt welding machines, semi-automatic hot-melt welding machines, and automatic hot-melt welding machines. The existing automatic or semi-automatic welding machines on the market generally use hydraulic pumps to provide welding power. Although the hydraulic pump can accurately control the required pressure, the hydraulic station part is bulky, expensive, difficult to handle and troublesome to maintain in long-term use.

With the development of modern motor control theory, servo motor control technology has become an important part and is developing in the direction of digitization. It has experienced the development process from stepper motor, to DC motor, and then to AC motor. Today's servo motors have the advantages of superior performance, good low-frequency characteristics, fast

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speed response, high control accuracy, and good torque-frequency characteristics [6]. And the price is relatively cheap. The characteristics of the servo motor can fully meet the requirements of the welding process of the hot melt welding machine, and the light weight and economy are more dominant. This subject takes the servo motor as the driving force, and uses the STM32 single-chip microcomputer as the core to drive the servo motor, perform timing, and collect data. The output torque of the motor is read by RS485 communication, the key data is displayed on the LCD in real time, and the data is stored in the SD card to complete the development of the control system based on the servo motor for the automatic hot-melt welding machine.

2. Process flow of hot melt butt joint

The hot melt welding process is divided into four stages: preparation stage, endothermic stage, switching stage, and welding stage [7]. The process flow diagram of this article describes the process of automating the welding process starting from the endothermic stage.

2.1. Process flow of hot melt butt joint

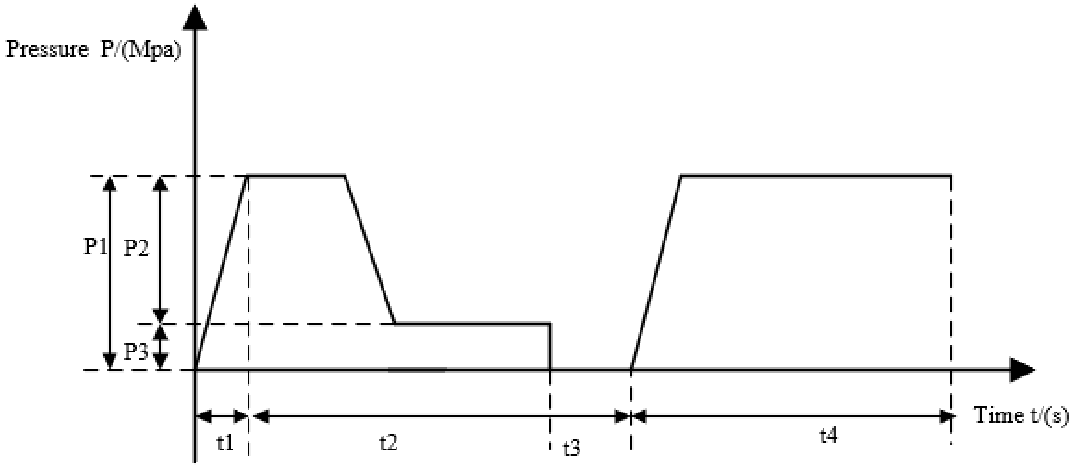

Figure 1 Welding process flow chart

(1) t1—drag time, the motor judges the drag force required to drag the pipe. When the motor torque increases from zero to just before the pipe can be dragged, the pipe remains stationary and there is no displacement feedback. When the pipe starts to drag, the motor encoder starts to feedback the displacement.

(2) t2—the heat absorption time of the crimping, the pipe is crimped first, and then the pressure is released to absorb the heat.

(3) t3—switching time, the time it takes to drag the pipe slightly backwards and then remove the heating plate. The switching time is required to be within 5S, and the shorter the switching time, the better.

(4) t4—welding time, when the switch ends, drag the two pipes closer to butt joint and maintain a certain pressure.

2.2. Drag force identification

PE pipes are widely used, which makes the environment of their welded pipes complex and changeable. As a result, when the pipeline is welded, the drag force may vary greatly, and the pressure during welding is constant during heat absorption and pressure holding, so it is necessary to identify the drag pressure required in the corresponding environment.

The principle of drag force identification is as follows:

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$$\mathrm{P_o} = P_0$$
$$\mathrm{P_o} = P_0 + \Delta P$$
$$\mathrm{P_o} = P_0 + 2\Delta P$$
$$\cdots\cdots$$
$$\mathrm{P_o} = P_0 + \mathrm{x}\Delta P$$

P_0 is the output drag force, P_0 is the initial input drag force, ΔP is a fixed value, and the gain drag force. To identify the required drag force, first give a small drag force, and the encoder feeds back the position information of the motor rotation. If it does not move, increase the drag force ΔP, and judge again that it is all moving. If it has not moved, continue to superimpose ΔP . Until the motor rotates, the output Po at this time is the welding pressure required in this welding. The output torque of the motor is equal to the load. When the motor starts to move, the output torque is the required drag force. After the motor starts to move, it starts to accelerate to the set running speed with the set acceleration, and approaches the heating plate at a constant speed.

3. Hardware Design

3.1. Structure of hot melt welding machine

The servo motor is connected with the reducer through a rigid coupling to increase the output torque to reduce the power requirement of the servo motor, reduce cost and overall power consumption. In the process of pipeline docking, there is a high requirement for concentricity. Both ends of the movable bracket need to be uniformly and synchronously stressed, and the welding process has certain requirements for displacement accuracy control. Therefore, the synchronous belt transmission is used to ensure the force. Synchronous belt material uses PU polyurethane steel wire with high strength and good wear resistance. The movement of the movable clamp is driven by a self-locking screw screw. It is convenient to use the mechanical gap to relieve pressure during the heat absorption stage. The structure diagram of the hot melt welding machine is shown in Figure 2 below.

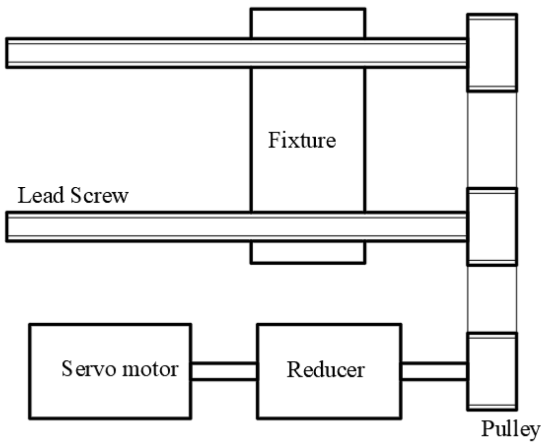

Figure 2 Model of automatic hot-melt welding machine

3.2. The overall module design scheme of the control system

The automatic hot-melt welding machine control system mainly includes the minimum system module of single-chip microcomputer, temperature and humidity sensor module, data storage module, servo driver module, button module, etc. The detailed system structure block diagram is shown in Figure 3 below. The minimum system of the single-chip microcomputer is the simplest hardware circuit that the single-chip microcomputer can work normally. This part of the circuit design is very mature and will not be introduced in detail here. Temperature and humidity sensors are used to detect environmental conditions and are not used as a control factor for automatic welding processes. The data storage is realized by SD card, the drive of the servo motor is controlled by pulse output, and the L298N module is used as an amplifier to output 5V voltage. The following space only introduces a few main modules of these modules.

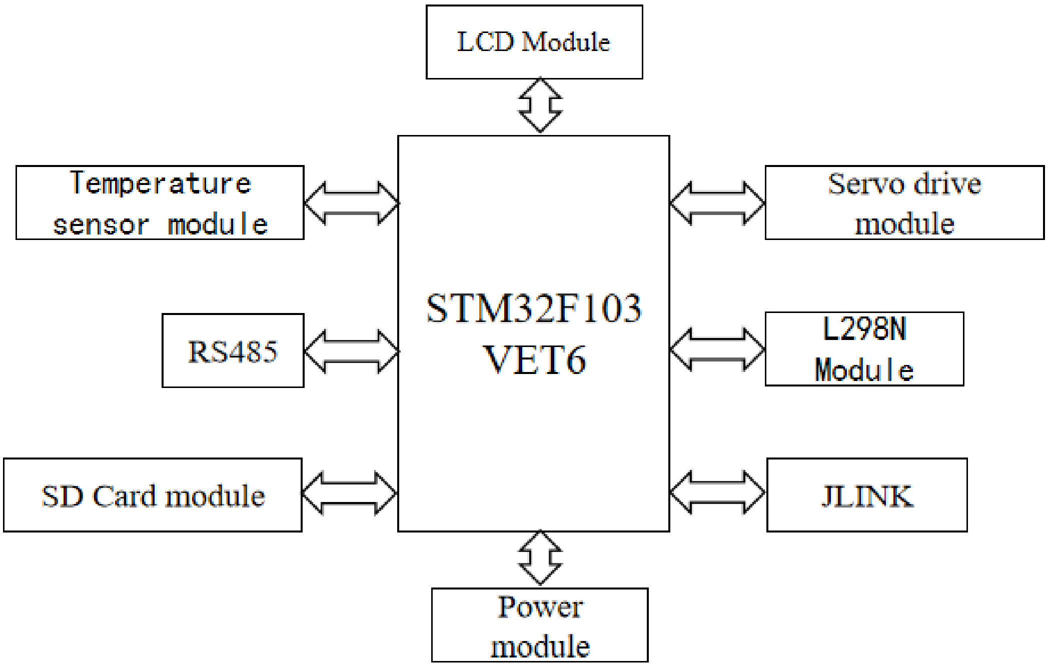

Figure 3 Block diagram of the hardware design of the control system

3.3. Main control chip

The main control chip of this design selects the STM32F103VET6 with the core 32-bit Cortex-M3 core. Low power consumption, high cost performance, the maximum operating frequency is 72MHZ[8], the memory 0 waiting cycle access can reach 1.2DMIPS/MHz, the response speed is fast, the I/O pins are rich, there is a parallel LCD interface and it is compatible with 8080/6800 mode , easy to develop and design, three 12-bit analog-to-digital converters, embedded with many peripherals, to meet the comprehensive needs of this design, but also provides a standard function library for system development, which greatly shortens the design and development time.

3.4. Servo motor

Servo motors have high positioning accuracy and mature technology, and are used in various equipment that requires precise control of position and torque. It can realize the closed-loop control of position, speed and torque, with fast response and excessive smoothness [9]. In this design, the polyethylene pipe diameter is 180mm as the maximum welding diameter, SDR11 is taken as an example, and the CJJ 63-2018 standard is inquired. The specified welding pressure P2 is 1261/A2 MPa ($P_2 = \frac{A_1 * P_0}{A_2}$, where A1 is the cross-sectional area of the pipe, and A2 is the hydraulic cylinder of the welding machine. effective area of the piston). According to the maximum pressure required for welding, the servo driver of Guangzhou Hechuang company model HC075C2 is selected. The power of the servo motor is 750W, the maximum allowable output torque is 2.4N˙m, and the encoder at the rear end of the motor feeds back the angular displacement signal at 2500 pulses/rev to meet the torque and accuracy requirements. The servo driver has two ports for MODBUG communication with the controller, and the analog DA

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output indicates torque and current information to identify the drag pressure. This system mainly selects the torque control mode.

3.5. Temperature and humidity sensor

The design of the ambient temperature and humidity detection circuit is based on the CHT11 digital temperature sensor developed by Guangzhou Xibochen Technology Co., Ltd. Because of its simple, reliable and cheap characteristics, it is widely used in industry, agriculture, food, medical and other industries . The sensor adopts high-reliability, high-precision humidity sensing components and external high-precision NTC temperature sensing components, and is connected with a high-performance, wide-voltage power supply (2.7-5.5Vdc) digital-analog hybrid microprocessor (MCU), It has an analog logarithmic linear processing circuit inside, and a built-in high-precision 14-bit ADC, with its own enhanced single-bus hardware drive output, with strong drive and anti-interference capabilities. The humidity and temperature drift are automatically compensated internally, and the data can be read. The pin functions are shown in Table 1.

Table 1 CHT11 temperature and humidity sensor pin function

Pin Function	Description
VDD	Power supply (2.7~5.5Vdc)
SDA	Serial data transceiver (bidirectional)
NC	Floating
GND	Power negative supply

3.6. Serial screen

The display screen is a resistive touch screen developed by Shenzhen Taojingchi Electronics limited company, model TJC4827T043-011R, 4.3 inches, with a horizontal and vertical resolution of 480,272. Using string instructions, the data structure is simplified, the screen firmware can be automatically upgraded, the price is moderate, and the development difficulty is small. The interface design is as shown below. The operator logs in to the operating system through the identity information and password to enter the operation interface, and selects the pipe material and diameter to enter the mode selection interface as shown in Figure 4. Manually complete the operation of the preparation stage, and enter the mode selection interface after confirming that the preparation stage is completed. This design supports manual operation mode and fully automatic mode, and the fully automatic mode (the interface design is shown in Figure 5) can also choose the process flow mode based on displacement parameters or Process mode for the pressure parameter process. The manual mode displays the reference data of the selected technological process and the parameter changes of the real-time operation, which is convenient for the construction personnel to work accurately.

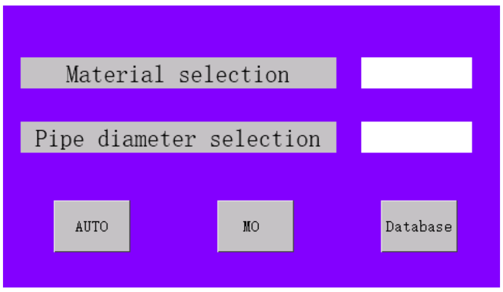

Figure 4 Profile selection interface diagram

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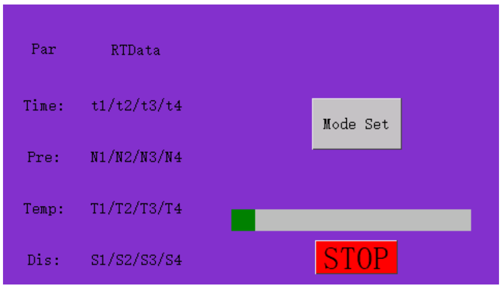

Figure 5Automatic mode interface diagram

4. System software design

The development of the control system designed in this paper is based on the Keil uVision5 software platform, and the program is written in C language. Keil uVision can support Cortex-M. The development of Cortex-R4, ARM7 and ARM&7 series devices has the industry-leading ARM C/C++ compilation tool chain, which has high development efficiency and simple project maintenance [10]. Using the firmware library officially provided by STM32 for programming, the mode development efficiency is high, and the program readability is strong.

4.1. System structure diagram

The single-chip microcomputer outputs pulses of a certain frequency, which enter the servo driver and pass through the amplifier to drive the servo motor to rotate, increase the torque through the reducer, and drive the movable fixture to move by the synchronous belt and screw drive. The system structure diagram is shown in Figure 6 below.

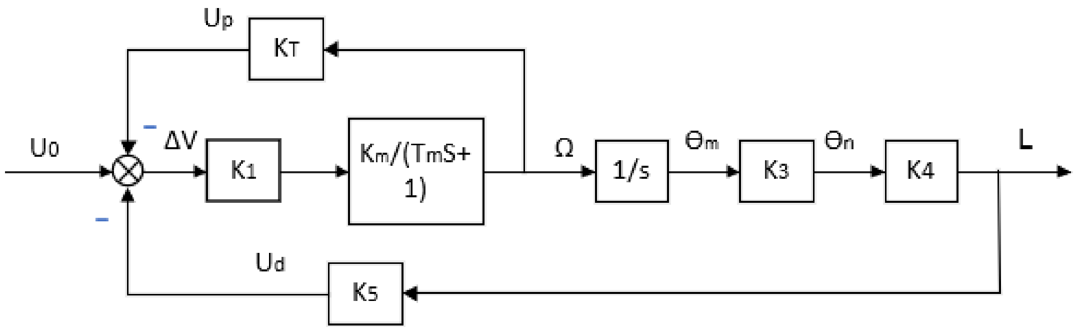

Figure 6 System structure block diagram

(U0, input voltage; Δu, ΔV, voltage signal after passing through the first and second feedback ports; K1, Km; K3, K4, K5, KT, Km, transfer function of each link; Tm motor torque; S, integral link; Ω, the rotation angle of the motor shaft; θm, the output angular velocity of the motor shaft; θn, the output angular velocity of the reducer; L, the output displacement value of the actuator; UP, Ud, the feedback signal)

4.2. Program initialization

All peripherals and modules of the system need to be initialized before the program runs. Mainly involved, GPIO port initialization, timer initialization, USART initialization, RS485 communication initialization

4.3. Program execution process

Referring to the hot-melt welding specification "Technical Standard for Polyethylene Gas Pipeline Engineering" combined with the characteristics of the servo motor, a set of practical and feasible automatic hot-melt welding machine program execution logic block diagram is formulated . Figure 7

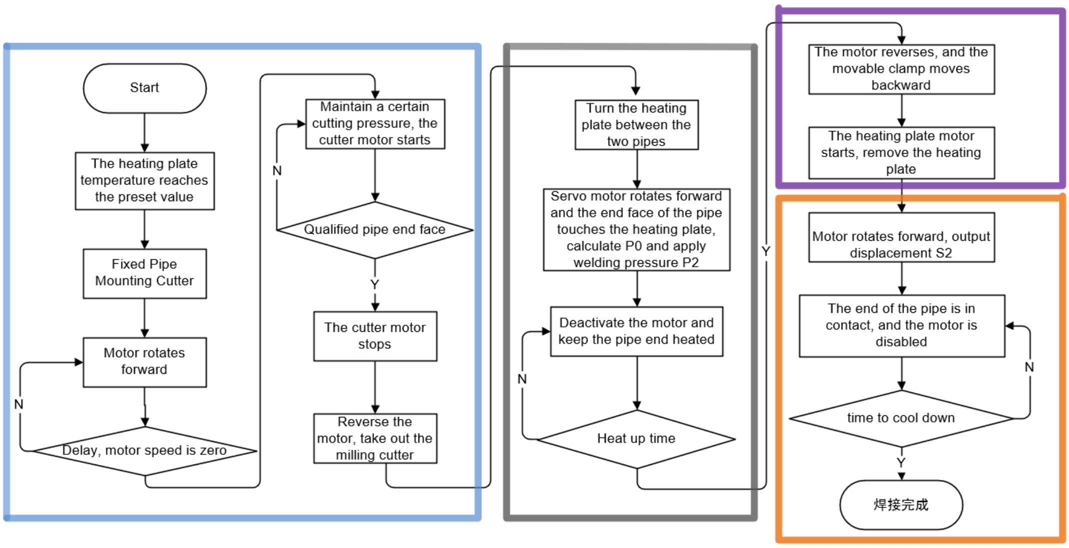

Figure 7 Logic block diagram

The four blocks in the logic block diagram correspond to the preparation stage, the endothermic stage, the switching stage, and the welding stage respectively in the hot melt welding process. The preparation stage mainly relies on manual operation and judgment, and the degree of automation is limited. The specific operation process will not be repeated here.

After the preparation stage is completed, the end faces of the two pipes are separated by a certain distance, and the heating plate is lowered between the two pipes. The servo motor rotates forward (set the direction that the servo motor rotates to make the two pipes close to the motor rotates forward) so that the two pipes touch the heating plate. During the forward rotation of the servo motor, the controller reads the torque data output from the CN2 terminal of the servo drive to calculate The driving force P0 is used as the basic data, and the pressure P2 required for welding is used as an increment. The pipeline reaches the heating plate and the servo motor is blocked, the current increases, and the torque continues to increase to meet the endothermic pressure requirements (that is, the end face of the pipeline is blocked. The pressure is P2), the motor is disabled, the screw is self-locking, and the position of the movable clamp remains unchanged. The pipe continues to absorb heat and wait for the end of the heat absorption.

When the servo motor is reversed, the clamp can be moved back by a distance, the heating plate is removed, and the servo motor is rotated forward. According to the welding specification, the switching time is controlled within 8S. In order to avoid the influence of the welding stage, the shorter the switching time, the better. In this design, the switching time is controlled within 4S.

The motor rotates forward to maintain the welding pressure and wait for the end of welding. The servo motor is disabled by the screw self-locking movable clamp to keep the position still, and wait for cooling to complete the welding.

5. Summary Outlook

This paper aims at the existing problems of the current fully automatic hot-melt welding machine: the hydraulic press is large in size, large in quality and expensive. A set of automatic hot-melt welding machine control system is designed, which relies on the servo motor with smaller volume and mass, easy to carry and relatively low price as the power. And due to the smooth curve of the servo motor, the constant and controllable torque, and the detailed monitoring parameters, this system also has a certain reference value for further exploration of the hot melt welding process.

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