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The Design and Implementation of Infrared Reflow Soldering System

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Abstract

With the development of SMT technology, the use of reflow soldering is more and more widely. The infrared reflow soldering system was introduced in this article, from the control method to hardware and software design aspects were introduced in detail.

Keywords: Reflow soldering, PID, Smith predictor

With the development of SMT technology, the use of Infrared reflow soldering is more and more widely. Nowadays there is trend which the traditional wave soldering was replaced by Infrared reflow soldering. Many research institutions and manufacturers are paying attention in developing high performance infrared reflow soldering. In the control of Industrial process, PID control algorithm with the good and mature feature is widely used in different fields.

Especially in the stable parameters process and not serious nonlinear circumstances, the PID controller can get better control effect. In the work of infrared reflow soldering, in order to improve the quality of PCB solder, we must guarantee the accuracy control of infrared temperature and average distribution of each temperature range.

However, it is difficult of single PID parameters in traditional different range to control accuracy and stability. But it will achieve excellent results with adding Smith Predictor in PID adjustor all areas in different range of PID parameters.

Reflow soldering is a key factor in the SMT production, the demand of manufacture level is very high, soldering temperature: the time curves is directly influence soldering quality, the curve is usually divided into four interval, it is often called rising temperature area (refer to 0 ~ 140 degrees Celsius), preheating area (usually refer to 140 ° ~ 160 degrees Celsius), backflow area(refer to from 210 degrees Celsius start), the cooling area. As shown in Figure 1.

1. System Structure

The system mainly consists of power supply, temperature detection, controller, execute units, alarm and protect circuit this several parts. And figures 2 are as follows:

2. The Control Method

2.1 Regulators Design

As the difficult to establish accuracy mathematical model of object, and system parameters are often changing. It will cost great price in identifying model when applying controller theory to analysis. But it often can not reach the expected effect. So there are many examples in automatic control field. The control system are using digital PID adjustor, it can be divided into position type PID and increment PID, the formula is as following:

$$u(k)=Kp\{e(k)+\frac{T}{Ti}\sum_{i=0}^{K}e(i)+\frac{Td}{T}[e(k)-e(k-1)]\}+u_0 \tag{1-1}$$

$$u(k-1)=Kp\{e(k-1)+\frac{T}{Ti}\sum_{i=0}^{K-1}e(i)+\frac{Td}{T}[e(k-1)-e(k-2)]\}+u_0 \tag{1-2}$$

$$u(k)-u(k-1)=a_0e(k)+a_1e(k-1)+a_2e(k-2) \tag{1-3}$$

$$a_0=Kp(1+\frac{T}{Ti}+\frac{Td}{T}),a_1=-Kp(1+\frac{2Td}{T}),a_2=Kp\frac{Td}{T};$$

$$\Delta u(k)=a0e(k)+a1e(k-1)+a2e(k-2) \tag{1-4}$$

Formula 1-1 is the position type PID, formula 1-4 is increment type PID, compared incremental type to position type, incremental type only calculating incremental. When happen calculation error or precision insufficient, less influence to calculation of empty quantity, However, when position type calculate the accumulative value deviation of past , it will likely to produce to deviation error, It takes long time for reflow soldering in preheating area, but less increment in temperature, it will easily happen error accumulation. So using increment PID algorithm is better.

Due to the reflow soldering system is divided into several different temperature area, and the rising percent of each temperature is different, the stay time is not consistent, we must take different control modes in temperature area, we try to rising temperature rapidly in temperature area, generally we can directly heat without PID control;

In preheating area, it requires that temperature changes slowly and keep for a certain time in this are. Due to the inertia of temperature is large, when enter preheating area, the temperature rising rate is big, in the middle of preheating area, the rising rate maintain in a medium speed rate, and due to entering backflow area in the late of preheating area, the rising temperature rate need improve. If you only use single PID parameters, it can not reach a very good effect, we can adopt the method of driving section. We drive preheating area into three sections, and each section with different PID parameters control, so it can make temperature curve smoother. Similarly in backflow area, there are different temperature rising rate in rising and backflow of temperature. So we take two different sets of PID parameters to control. Specific schemes are as shown in Figure 3.

2.2 Smith Pre-estimated Compensation Aspect

The time lag of temperature control is big, the average temperature can be viewed as a lag system, this lag feature can lead that control effect will not happen timely, cause system overshoot and oscillation, in the system of industrial control, its model often use first-order inertial elements to express, specific formula is:

$$G(s)=\frac{Ke^{-\tau s}}{1+Tis} \tag{1-5}$$

In such system, if only use to PID controller it can not achieve good dynamic effect, and when the time constant is big, it will produce sustained oscillation. Using Smith predictor can achieve good effect for compensation. Schemes are as shown in Figure 4.

Increased the pure lag compensation element and control object are together constituted generalized object, it has the transfer function:

$$\overline{G}(s)=\frac{K}{1+Tis} \tag{1-6}$$

The inertial element in PID controller, it will not happen a series of problems which time-delay brings, and it can achieve better effect. Due to the real object is generalized object with a pure time-delay, so the system output is the generalized object output.

The lag compensation element is:

$$\overline{G}(s)=\frac{K(1-e^{-\tau s})}{1+Tis} \tag{1-7}$$

The discretization of the above formula,it is convenient to use computer to realize idiscretization formula:

$$v(k)=(1-\sigma)u(k-l)+\sigma v(k-1) \tag{1-8}$$

$$d(k)=K(v(k)-v(k-1)) \tag{1-9}$$

$$\sigma=\exp(-\frac{T}{Ti}), l=\frac{\tau}{T}$$

2.3 Hysteresis Comparator

Due to the different temperature control, mainly judge through the temperature of entering warm area as switch signals. If temperature changes in near area, it may be switch control algorithm of this system near controller in two different temperatures. And it caused oscillate over and over in this temperature. To avoid this kind of phenomenon, using the method of hysteresis comparator can be very useful to prevent such interference into occurring. While temperature rises, only when the temperature is higher than the certain point, the system will switch into the temperature area. While the temperature drops, only when the temperature dropped to a certain point, the system will exit the temperature area into another. The diagram is as shown in Figure 5.

3. Hardware Design

3.1 Controller

The control system using ATMEL company ATMega8 chip microcontroller, it is high level chip in AVR series, It also is a kind of embedded high-performance 8 bits microcontroller with advanced RISC Architecture. The microcontroller clock frequency can reach 16MHZ. The MCU speed is 16MIPS, which have two hardware multiplier and 32 8-bit working registers. 32×8-bit general working registers R0 ~ R31 directly connected to in the MCU. And it can directly operate data in 32 working registers.

ATMega8 has three different types of memory, Flash module is one of program memory with 8KB capacity, and each Flash address unit can store binary 16 instruction code block. EEPROM is an electrically erasable programmable read-only memory with capacity of 512×8, static RAM memory with capacity 1K×8. The 8KB FLASH memory can be used 10,000 times and it has online programming (ISP) and in application programming (IAP), users can programme through weld wire high byte, and it can divide FLASH into space area, application area and Boot area. In addition, it can load programme to realize IAP programming through Boot area. ATMega8 has a 4×16 read-only memory, for ATMega8 logo bytes and internal correct value of RC oscillator.

A flexible interrupt module has its control registers in the I/O space with an additional global interrupt enable bit in the status register. All interrupts have a separate interruptvector in the interrupt vector table. The interrupts have priority in accordance with their interrupt vector position. The lower the interrupt vector address, the higher the priority. It has a 18-level interrupt system, each system interrupted by the interrupt source, the priority fixed by the hardware circuit.

ATMega8 has 23 I/O port which can be use programmed, it can not only be used as a general I/O port but also as a function, that is two functions. There are two 8-bit Timer/Counter with Separate prescaler TC0 TC2. And TC2 has compare mode input and asynchronous mode.

ATMega8 has a 16-bit Timer/Counter Prescaler TC0 and TC2 with output comparison function and asynchronous mode which can produce PWM output. WDT is watchdog timers which can return to reset vector in order to run user programme again when make the system disorder because of interference. ATMega8 has three serial I / 0 mouths such as SPI, USART, TWI. Among them, SPI is a serial synchronous peripheral interface, which used in host SPI and other SPI to realize high-speed serial data transmission. ATMega8 integrated a 10 bit A/D converter and simulation comparator. A/D converter can take any analog data to convert for 10 bit digital. These functions of ATMega8 can completely satisfy the infrared reflow soldering requirements.

As the temperature curve data display, real-time tracking of the temperature curve and keyboard scan to occupy a large part of the time. So we use two pieces of ATMega8 respectively to deal with, the one responsible to control and algorithm, the other mainly responsible for the display and keyboard scan, it can make the data transmission with high speed between two SCM by SPI communication. Controller diagram is as shown in Figure 6.

3.2 sensor circuit

Temperature testing is an important factor of temperature control, because the non-linear feature of thermocouple temperature, therefore the temperature need handled by computer linearization. In addition ATmega8 A/D itself exists gain error and disorder itself, and computer must deal with it. So it not only increases the procedure, but also increased the time of computer performs. PT100 Platinum resistor between 0 and 280 ° c perform better and preciser than ordinary thermocouple linearity. It is widely used in this system, so as to PT100 platinic resistance temperature sensor. But the platinum resistance to PT100 temperature curve is still some nonlinear, usually we use method which use software look-up table or computer calculate compensation to compensate linear, but this method occupy many resources and time of controller, and this make the system to decrease efficiency, so we use hardware linear method which not only can reduce the computer for data processing time, but also increase efficiency of controller.

The circuit make linearization compensation to PT100, in the first place, operational amplifier circuit is a process of linearization, it uses the positive feedback to make the compensation. In the second place, operational amplifier circuit is made enlarge and zero adjustment. Use this circuit, the computer can directly read and gather data. In 0 ~ 270 ° c, the temperature rise in linear, without linearization, all of these meet the requirements of the reflow soldering temperature detection. With the hardware circuit for linearization can save a large part of computer resources, and can increase the controller's efficiency. Specific hardware circuit shown in Figure 7.

3.3 Implementation Unit

Infrared heating tubes have some good features which is heating faster, heat evenly and easy to control. It is better than other heat resistance. this system uses infrared tube as heating elements. Its drive circuit using two-way controllable BTA16, and BTA16-off can be used to control AC voltage on and off, and it is triggered by optocoupler MOC3060, so the weak internal control panel will be isolated with strong signals. And the DS2003 are comprised of seven high

Voltage and high current NPN Darlington transistor pairs drive optocoupler MOC3060. Specific hardware circuits are as shown in Figure 8.

3.4 Power and Voltage Protection

Switching power supply with low consumption, high efficiency, small volume, light weight, wide range, high efficiency, the filter can make filter capacitance capacity and volume is greatly reduced, and we considered panel of operational amplifier need power supply of ± 15V. So power part adopts the output of ± 15V DC - DC switching power supply module.

In order to prevent over-high dc bus voltage, over the input voltage switch power supply range , then it damage switching power supply module. So we consider using voltage detection link. Hall voltage and current sensor with large measuring range can measure arbitrary waveform in the any current and voltage. It is fast response(the fastest response time is 1us) and high precision measurement(the measurement precision more than 1%), and the accuracy fits to measure any waveform; Excellent linearity, good dynamic performance, response time May 1us less, Work band is wide, between 0 and 100 KHZ frequency signal can be measured; High reliability, long trouble-free work time and so on. This system uses hall sensors, the input voltage of busbar voltage via a resistor to convert current signal and its value is proportional to the vice current. The vice current signal via next resistor to convert voltage signal, followed by A voltage transmission device of the A/D controller, then it can obtain voltage values of the busbar to prevent over-voltage in busbar. As shown in Figure 9.

4. The Software Design

The display and controller of system are handled respectively by Micro Controller Unit, in order to guarantee the real-time of communication, designing software uses 50us timer interrupt on SPI communication. The communication is by way of inquiry. Judging whether Per 50us every query with a pass judgment whether data need to output or input, and process these data.

Considering temperature change slowly, it do not need sample too fast period, so we formulate sampling period(300ms), this 300ms sampling period is counted by interrupt counting, and in this process, AD samples are filtered, and we use Inertia filter that is first-order resistance and capacitance filtering, its characteristic is good dynamic response. Its equivalent to a low-pass filter algorithm of RC filter simulation algorithm. When hardware simulation RC filter on low frequency interference signals filter, circuit is very difficult to realize, on the other hand, inertia filtering is in digital form to realize dynamic filter method. And method overcomes the shortcomings of simulated filter. Its algorithm is shown in below:

$$Y(k) = (1-a)Y(k-1) + aX(k)$$

All above calculated value will be sent PID adjustor to adjust, controller according to the regulation of output value to control, and according comparing to feedback temperature data (from the value after the filter), determine whether opening or shut off the bidirectional sensitive gate triacs BAT16. Specific software flow chart is as shown in Figure 10.

In the main function, the main task is to deal with temperature data, PID and fault. When the controller do not execute handling interruption, it can always control PID, and it also can calculate more accurately. Troubleshooting primarily is to prevent busbar over-voltage and over temperature. Specific software process show in Figure 11.

Initialization procedure is as follows:

```
.macro     SysInitiation                  ;System Initialization
LDI   rTempMain0,LOW($45F)                ;Set the stack address
OUT   SPL,rTempMain0
LDI   rTempMain0,HIGH($45F)
OUT   SPH,rTempMain0
LDI   rTempMain0,0x0
OUT   SFIOR,rTempMain0                    ; Start on pull-up resistor
OUT   MCUCR,rTempMain0                    ; Free mode
LDI   rTempMain0,0x0                      ;INT0 Pin used as a limit position switch
OUT   GICR,rTempMain0
.endm
.macro     IOInitiation                   ; I/O   Initialization
LDI   rTempMain0,0x2f
OUT   DDRB,rTempMain0
LDI   rTempMain0,0x0
OUT   PORTB,rTempMain0
LDI   rTempMain0,0x0
OUT   DDRC,rTempMain0
LDI   rTempMain0,0b0000000
```

```
OUT     PORTC,rTempMain0
LDI     rTempMain0,0xfd
OUT     DDRD,rTempMain0
LDI     rTempMain0,0x0
OUT     PORTD,rTempMain0
.endm
.macro      ADInitiation                        ; A/D   Initialization
LDI     rTempMain0,0b10011000
OUT     ADCSRA,rTempMain0                       ;enable ADC
;clear ADC Interrupt Flag
;enable ADC Interrupt
LDI     rTempMain0, 0xd0                        ;internal voltage reference with
; extern capacitor,left,
;adjust result,start ADC0 channe
OUT     ADMUX,rTempMain0
LDI     rTempMain0, 0x0
STS     gAdcChannel,rTempMain0
OR      rTempMain0, 0xd0
LDI     rTempMain1,0xd8
OUT     ADMUX, rTempMain0                       ; Start first AD conversion
OUT     ADCSRA, rTempMain1
.endm
.macro      EepromInitiation                    ; Eeprom    Initialization
LDI     rTempMain0,0x0
OUT     EECR,rTempMain0
.endm
.macro      TimerInitiation                     ; Timer initialization
LDI     rTempMain0, 0x9c
OUT     TCNT0,rTempMain0
LDI     rTempMain0,0xff
OUT     TIFR,rTempMain0
LDI     rTempMain0,0x01
OUT     TIMSK,rTempMain0                        ;enable Timer/Counter overflow interrupt
LDI     rTempMain0,0x02                         ;clkI/O/8
OUT     TCNT0,rTempMain0
.endm
.macro      SpiIniation                         ;SPI    initialization
LDI     rTempMain0,0x01                         ;disable SPI interrupt
                                                ;the MSB of data word is transmitted first
                                                ;Master mode,
OUT     SPSR,rTempMain0
LDI     rTempMain0, 0x5
OUT     SPCR,rTempMain0
.endm
```

PID adjustment mainly include Smith compensation algorithm and handling adjusting value conversion; Accumulation the compensation value and feedback value, and then calculating the given value deviation to obtain deviation value. The deviation value is sent into the PID algorithm to handle. After the treatment of data, the data which is value related to temperature will be converted into a time quantity to send to execution unit in order to control the conduction time. As shown in Figure 12.

Processing temperature data is mainly including judgment various temperature area and temperature of the boundaries. In the first place, judging in which temperature area, if it is in the first temperature area, it is directly heated without PID controller, and temperature can rise rapidly. When it is in the second temperature area, we must adjust the data in which temperature area, in order to select the corresponding PID Parameters to control; In the third temperature area, the method is same as the second temperature area, it is also based on the judgment different temperature area so as to select appropriate PID parameters, When it entering the fourth temperature area, namely, cooling area, the backflow process has already ended, and temperature will drop quickly. Then at the moment, all infrared tubes can be quickly closed off, through the air to cool, and the temperature drops rapidly. As shown in Figure 13.

5. Summation

The experiment proved that this system are practical,debuging convenient and high temperature curve smoothness. It is controlled section by section in temperature area so as to changing temperature more smooth, good control effect and temperature rise evenly in preheating area, and then it can make the solder fully heated. With the continuous development of electronic industry, technology of patch is widely used, more and more demand for reflow soldering, and the requirements of controlling temperature area will be more and more high, this system can not only meet the requirement of temperature control, but also it can make the volume of reflow soldering compared with the traditional desktop device smaller. Then it result that the costs are decreased, and it can be more widely used.

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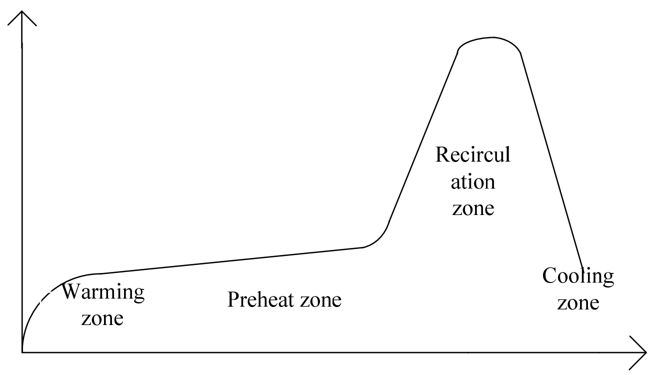

Figure 1. Reflow Temperature Area

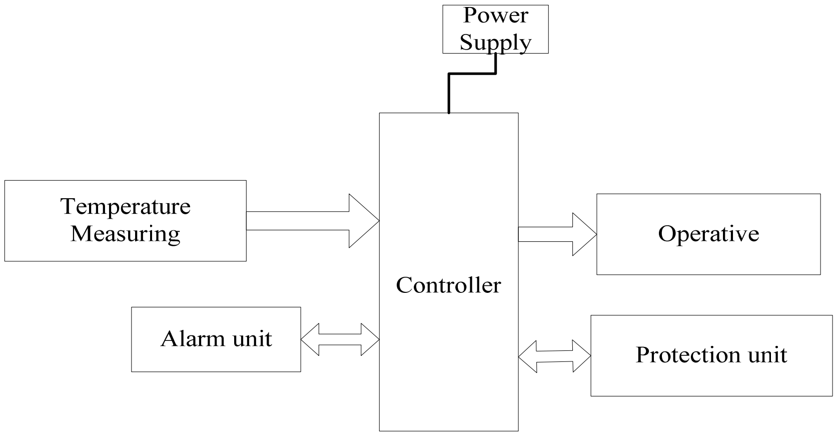

Figure 2. the System Structure

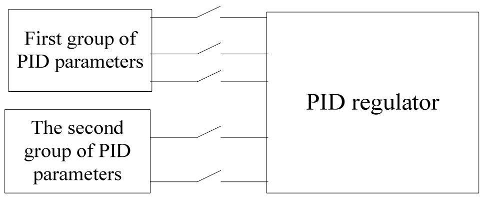

Figure 3. PID parameter selection

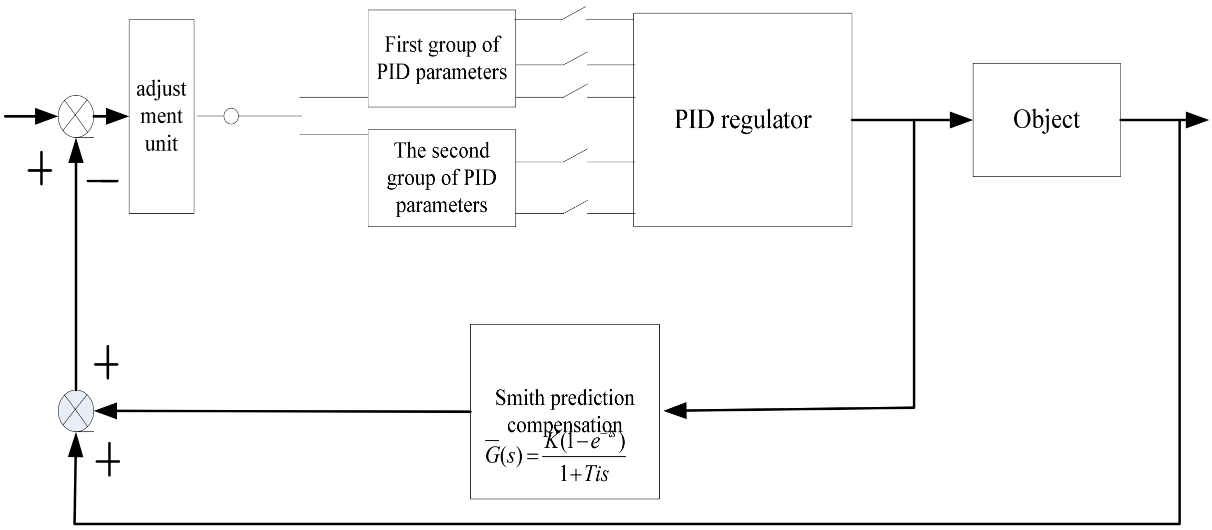

Figure 4. Smith Predictor after Compensation Diagram

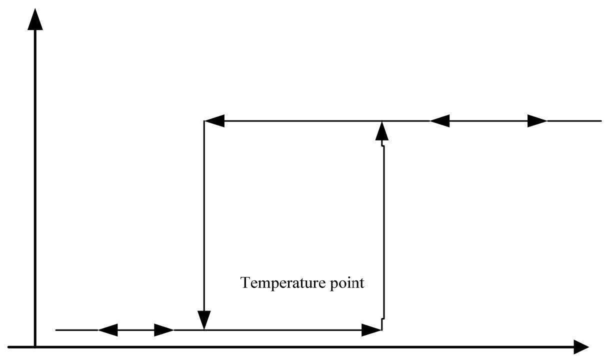

Figure 5. Hysteresis Comparator

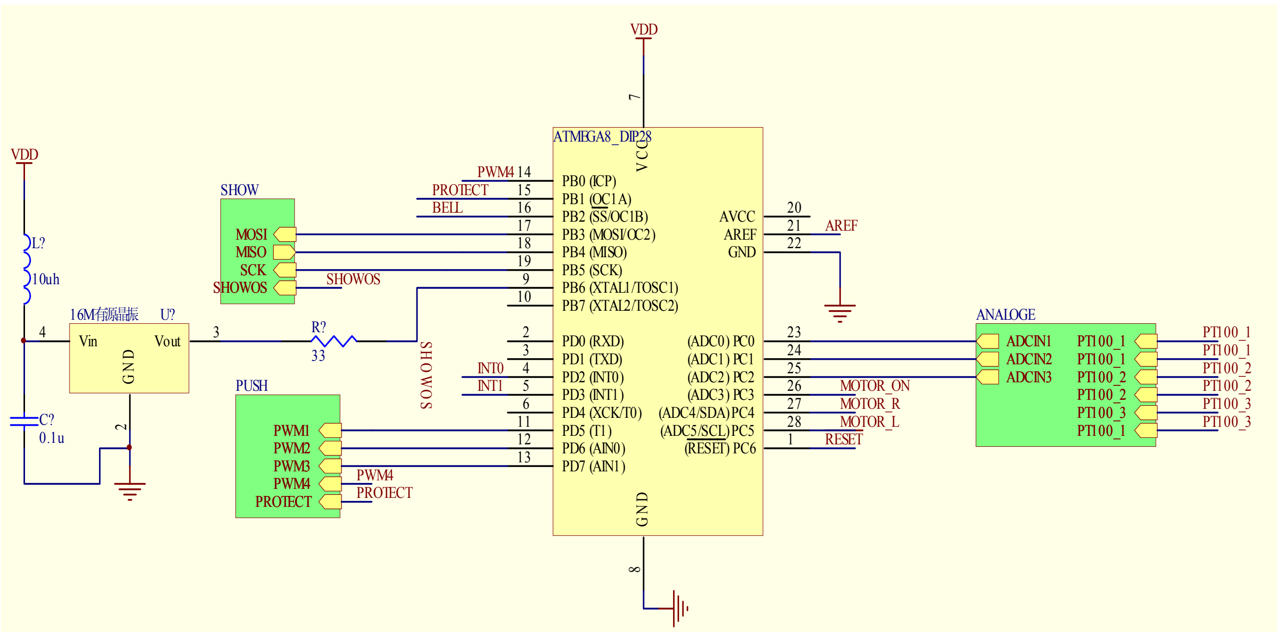

Figure 6. The Controller Circuit Diagram

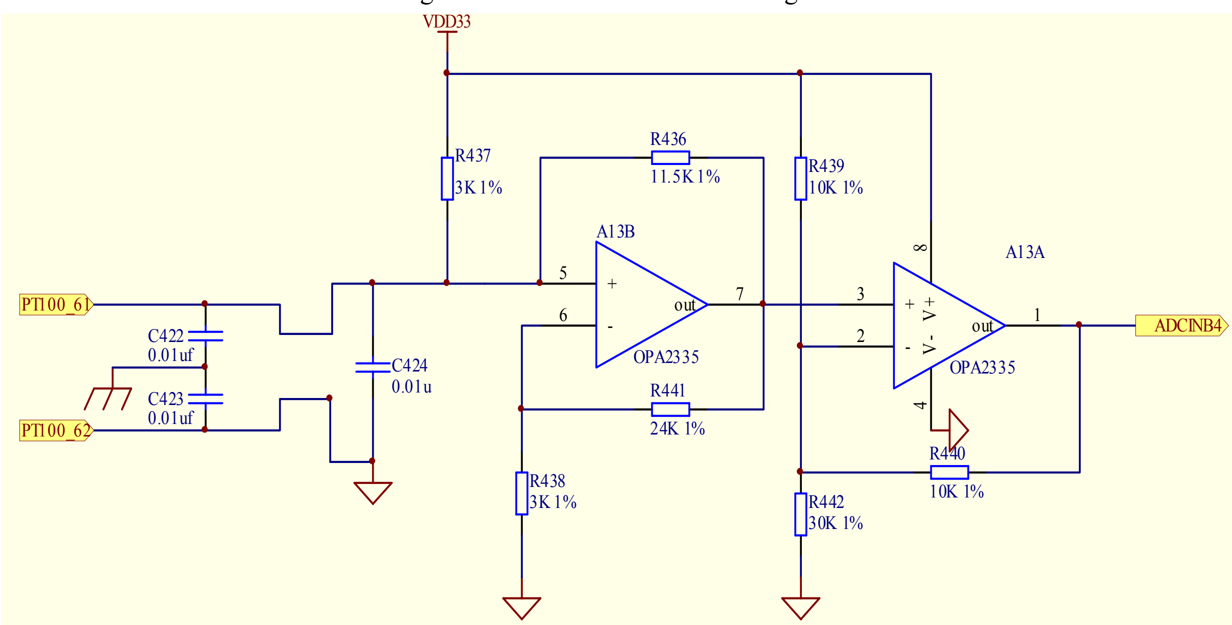

Figure 7. Sensor Circuit

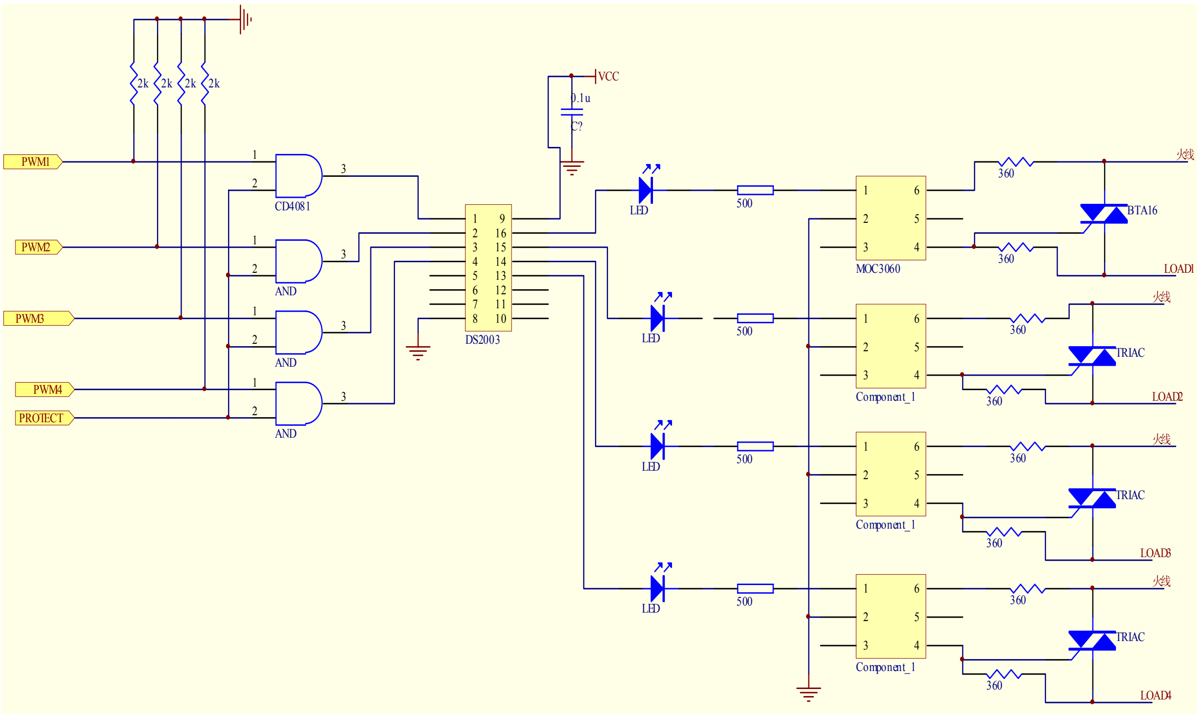

Figure 8. Heating the Implementation Unit

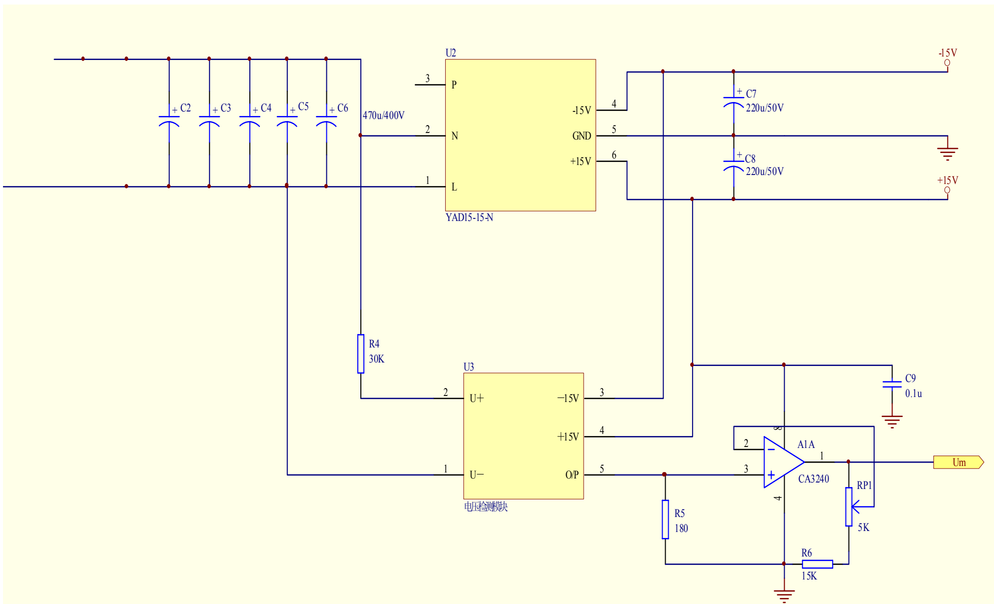

Figure 9. Power and voltage Protection Circuit

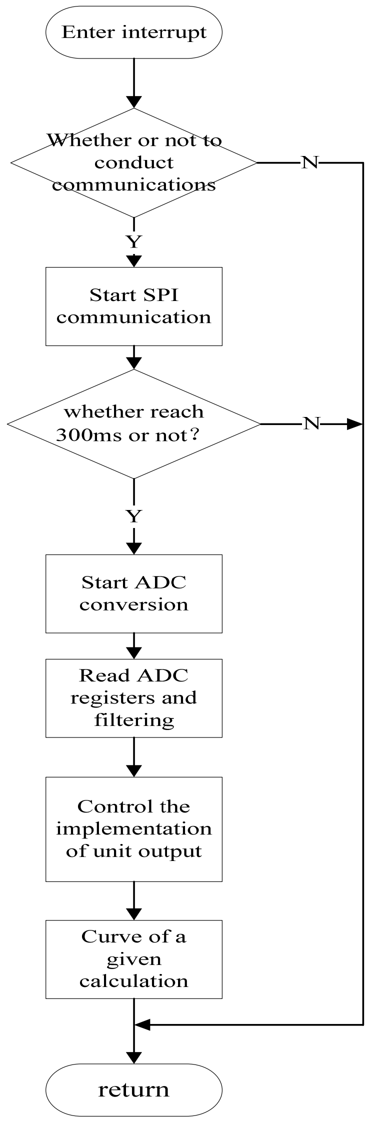

Figure 10. The Timer Interruption

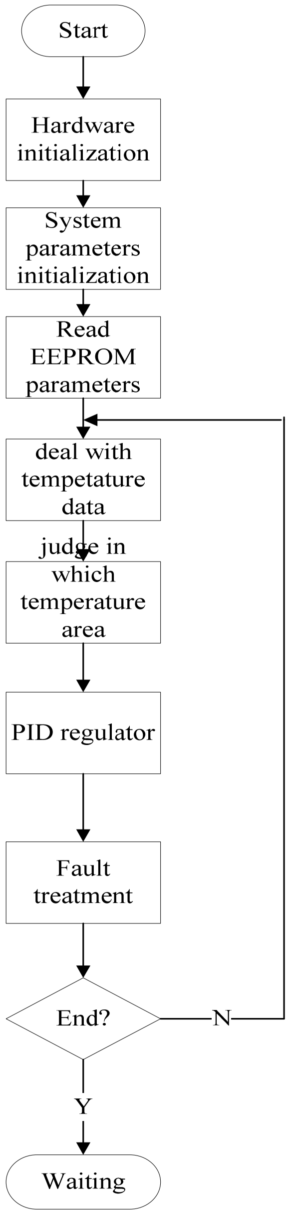

Figure 11. The Main Function of Flow Chart Flow Chart

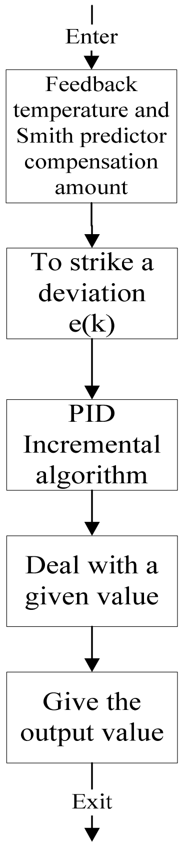

Figure 12. PID Flow Chart

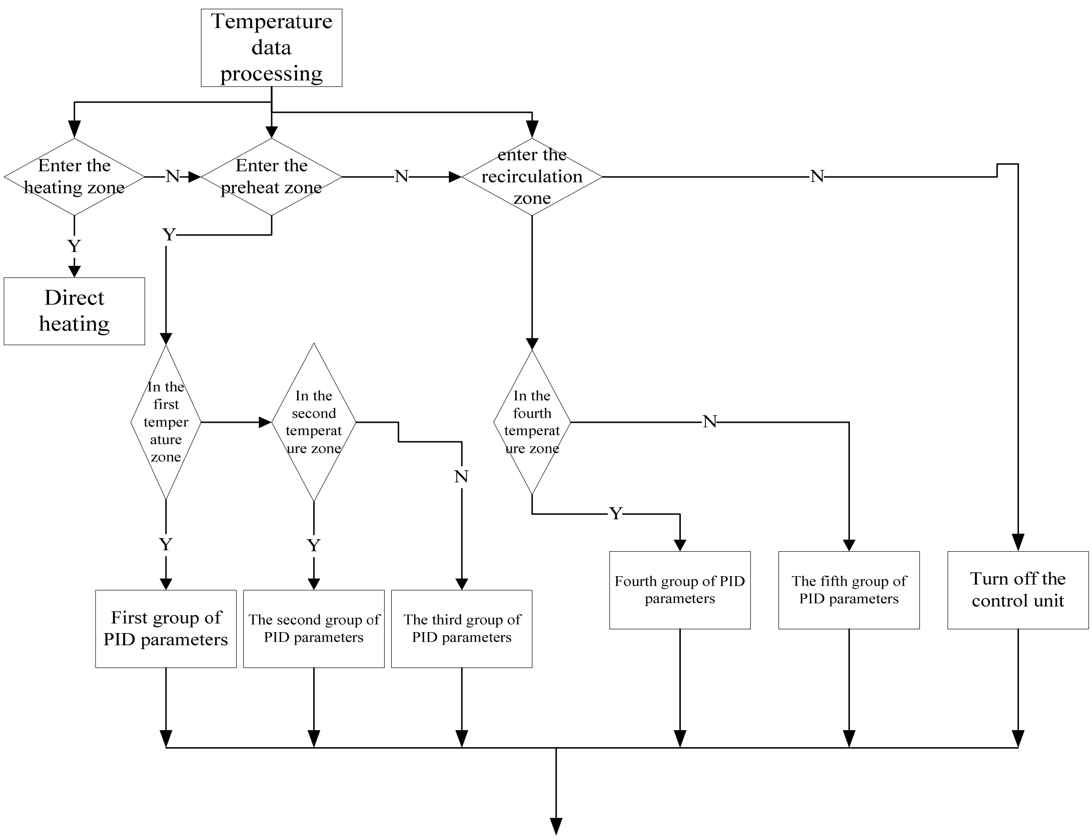

Figure 13. Judgment of Temperature Area