

An Improved Design for Lab-used Thermostat with High Accuracy

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Abstract—This thermostat designed is for lab, with PID algorithm applied. The hardware includes PIC16F887 as processor, the 16-bit Σ - Δ A/D ADS1100 conversion as forward simulation, the thermal resistance PT100 as temperature sensor. The testing and control procedure is fixed by cooling and heating interaction.

Keywords-PIC16F887,XTR105, Temperature Control, high accuracy, PID

I. INTRODUCTION

Temperature testing and control is closely related to our life, widely used in much fields (such as Industrial control, medicine and research organizations), which involves temperature control as parameters to ensure the work execution. Early thermostat system consists of relay temperature control circuit, it is concise on structure with low development pay and price. But it is low accuracy with more error due to much action on contact and bad contact quality [1][2].

The advanced thermostat is for industry testing and lab, which involves digital PID control algorithm, PIC16F887 as processor, 16-bit Σ - Δ A/D ADS1100 conversion chip, XTR105 as analogy front simulation, PT100 as temperature sensor and 4-bits LED as displaying. It completes temperature testing and control by cooling and heating interaction. The control range is $-40^{\circ}\text{C}\sim 20^{\circ}\text{C}$, control accuracy $\pm 0.1^{\circ}\text{C}$. The software could be set based on requirements. It is with high accuracy, better stability and high speed in use.

II. CONTENT

A. The overall design [3]

1)Interface Graph

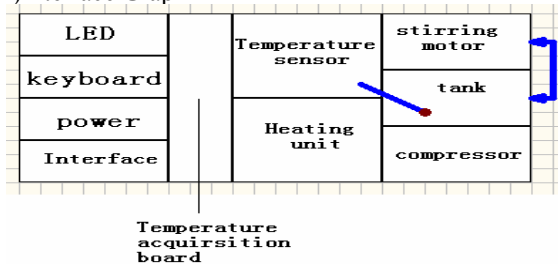


Figure 1. Interface Graph

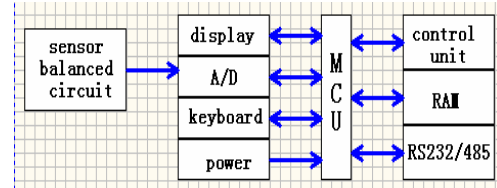


Figure 2. Temperature signal acquisition circuit Graph

2)Temperature signal acquisition circuit

Temperature sensor PT100 is used to test ethanol in tank, the signal is transferred into voltage signal through XTR105. The signal is transferred through processing such as amplifying, filter, A/D and be sent into PIC16F887 MCU system. It is compared with the default one in MCU system, if it meets the power-on point, the heater works following the digital PID control algorithm. This process could satisfy the higher accuracy on temperature control.

B. Hardware design

1)Center control and display unit

a)MCU selection [4]

We select PIC16F887 (Microchip) as the processor of data acquisition system. The architecture of PIC system is Harvard Bus, which apply the different bandwidth to realize “waterfall process” and “single-bit command”, it is benefit on command executing efficient.

b)Peripheral interface circuits

①Communication interface

RS-232 is former, which could confirm closer link (<15M) and widely used in serial communication. Latest RS-485 solves the previous shortcoming such as less distance and low rates. But an inconvenient DB9 transfer between RS-485 and RS-232 was injected in due to matching problem with PC.

c)keyboard circuit

This system includes 5 single-contact keys: SET(temperature configuration), RUN, UP(increase), DOWN(decrease) and RESET. Each key has special I/O. Some reuse realizes one key more function.

d)Display circuit

Because the thermostat is for lab and industry, a visible and clear vision is required. LED has more advantage than LCD, so we choose 4-bits, 0.8”LED.

2)The forward channel

a)Temperature sensor selection and interface [5] [6]

①Temperature sensor selection

Sensor is a device which transfers income form into outcome form, it could support observation, measurement and research work. Platinum resistance sensor output Pt resistance under different temperature condition. It is fatal for PT resistance sensor testing to ensure the resistance all the time. Base on IEC751 international standard. The common producer is Pt100, with temperature parameter TCR=0.003851. Its feature contains:

$$\text{if } -200\text{ }^{\circ}\text{C} < t < 0\text{ }^{\circ}\text{C}, \\ R_t = R_0 [1 + At + Bt^2 + C(t - 100)t^3] \quad (1)$$

$$\text{if } 0\text{ }^{\circ}\text{C} < t < 850\text{ }^{\circ}\text{C}, \\ R_t = R_0 (1 + At + Bt^2) \quad (2)$$

R_t is the resistance on $t^{\circ}\text{C}$, R_0 is that on 0°C . The parameters are following:

$$A = 3.90802 \times 10^{-3} \text{ }^{\circ}\text{C}^{-1}, \quad B = -0.5802 \times 10^{-7} \text{ }^{\circ}\text{C}^{-2}, \quad C = -4.2735 \times 10^{-12} \text{ }^{\circ}\text{C}^{-4}$$

② XTR105 circus [7]

This section is described in chapter key technology in detail.

b) ADS1100 and interface circuit [8]

ADS1100 is accuracy continuously self-calibration A/D. It has differential input and resolution to 16-bits. ADS1100 could make sampling on 8/16/32/128 per second. The programmed gain amplifier (PGA) supply 8 times gain for weak signal measurement.

① Registers in ADS1100

ADS1100 has two major registers, both could be visited by I2C. Output register store the latest result; Configure register keep the function for user to configure the work of ADS1100 and check circuit state.

Output register: The latest A/D result is stored in 16-bit output register, it is on complement form. It is clear and maintains "0" till the first A/D transfer from reset or power on.

Configure register: 8-bit register is for ADS1100 work, data rate and PGA configuration. The defaults configure register is 8CH.

② ADS1100 read operation

The user is allowed to read from output register and configuration. It is needed to addressing and read 3 bits address. The front two bits represent content of output register and the last one is content of configuration register.

③ ADS1100 write operation

The user is allowed to write new words in configuration register. It is needed to make writing operation on ADS1100 addressing to complete this function. One bit word is special for configuration register here.

3) Heating control circuit and cooling device

The core device is optocoupler Zero-triggered solid-state relays S203ZL, the input driving could be connected with TTL, and output controlling is 220AC/50 Hz. The minimum time interval is 10ms, current is 5A. We select resistance wire heater as load with 800W power. We control compressor to refrigeration by the switch of system valve and balance valve.

4) Asynchronous serial communication circuit

RS-232 interface chip is MAX232 that keeps transferring of TIA/TIA-232-E and TTL/CMOS.

C. System software design

1) The system software design by C51

This system applies MPLAB IDE with HI-TECH PICC tool for system coding and compiling. It has more advantages.

2) system software composition

a) The flow chart of main program is in graph of appendix.

In flow loop, it is needed to type RESET key to reconfigure temperature point, the system will return to former mode and run then.

b) Keyboard module design

Keyboard includes 5 keys to fulfill following functions:

SET: enter temperature control interface and standby state;

RUN: enter temperature testing and control state;

UP: add 0.1 per type, continuous add on pressing;

DOWN: reduce 0.1 per type, continuous decrease on pressing;

RESET: reset system.

c) Display module design

PICs can afford high load driving capability through I/O. It can afford 25mA on high and low level. The system utilizes above features, so we select 0.8' common cathode LED as display module.

d) temperature control circuit

The temperature signal is sent into PIC16F887 through XTR105, A/D. the MCU executes PID control of self-calibration and output PMM signal. PID controls duty cycle of PWM in order to control compressor from relay switching.

e) The serial communication program of MCU.

Use USART of PIC16F887 to complete serial communication with PC.

T1 is rate generator, which is 9600bps, working on auto-reload mode. Its interface is 10-bit asynchronous receiver, it includes 8-bits for data group, 1-bit for start and 1-bit for end, two bits as one signal group, low value in the former and high in the post.

III. KEY TECHNOLOGY

A. XTR105 circuit design

The temperature testing circuit can be two-wire, three-wire and four-wire. This system selects three-wire current source driven method to drive Pt resistance sensor. It could remove the resistance of Pt sensor, measure the change of sensor directly.

Illustration: RZ, RG, RLIN1 value calculation (assume temperature range TMIN ~ TMAX)

$$RZ = \text{RTD resistance at TMIN}$$

$$RG = [2(R2 - RZ)(R1 - RZ)] / (R2 - R1)$$

$$RLIN1 = [RLIN(R2 - R1)] / [2(2R1 - R2 - RZ)]$$

$$RLIN2 = [(RLIN + RG)(R2 - R1)] / [2(2R1 - R2 - RZ)]$$

$$R1 = \text{RTD resistance at } (TMIN + TMAX) / 2$$

$$R2 = \text{RTD resistance at TMAX}$$

RLIN = 1k Ω (Internal)

B. Parameter calculation

TMIN = -40°C, TMAX = 20°C, (TMIN+TMAX)/2 = -10°C

We can get following result based on Pt resistance formula:

R(TMIN) ≈ 84.27 Ω, R(TMAX) ≈ 107.79 Ω, R[(TMIN+TMAX)/2] ≈ 96.09 Ω

R1 = 96.09 Ω, R2 = 107.79 Ω

Based on three-wire connection RZ, RG, RLIN1 formula, we can get:

RZ = 84.27 Ω, RG = 47.52246 Ω, RLIN1 = 49000 Ω, RLIN2 = 51066.72 Ω

RZ is made up of 100 Ω precision wire wound potentiometer (turn to 84.27 Ω), RG is made up of ±0.02% precision resistor, RLIN1 and RLIN2 are made up of 47k Ω and 51k Ω resistors.

The standard on equal testing is -40°C~20°C in temperature and ±0.1°C in accuracy.

IV. INCUBATOR MEASUREMENT

A. Incubator measurement

Connect the PT100 with measurement system and put it into incubator to calibrate. It is attention to the tightness of incubator to improve reliability, 10 times every 10 minutes. The results are in following table:

TABLE I. MEASURING RESULTS AND ERRORS OF THE CONSTANT-TEMPERATURE-CHEST

SetTemp/°C	Measre/°C	Random Error	Sys error
-40.00	-39.92	0.01	-0.08
-30.00	-30.05	0.01	0.05
-20.00	-19.97	0.01	-0.03
-10.00	-9.96	0.01	-0.04
0.00	0.01	0.01	0.00
10.00	9.95	0.01	-0.05
20.00	20.00	0.01	0.00

From these data the maximum random error is 0.05°C, and get minimum on room temperature; The maximum error of measurement system is -0.08°C, it could meet the requirement of high accuracy thermostat.

B. Result analysis of the temperature control

The volume of this thermostat is 0.6L. It is confirmed that it meets target in 60s with over 1°C. It takes 360s to get constant state completely.

V. CONCLUSION

The thermostat with three-wire constant current source-driven solves the influence from resistance of line and self-heating; the self-calibration of XTR105 realize the accuracy calibration for component drift and PT sensor. It improves the accuracy and reliability on testing; ADS1100 with differential input and 16-bit resolution conversion accuracy, it apply scaled-conversion power to maintain conversion accuracy and remove error; High accuracy testing mode with self-calibration incremental PID effectively control testing features and meet the requirements the user needs.

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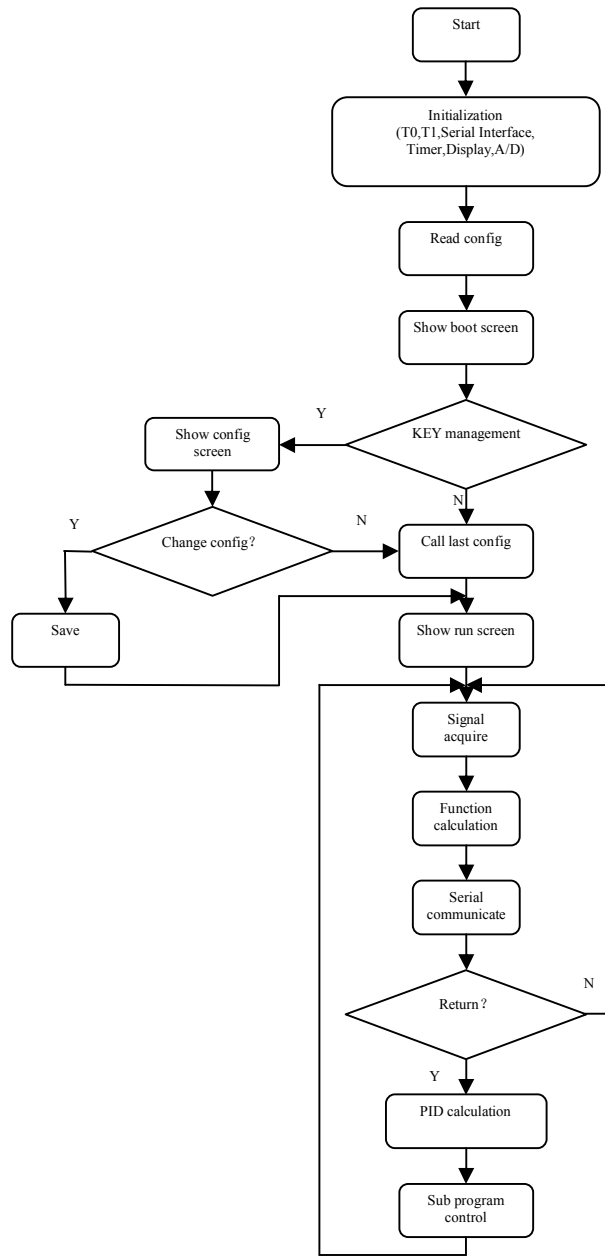


Figure 3. The main program flow chart