RESEARCHING ON AND DESIGNING TEMPERATURE CONTROLLER FOR HEATERS

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Abstract - This paper presents design solutions of control circuit and temperature stability in a closed environment, in order to increase stability and the fast response of heaters to save energy efficiently. A PIC micro-controller is used to perform P.I.D and ON/OFF algorithms in temperature control and stabilization.This is the new point compared to traditional temperature stability systems. The temperature of the heater is updated through the PT100 temperature sensor. The output of the control system includes the cooling fan and thermal wire to create temperature. The output control signal is a stimulus angle control signal of the Triac. This signal is calculated by P.I.D algorithm. The control program of system contains the P.I.D and ON/OFF program. The results of the paper are to evaluate the fast response, stability, reliability and accurate control of the circuit.

Key words - PIC16F877A; PID control; ON/OFF control; Zero Crossing; Temperature Control.

1. Introduction

Temperature control application areas are very broad, which could be as large as industrial production, aerospace or as small as our daily life. Currently, most temperature control systems use computer control technology with a microprocessor core, both improving the degree of automation of the device and the accuracy of the control.

PID control is by far the most common control method. Because of its high reliability, simplicity and algorithm robustness, it is widely used in process control, especially for establishment of deterministic system of a precise mathematical model. PID control effect depends entirely on the four parameters [1], [2], namely the sampling period $\mathbf{T}_s$, the proportional coefficient $\mathbf{K}_p$, integral coefficient $\mathbf{K}_i$ and differential coefficient $\mathbf{K}_d$. Thus, the PID parameter setting and optimization are two important topics of research in the field of automatic control. PID in industrial process control applications nearly has a hundred years of history, and during this period, despite the advent of many control algorithms, thanks to the long-term use of the PID algorithm and its own characteristics, coupled with people accumulating a wealth of experience it is widely used in industrial control. In PID algorithm, the key issues lie in the setting and optimization of the three parameters of the P.I.D [3], [4]. With the continuous development of science and technology, people have increasingly high requirement for temperature control system, so temperature control system that is highly precise, intelligent and humane is the inevitable trend of development at home and abroad. The introduction, application, development and production of programmable controller begin along with the reform and opening up.

The PID controller output is converted into high and low signal input control, controlling the zero trigger plate according to certain duty cycle conduction. It controls energization time of both ends of thermal resistance wire or cool fan, achieving closed-loop temperature control.

2. Temperature Stable and Control System

The control system includes an heater containing a 500W thermal wire to generate heat, one PT100 temperature sensor, a sensor amplifier circuit located outside, Zero crossing detector, one Triac controller and an AC cooling fan. MCU circuit using PIC16F877A microcontroller perform PID algorithm for control of stimulus corner and ON/OFF of the Triac.

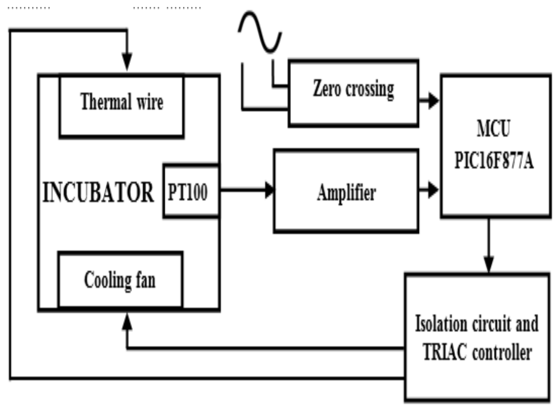


Figure 1. *Block diagram of the control system*

Input of control system has a PT100 sensor, one sensor amplifier and zero crossing detector.

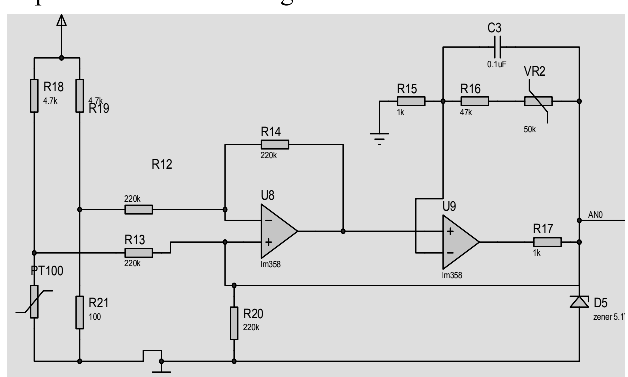


Figure 2. *Heat sensor and Measurement amplifier*

PT100 sensor and R18, R19, R20 make up a resistor bridge; the output of this resistor bridge is put into the differential amplifier using Opamp, then further passed through the non-inverting amplifier with amplification factor adjusted by VR2. To calibrate the circuit, by replacing PT100 with 195.9Ω resistor and adjust VR2 so that the voltage will be 5V at AN0 pins. R17 and zener D5 controlling the output voltage of the amplifier is 5.1V, the load which is not connected to the sensor. When the temperature changes from 0 - 255°C, corresponding to the output voltage changes from 0 - 5V. Thus, if using an 8-bit ADC converter respectively to one,the change level of the ADC is 1^0C.

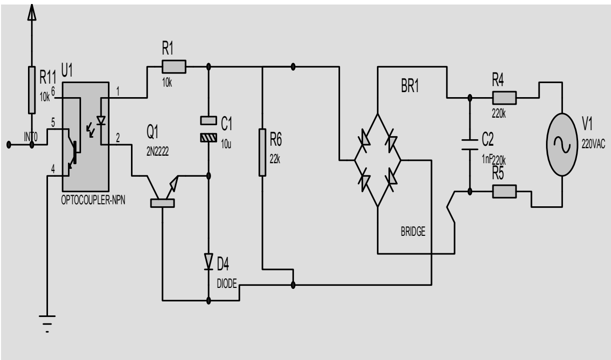


Figure 3. Zero Crossing detector circuit

Zero-crossing detector is located between 02 semi period of the AC source, helping the microcontroller determine the accurate positioning to find the stimulus angle, $\boldsymbol{\delta} = 0^0$ of Triac.

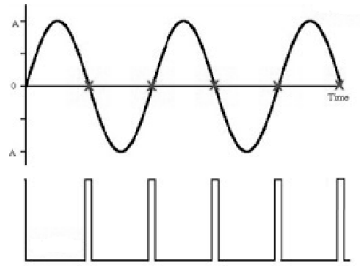


Figure 4. Zero Crossing detector signal

Experimental results from Zero Crossing detector circuit is given by Figure 5, performed on oscilloscope meter.

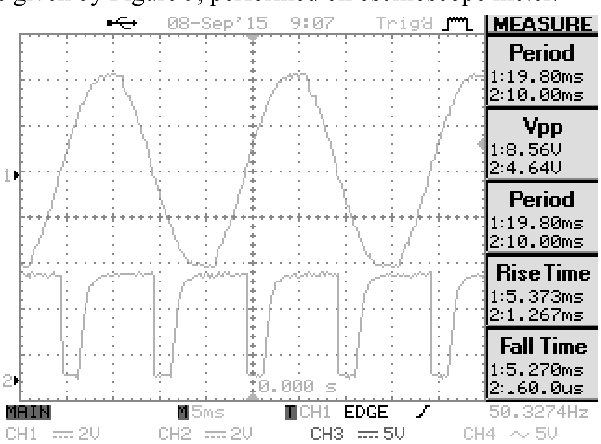


Figure 5. Zero Crossing detector real signals

Because PIC microcontroller uses external interrupt 0 and impacts along the side down to find the location zero crossing, the signal out of detector should need reverse-phase versus the signals in Figure 4.

Trigger and Triac control circuit include an opto-triac MOC3021 used to isolate stimulus signal of microcontroller with the grid power 220V/ 50Hz.

$\boldsymbol{R}_9 = (\boldsymbol{V}_{CC} - \boldsymbol{V}_F)/\boldsymbol{I}_{FT}$. Where: $\mathbf{V}_F$ is the forward voltage of infrared light - emitting diode and it can take values from 1.2V to 1.4V; $\mathbf{I}_{FT}$ is the trigger current of infrared emitting diode. If the working temperature is below 25^OC, the value of $\mathbf{I}_{FT}$ should be appropriately increased. $\mathbf{R}_{10}$ is the triac gate resistor. In the case of relative high SCR sensitivity, the gate resistance is also high. The paralleling of $\mathbf{R}_{10}$ can improve the interference resistance.

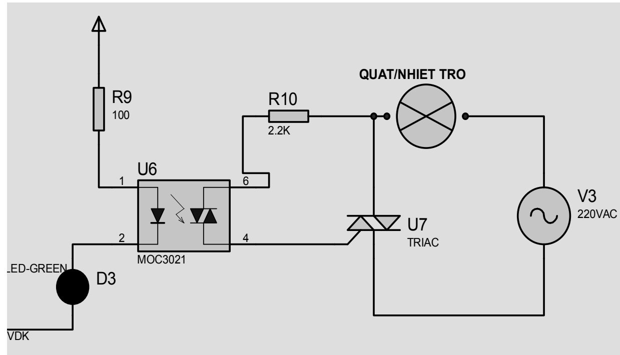


Figure 6. Isolation circuit and Triac controller

3. Control Method

The controller allows the temperature in the heater to stabilize at one pre-determined value by controlling speed of the cooling fan and the heating level of the thermal wire.

3.1. ON/OFF control

An on-off controller is the simplest form of temperature control device. The output from the device is either on or off, with no middle state. An on-off controller will switch the output only when the temperature crosses the setpoint. For heating control, the output is on when the temperature is below the setpoint, and off above setpoint. Since the temperature crosses the setpoint to change the output state, the process temperature will be cycling continually, going from below setpoint to above, and back below. In cases where this cycling occurs rapidly, and to prevent damage to contractors and valves, an on/off differential, or "hysteresis," is added to the controller operations. This differential requires that the temperature exceed setpoint by a certain amount before the output turns off or on again. On-off differential prevents the output from "chattering" (that is, engaging in fast, continual switching if the temperature's cycling above and below the setpoint occurs very rapidly). On-off control is usually used where a precise control is not necessary, in systems which cannot handle the energy's being turned on and off frequently, where the mass of the system is so great that temperatures change extremely slowly, or for a temperature alarm. One special type of on-off control used for alarm is a limit controller. This controller uses a latching relay, which must be manually reset, and is used to shut down a process when a certain temperature is reached.

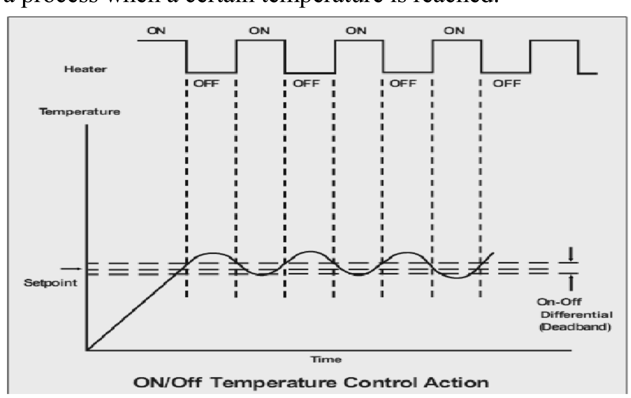


Figure 7. ON/OFF control signal

3.2. PID control

A PID (Proportional-Integral-Derivative) controller is a control loop feedback mechanism commonly used in industrial control systems. A PID controller continuously calculates an "error value" as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error over time by adjusting a control variable, such as the position of a control valve, a damper, or the power supplied to a heating element, to a new value determined by a weighted sum:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de}{dt} \quad (1)$$

Control signal of the PID controller for each sampling interval (T) is determined as;

$$P_1 = P_0 + (e_1 - e_2)K_P + (e_1 - 2e_2 + e_3)\frac{K_d}{T} + (e_1 + e_2)\frac{K_i T}{2} \quad (2)$$

Where, $\mathbf{K}_p$, $\mathbf{K}_d$ and $\mathbf{K}_i$ are coefficients of proportional, integral and derivative elements, respectively. $\mathbf{P}_0$ is the control signal of the previous sampling, $\mathbf{e}_1$ is the current error, $\mathbf{e}_2$ is error of previous sampling and $\mathbf{e}_3$ is the error of the sampling before previous sampling [5].

Application of PID to control temperature stability is to calculate stimulus angle for Triac by the phase angle control method.

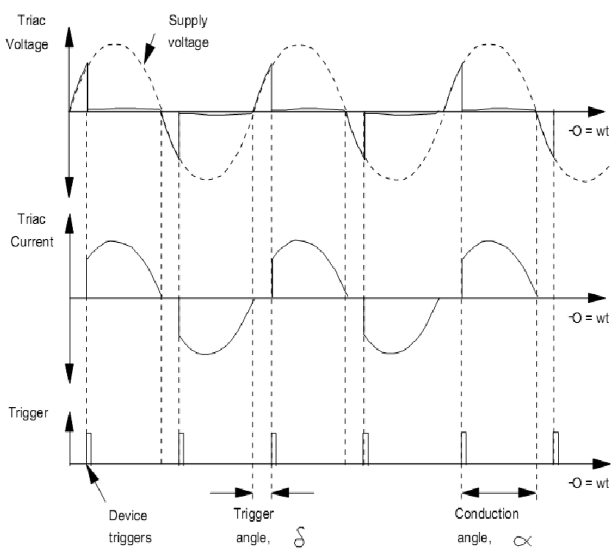


Figure 8. *Phase controller - resistive load*

The operation of a phase controller with a resistive load is the simplest situation to analyse.Waveforms for a full wave controlled resistive load are shown in Figure 8. The triac is triggered at angle **δ**, and applies the supply voltage to the load. The triac then conducts for the remainder of the positive half-cycle, turning off when the anode current drops below the holding current, as the voltage becomes zero at **θ** = 180˚. The triac is then re-triggered at angle (180 + **δ**)˚, and conducts for the remainder of the negative half-cycle, turning off when its anode voltage becomes zero at 360˚.

The sequence is repeated giving current pulses of alternating polarity which are fed to the load. The duration of each pulse is the conduction angle **α**, that is (180 - **δ**)˚. The output power is therefore controlled by variation of the trigger angle **δ**. For all values of **α** other than **α** = 180˚ the load current is non-sinusoidal. Thus, because of the generation of harmonics, the power factor presented to the a.c. supply will be less than unity except when **δ** = 0. For a sinusoidal current the rectified mean current, $\mathbf{I}_{T(AV)}$ and the rms current, $\mathbf{I}_{T(RMS)}$, are related to the peak current, $\mathbf{I}_{T(MAX)}$, by equation 4.

$$I_{T(AV)} = \frac{2.I_{T(MAX)}}{\pi} = 0.637.I_{T(MAX)}$$

$$I_{T(RMS)} = \frac{I_{T(MAX)}}{\sqrt{2}} = 0.707.I_{T(MAX)} \quad (3)$$

Where,

$$I_{T(MAX)} = \frac{V_{T(MAX)}}{R_L} = \frac{\sqrt{2}.V_{(RMS)}}{R_L} \quad (4)$$

4. Experimental Results

The control program is written in C codes and converted to hexadecimal codes by the PIC.C software. Hex codes are transferred to the PIC by a programmer that we have formed according to the scheme below [6].

Flowchart of the program is shown in Figure 9:

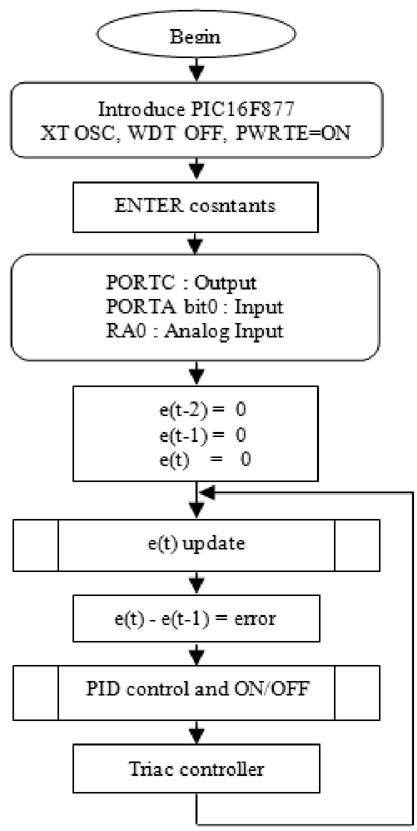


Figure 9. *The control program flow chart.*

While the temperature of the outer environment is 29^0C, the heater is heated during 6 minutes and then heat of inner environment is measured at 40^0C. Graph of heating versus time for the heater is shown in Figure 10.

Ziegler-Nichols method is used to adjust PID for temperature control system of the heater. Model open-loop system of the heater is implemented in the laboratory as follows: K=200, L=40,T=1200, then transfer function of the object: $H(s) = \frac{200}{(40s+1)(1200s+1)}$. This function is performed on simulink such as Figure 11.

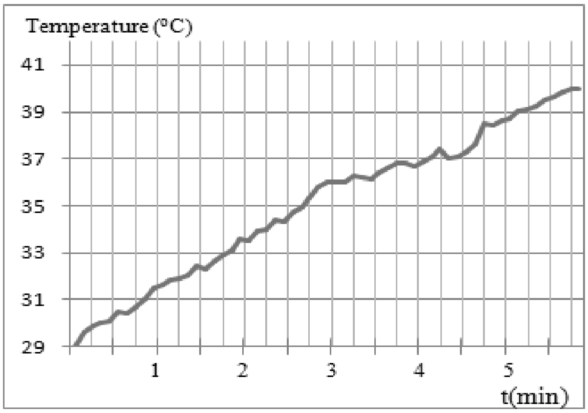


Figure 10. *Temperature result in the heater*

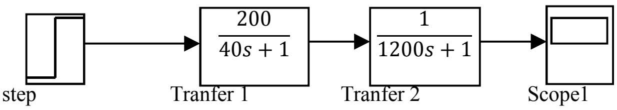


Figure 11. *Model open-loop system of the heater*

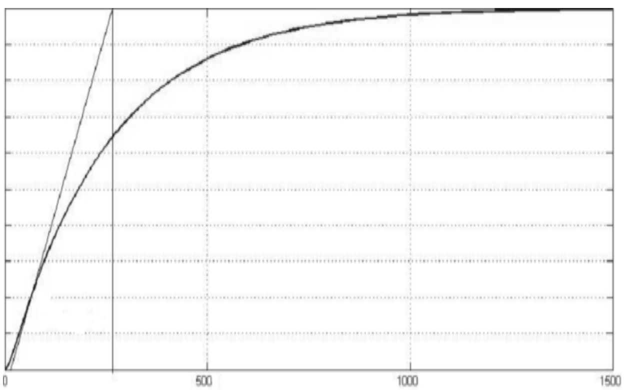


Figure 12. *The response of the open-loop system*

In Figure 12, we draw a tangent at the inflection point to figure out the parameters $T_1 = 5$, $T_2 = 80$ then find out the parameters of the PID controller follow Ziegler-Nichols method:

Table 1. *Adjust the PID parameters follow Ziegler-Nichols*

Controller	K_P	T_i	T_d
PID	$1.2\frac{T_2}{T_1 K} = 0.1$	$2T_1$=10	$0.5T_1$=2.5

Find $G_{(PID)s}$:

$$G_{(PID)}=K_p(1+\frac{1}{T_I s} + T_D s)=0.1+0.01s+0.25s$$

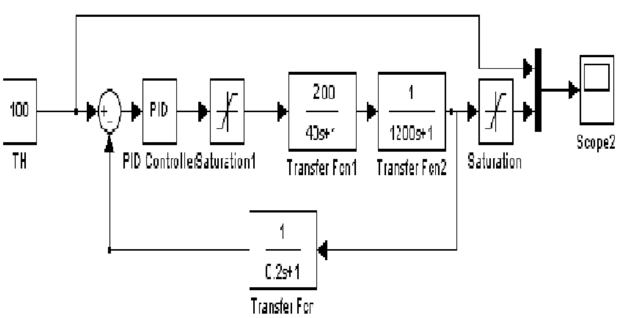
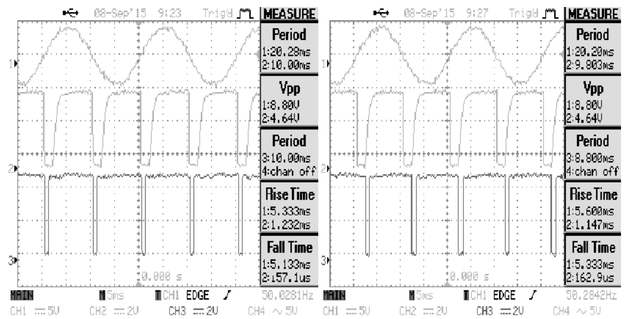


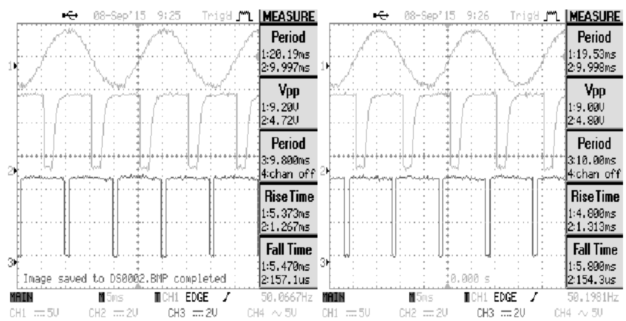
Figure 13. *PID controller by simulink*

Through the survey of the parameters affecting K_p, K_d, K_i, PID controller can find a transfer function of the controller to respond to the best of the object: $K_p = 0.5$, $K_d = 0.2$, $K_i = 0.01$.

Control system with PID algorithm determines the stimulus angle, **δ** to enable Triac controlling the rotation speed of the cooling fan, helping the heater temperature reduce to the setpoint value of 36^0C. The figure below shows the changes of **δ** corresponding to the changes of temperature in the heater.



(a) Temperature >=40^0C (b) Temperature = 39^0C



(c) Temperatue = 38^0C (d) Temperature = 37^0C

Figure 14. *(a), (b), (c), (d) are the different temperature*

When the temperature into the heater is larger and greater than setpoint value, the error (current temperature value – setpoint) increases. The stimulus angle, **δ** = 0^0 means Triac for active load with 100% capacity. As the temperature decreases to the setpoint, **δ** will gradually increase to 180^0 meaning the value of the heater temperature reaches the setpoint and the Triac will turn off, corresponding to the load of the cooling fan or in the opposite, the thermal wire will stop operations.

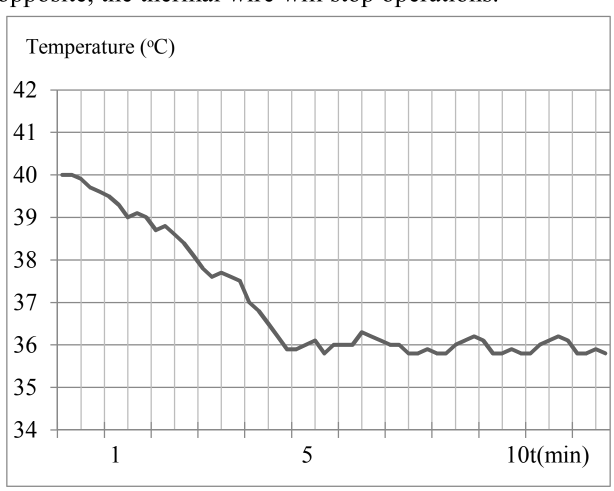


Figure 15. *PID control results on the circuit*

Using ON/OFF controller is started with setpoint is 36^0C, as shown in Figure 16.

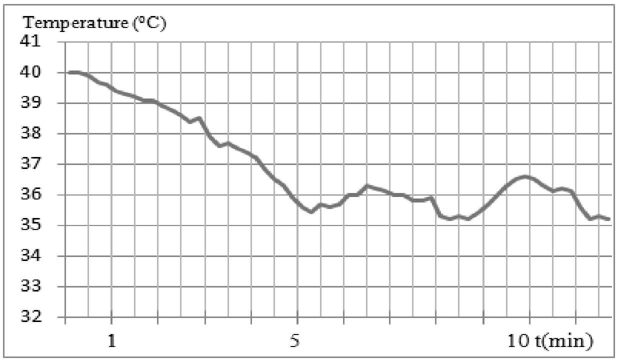


Figure 16. *ON/OFF control results on the circuit.*

From the results of the two of control methods, we can see that: settling time of the PID controller is faster than the ON/OFF controller. Overshoots and undershoots are relatively small. Thus, compared with the control method of the traditional heater, the control circuit and temperature stabilization by PID and ON/OFF enables the heater to have more flexible control and temperature stability, energy saving through reducing the losses due to the phenomenon of temperature control inefficiency of ON/OFF methods.

5. Conclusion

In the temperature control system, the heater is aimed to be cooled by PID and ON/OFF control methods. In the both methods, system is cooled linearly until a certain degree which is above the heat of outer environment. Oscillations after this temperature is sourced by rolling-off the PAN speed. Cooling rate is reduced relative to the reduction in the error and can not remove the heated air away sufficiently.

That is why temperature occasionally increases and decreases. In order to set the temperature under the heat of the outer environment, a cooler, such as Peltier cooling elements can be used instead of the fan. These elements can reduce the temperature under negative degrees. This will also reduce the settling time.

The results have proved that the PID control system has fast response, high accuracy and stability.

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