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PI Controller for The Heating Process in The Real Time System Based on LAB VIEW 8.2 Packages

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Abstract

This paper experimentally investigates the control of the heating process in a water tank. A trial and error method is used to find the best system response depend on the tuning parameters of the PI controller based on a Matlab simulation package in order to replace these parameters in the real time digital PI controller system based LabVIEW package. The PI control action in the real time system technique shows more oscillation in comparison to that the PI simulation control action. Simulation and real time results for heating process experiment has successful for maintaining water tank temperature.

المسيطر PI للعملية الحرارية في النظام الوقت الحقيقي مبني على اساس البرنامج LABVIEW8.2

الخلاصة

ان هذا البحث يحقق بالتجربة كيفية السيطرة على عملية تسخين الماء داخل الخزان. ولقد نفذت طريقة التجربة و الخطأ للحصول على أفضل استجابة للنظام اعتمادا على معاملات التنغيم للمسيطر PI باستخدام محاكاة برنامج ال Matlab ثم اخذت معاملات المسيطر وطبقت في نظام الزمن الحقيقي للمسيطر الرقمي PI الذي اساسه LabVIEW .

ان اداء المسيطر PI في نظام الزمن الحقيقي كان اكثر تذبذبا من اداء المسيطر PI في نظام المحاكاة.

ان نتائج المحاكاة و الزمن الحقيقي لتجربة عملية التسخين كانت ناجحة للمحافظة على درجة حرارة الماء المطلوبة

1- Introduction

Many industrial applications used PID control to maintain constant process variable. The output of PID controllers (proportional-integrative- derivative controllers) is linear combination of the input, the derivative of the input and the integral of the input therefore it is widely used and enjoy significant popularity, because it is simple, effective and robust [1].

The first Ziegler-Nichols tuning rule for (usual, integer) PIDs for the plant to control is needed only an S-shaped step response [2]. Also the PID control has been implemented for a heat exchanger in a closed flow air circuit [3]. A new adaptive internal model control scheme based on adaptive finite impulse response filters for the heating process provides the same design procedure for both minimum and non-minimum phase plants [4].

Also method for auto-calibration of PI & PID controllers, using a frequency domain model of the air heater process to be controlled (obtained by relay excitation) is compared with the Ziegler – Nichols method to cover a large domain of current real application [5].

Actually, the trail and error tuned PIDs often perform in a non-optimal way. But even through further fine – tuning be possible and sometimes necessary and provide a good starting point. Their usefulness is

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obvious when no model of the plant is available, and thus no analytic means of tuning a controller exists, but this method may also be used when a model is known . In the work, we present here, experimentally investigates the tuning parameters of the PI controller of the heating process by using trial and error method to find the best system response based on a Matlab simulation package in order to replace these parameters in the real time digital PI controller system based LabVIEW (lab Vision Instrumentation Engineering Workbench) package approach is proposed.

The organization of this paper is as follows: *Section two* represents the proposal scheme describes design and implementation in real time temperature control of a heating process and analysis the mathematic model of the system and describes hardware design. *Section three* describes control methodology use PI controller and simulation results (Matlab package) and real time results by using LabVIEW package. *Section four* contains the conclusions of the entire work.

2- Experimental Arrangement in Real Time Implementation:

The proposed scheme describes design and implementation in the real time temperature control of a heating process. In these experiments, a stand d IBM PC-type Pentium IV is used for the computation in real time. Data acquisition is accomplished by standard parallel port protocol and the controller is implemented in LabVIEW 8.2 a graphical programming language.

The picture of the experimental facility for the real-time control of temperature of a heating process and the schematic of the experimental arrangement used in this work is shown in figures (1 and 2) respectively. The process is composed of a heating actuator, water tank, and temperature sensor thermocouple type J. AC power supply provides power to the heater actuator. Initiating an appropriate controlling signal from the digital phase controller by using AT89C51 micro-controller and the computer program algorithm can control this power magnitude. The proposal process can be considered as a first-order time delay system as the mathematical model described it and used heating actuator with heat energy (0 to 1500) watt ***(input to heating process)*** and the output is the temperature of water tank.

2-1 Mathematical Model:

The mathematical model of the heating process can be driven as follows by using heat balance equation [6]:

Heat input – Heat output = Heat accumulation

$$Q_i(t) - Q_{loss}(t) = Q_{Acc}(t) \quad \text{---(1)}$$

Unsteady equation is:

$$Q_i(t) - hA(T(t) - T_{air}(t)) = MCp\frac{dT(t)}{dt} \quad \text{---(2)}$$

Steady equation at t=0 is

$$Q_i(0) - hA(T(0) - T_{air}(0)) = 0 \quad \text{---(3)}$$

The difference between the equations

$$Q_i(t) - hAT(t) = MCp\frac{dT(t)}{dt} \quad \text{---(4)}$$

By take Laplace Transformation

$$Q_i(s) - hAT(s) = MCpST(s) \quad \text{---(5)}$$

$$\frac{T(s)}{Q_i(s)} = \frac{1/hA}{MCp/hAS+1} \quad ---(6)$$

$$\frac{T(s)}{Q_i(s)} = \frac{K}{tS+1} \quad -----(7)$$

Where $K = 1/hA$ and $t = MCp/hA$.

The real parameters of the heating process can be taken from table (1).

After apply the parameters of the system in equation (7), the final equation that describes the model is:

$$\frac{T(s)}{Q_i(s)} = \frac{1.21}{10.6S+1} \quad ---(8)$$

Where the time constant t is equal to 10.6 hour or 38181.8 second.

2-2 Hardware Design:

The design and implementation of the control circuit is shown in figure (3). It consists of the thermocouple temperature sensor J type with analog device AD594 is used as a Celsius thermometer and linearization output voltage of the thermocouple with sensitivity is equal to $10mV/C^o$ with range of operation (0 to 100)C^o [7], applied signal condition circuit with gain (10) by using TLO64 CMOS operation amplifier, and 12 bit a high speed, low power analog to digital converter ADC574 successive approximation with one LSB is equal to 2.44mV/count [8,9]. Some TTL devices are used for interface with standard parallel port (Line Printer Port) LPT1 with SPP protocol mode [10].

Digital Phase Controller is designed and implemented by using micro-controller AT89C51 [11]. The digital phase controller receives digital data action from personal computer (parallel port) then analysis data by using the assembly program of 89C51 microcontroller which convert the digital data action (00 – FF) hex to the firing angle pulse (0 – 20) mSec (assume the AC frequency is 50Hz) on the gate of the Traic device BT136 through isolator pulse transformer in order to control the AC power of the heater actuator (0 – 1500) watt.

The isolator has been used as interface between the DAQ (Data Acquisition card) and the heater actuator to prevent the possibility of any back flow of AC current to the DAQ card from Triac device controller of heater actuator.

The phase detector control action program has been written in assembly language of AT89C51 microcontroller as shown below:

```
ORG 000h
        SJMP START
ORG 003H
        MOV IE,#00H
        MOV R0,P2
        CLR TF0
        CLR TR0
Count:  MOV TL0,#0DCH
        MOV TH0,#0FFH
        SETB TR0
Cheak1:   JNB TF0,Cheak1
        CLR TR0
        CLR TF0
        DJNZ R0,Count
        SETB P1.0
        MOV TL0,#18H
        MOV TH0,#0FCH
        SETB TR0
Cheak2:      JNB      TF0,Cheak2

        CLR TR0
        CLR TF0
        CLR P1.0
        MOV IE,#81H
        RETI
START:   CLR P1.0
        CLR TF0
        CLR TR0
        MOV TMOD,#01H
```

```
        MOV IE,#81H
        MOV IP,#01H
        SETB IT0
Cheak3:    SJMP Cheak3
END
```

The control algorithm has been written in the LabVIEW 8.2 as shown in figure (4).

3- Control Methodology

Varying the power of heater actuator can control the water temperature inside the tank. The PI control algorithm has been implemented and their details have been discussed in the following section.

3-1 PI control

The input to the actuator or the output (u (t)) of the PI controller is the summation of proportional gain, and integral action, which is expressed as:

$$u(t) = K_P e(t) + K_I \int e(t)dt \quad \text{---(9)}$$

Where e(t) is the error between the set-point (T_{des}) and the actual output ($T_w(t)$),(KP) Proportional gain, and (KI) Integral gain.

The PI parameters affect system dynamics are most interested in four major characteristics of the closed-loop step response.

They are: Rise Time, Overshoot, Settling Time, and Error Steady-state.

The effects of increasing each of the controller parameters KP, and KI can be summarized as in table (1) [2].

The proper tuning of the PI parameters are therefore essential for proper control and the parameters for the PI control have been determined using trial and error method depended on the simulation Matlab (6.5) package to find the best system response.

3-2 Simulation Result:

In this section, it is applied the mapping between the real process and the simulation Matlab (6.5) package as shown in figure (5). The proposal of the Traic device transfer function in conjunction with the heater unit is linear with saturation transfer function that slope is equal to 150 as a gain and limit to 1500 watt maximum depend on the heater description.

The open loop step response of the heating process is shown in figure (6), when apply step change in the heater actuator and it is equal (21.45) watt that will increase one-centigrade degree in the output temperature from $25C^o$ to $26C^o$. And from this response the time constant of the heating process is equal to 10.6 hour or 38181.8 second as show in figure (6).

In the Matlab simulation package, apply the block diagram in figure (5) with the trial and error method for many times to find the best system response by tuning parameters of the PI controller, and then choose the best PI controller parameter in the simulation package as shown in table (2).

The closed loop time response of the water heater with only P-controller in Matlab simulation is illustrated in figures (7-a, b) for the initial temperature condition is $25C^o$ and have small error steady state.

The closed loop time response of the water heater with PI-controller in Matlab simulation is illustrated in figures (8-a, b) for the initial temperature condition is $25C^o$.

The response of the process in figure (7-a) reaches the steady state at (600 sec.) and has small error with smooth control action as shown in figure (7-

b). But the response of the process in figure (8-a) reaches steady state at (550 sec.) with oscillation control action at steady state to eliminate the error as shown in figure (8-b).

3-3 Real Time Results:

In this section, apply the same best tuning parameters of the PI controller in the discrete time "Real Time Computer Controller" after converting the continuous PI parameters controller of the table (2) to discrete PI controller by using Euler's method [6]:

$$U(z) = (K_P + K_I \frac{T_S}{Z-1})E(z) \quad \text{---(10)}$$

$$U(k) = K_P E(k) + (K_I T_S - K_P)E(k-1) + U(k-1) \quad \text{-----(11)}$$

The sampling interval for the temperature of the heating system selected is one minute by using Shannon theory $T_S = 1$ Min. The closed loop time response of the water temperature with only P-controller in real time is illustrated in figures (9-a, b, c, d) for the initial temperature condition is $25\,C^o$.

The response of the process in figure (9-a) reaches the steady state at 600 sec approximately and from figure (9-c) the steady state error of the process temperature is oscillation to $\pm 2.2\,C^o$.

The closed loop time response of the water temperature with PI-controller in real time is illustrated in figures (10-a, b, c, d) for the initial temperature condition is $25\,C^o$.

The response of the process in figure (10-a) reaches the steady state at 550 sec approximately and from figure (10-c) the steady state error of the process temperature is oscillation to $\pm 1\,C^o$.

The real time control action for P and PI controller have more oscillation than P or PI simulation controller because in the real time there are accumulation errors such as undesirable characteristics of temperature sensor "non-linearity, drift, and offset", offset of the operation amplifier, and the quantization error of the analog digital converter.

4-Conclusion:

The real time control system consist of a water tank, phase control based AT89C51 micro controller, temperature sensor such as thermocouple type J and data acquisition card in IBM PC AT.

The water tank temperature “heating process” has been controlled by variation of the heat energy from 0 to 1500 watt inside the water tank by digital control action from computer and digital phase gate control of the Triac device for the heater actuator.

Both the real time PI controller has been implemented in labVIEW platform through a DAQ card and the simulation PI controller using Matlab package are successful for maintaining water tank temperature.

In the simulation package, the trial and error method used for many times to find the best system response by tuning parameters of the PI controller, and then choose the best PI controller parameters. Then apply the same best tuning parameters of the PI controller in the discrete time "Real Time Computer Controller" after converting the continuous PI parameters controller to discrete PI controller.

The result of the real time control action has more oscillation than the simulation control action and the steady-state error in real time is equal to $(\pm 1)\ C^{o}$ for PI controller but in the simulation is equal to zero because in the real time there are accumulation errors such as undesirable characteristics of temperature sensor "non-linearity, drift, and offset", offset of the operation amplifier, and the quantization error of the analog digital converter.

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Table (1) The real parameters of the heating process

Real parameter	Values
A: surface area of the tank	**0.075** m^2
h: over heat transfer coefficient	**11** $watt/m^2C^o$
M: mass of water in tank	**7.5 Kg**
Cp: specific heat of water	**4.2** KJ/KgC^o

Table (1): Effects of the controller parameters KP, and KI

Response	Rise Time	Overshoot	Settling Time	Error S-S
Kp	Decrease	Increase	-	Decrease
Ki	Decrease	Decrease	Increase	Eliminate

Table (2): The best PI controller parameters in the Matlab simulation package

Controller	K_P	K_I
P	**50**	**0**
PI	**100**	**0.1**

Figure (1): The picture of the experimental for the real-time control of temperature of a heating

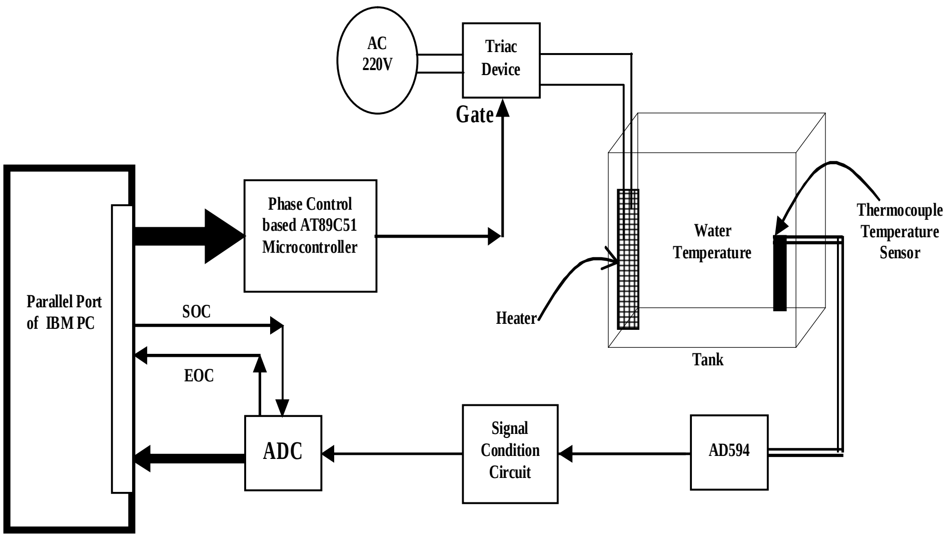

Figure (2): The schematic of the experimental of temperature of a heating process

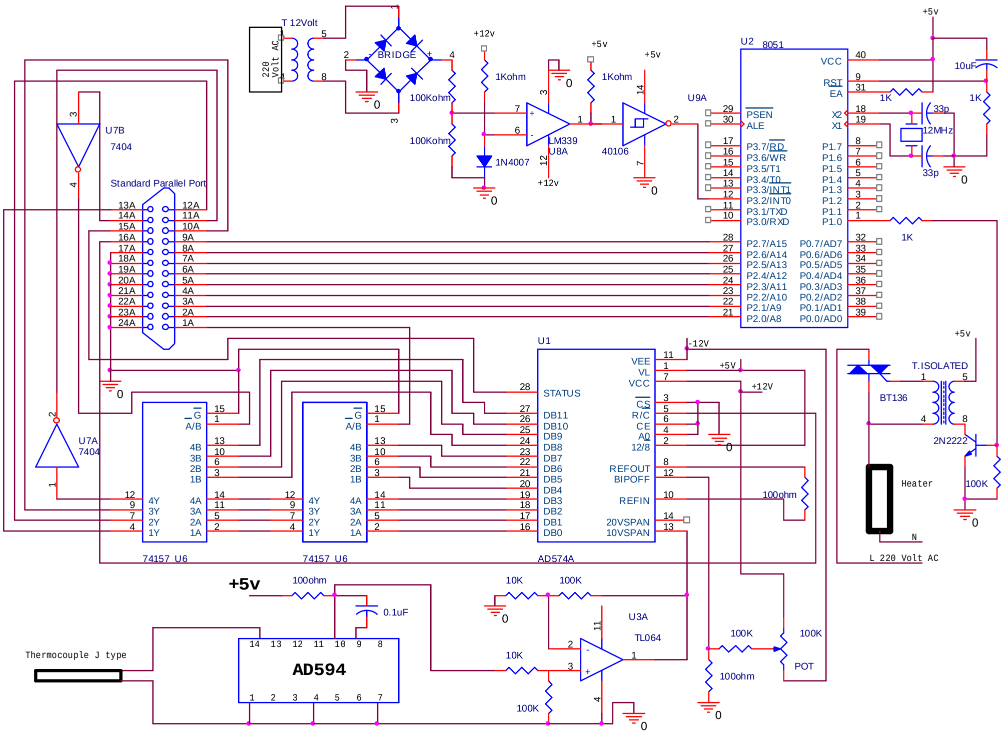

Figure (3): The schematic diagram of the control circuit

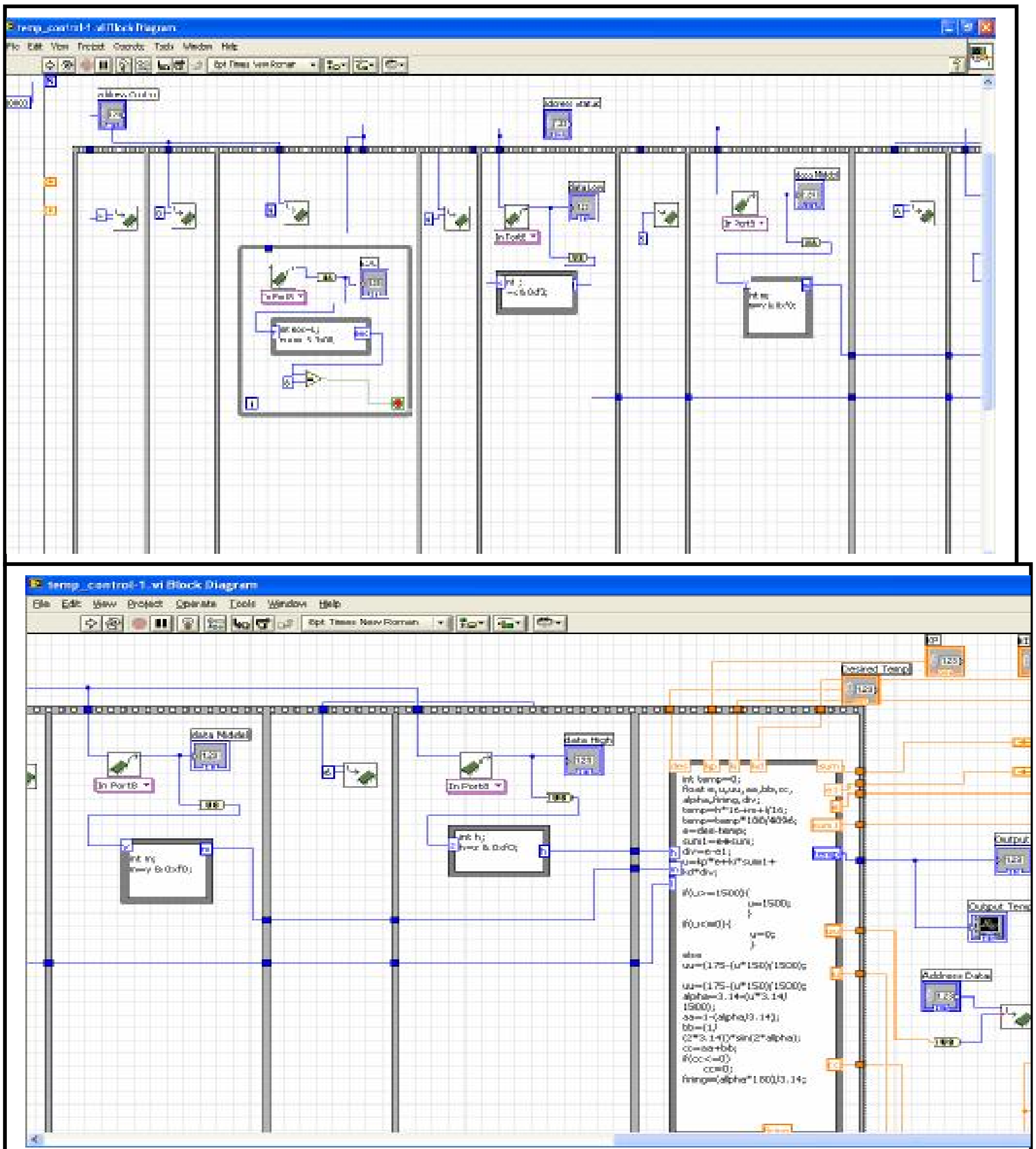

Figure (4): The computer code in LabVIEW program

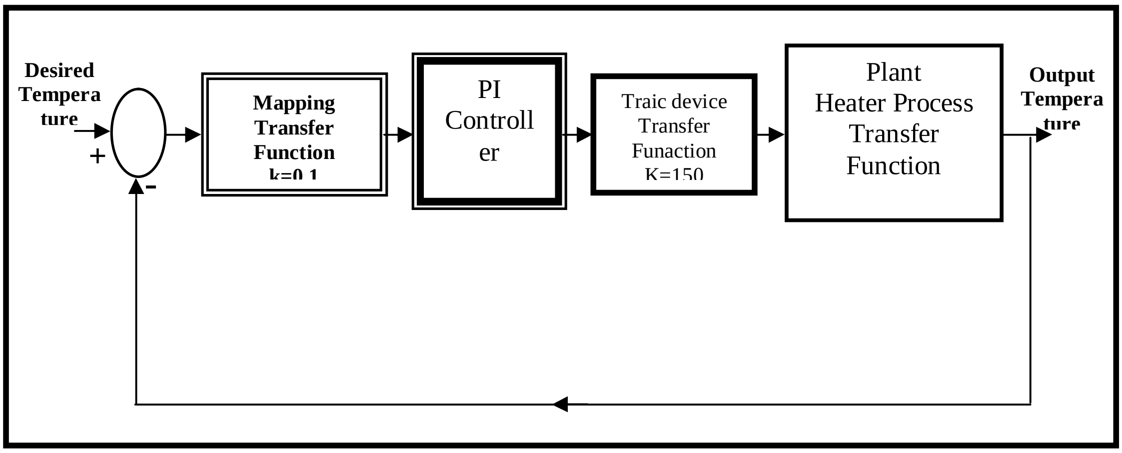

Figure (5): The mapping block diagram between the real process and simulation Matlab

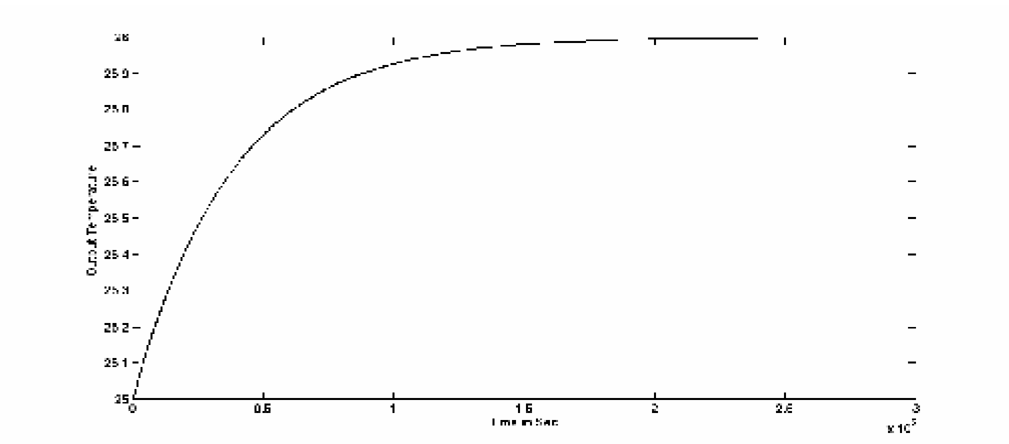

Figure (6): Open loop step response

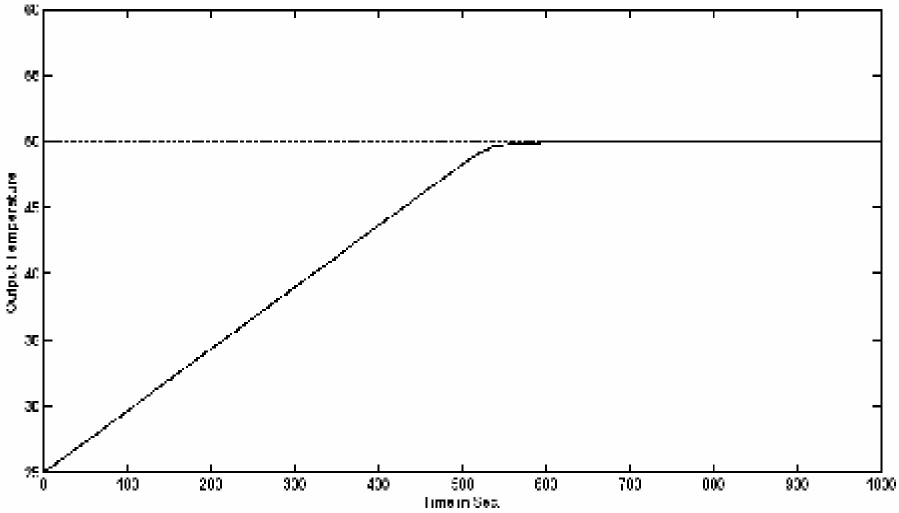

Figure (7-a): The Simulation output temperature of the heater process

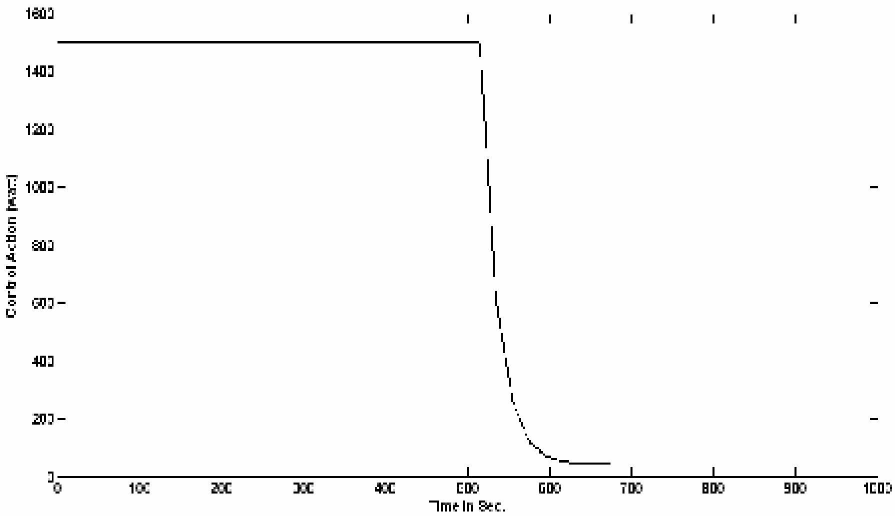

Figure (7-b): The Simulation control Action

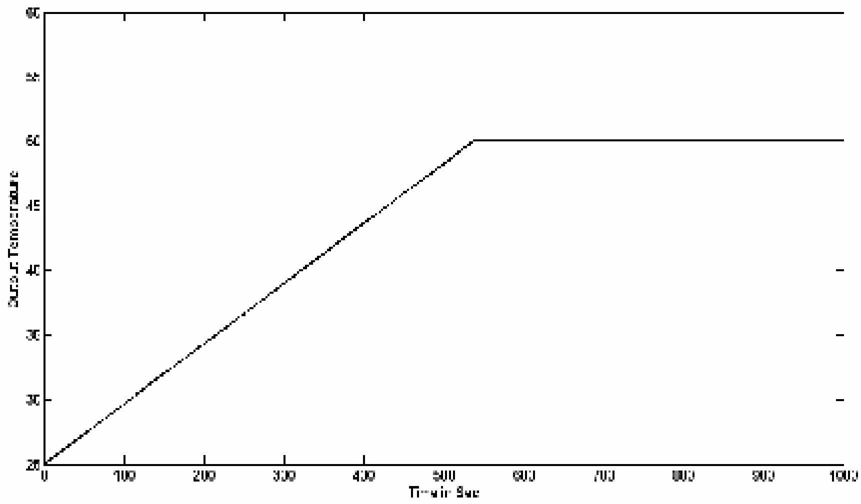

Figure (8-a): The Simulation output temperature of the heater process

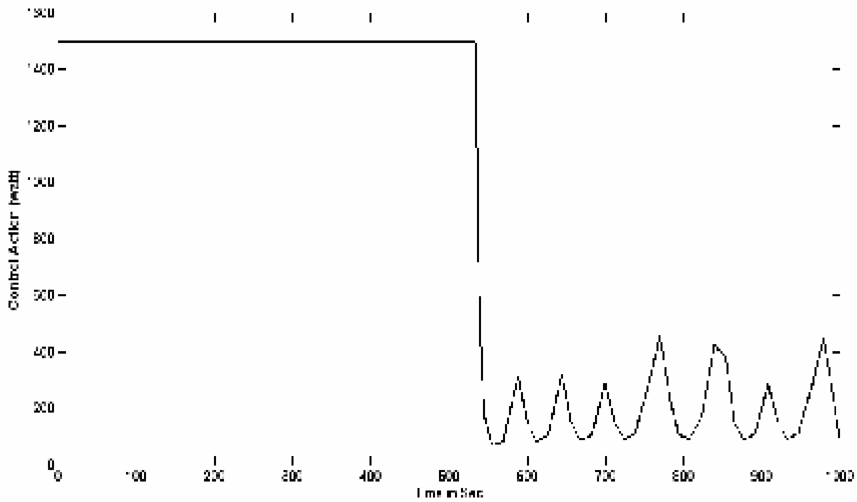

Figure (8-b): The Simulation control Action C^0.

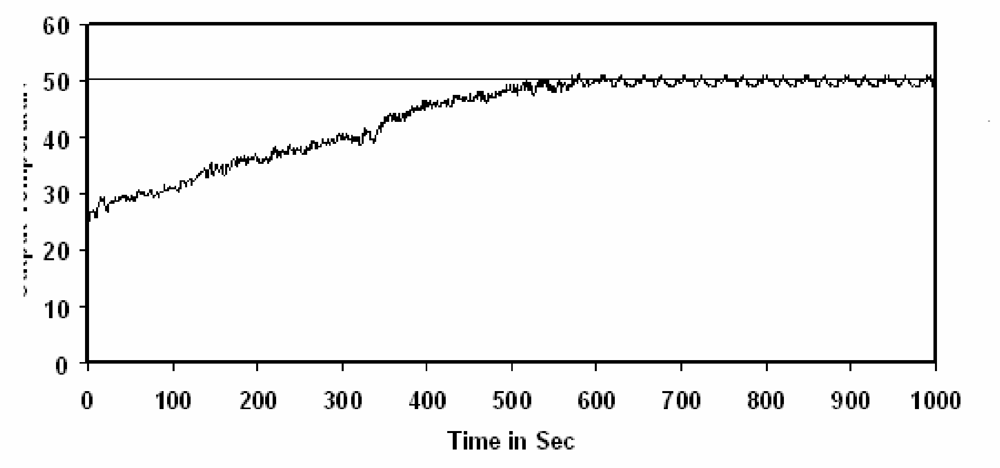

Figure (9-a): The Real Time closed loop time response of the water temperature with only P-controller

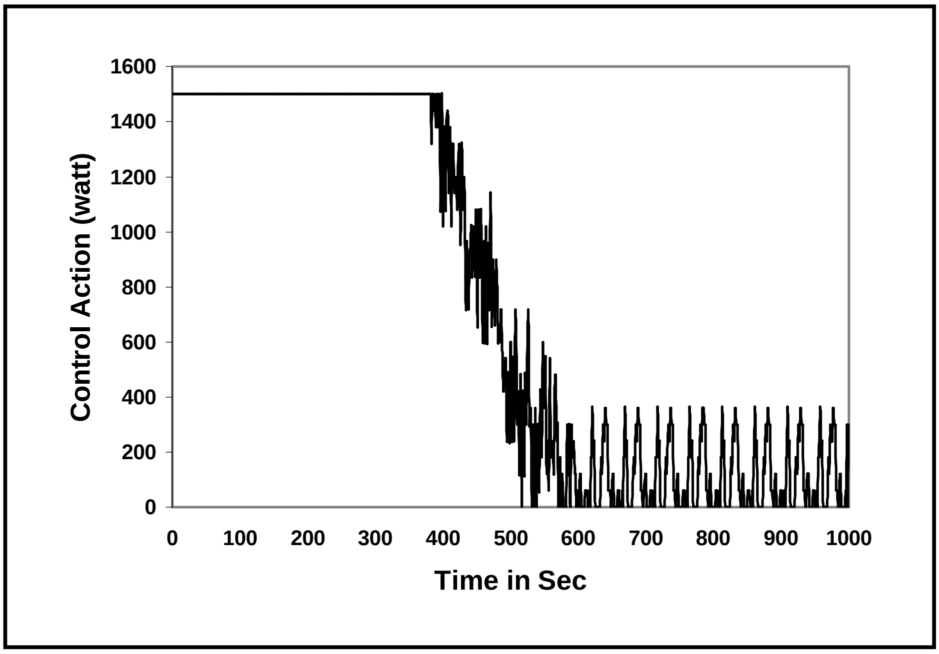

Figure (9-b): The Real Time heater control action

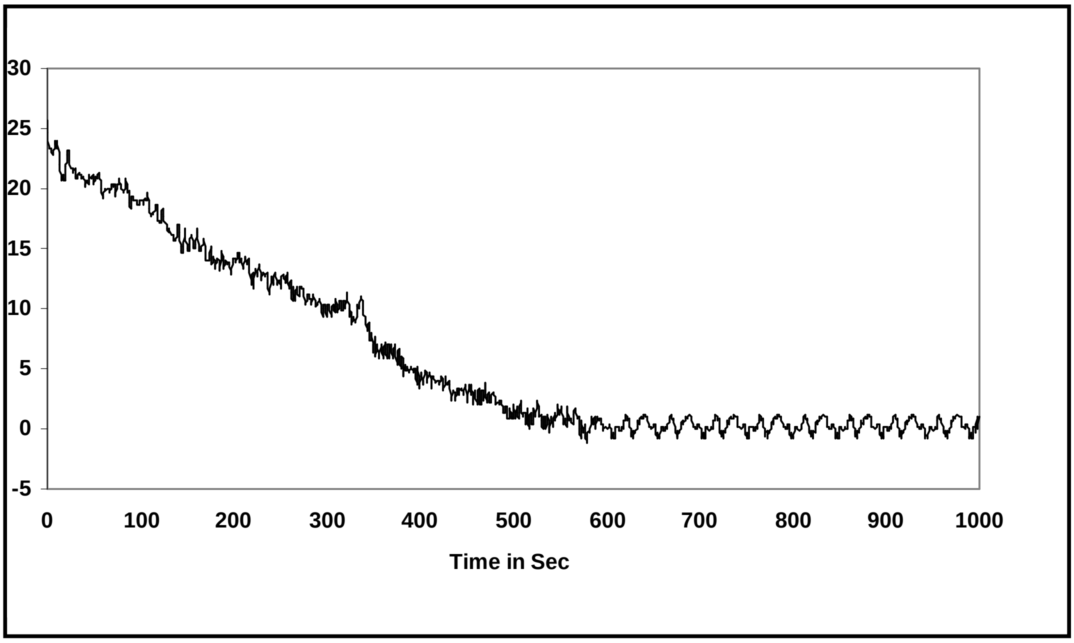

Figure (9-c): The Error between the desired temperature and the water temperature

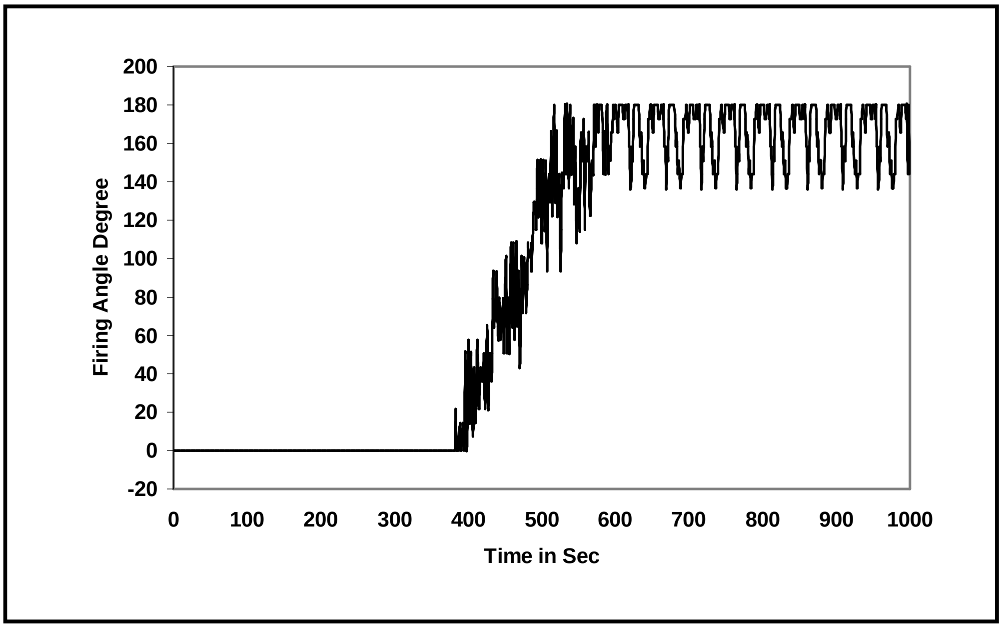

Figure (9-d): Firing angle degree of Traic device

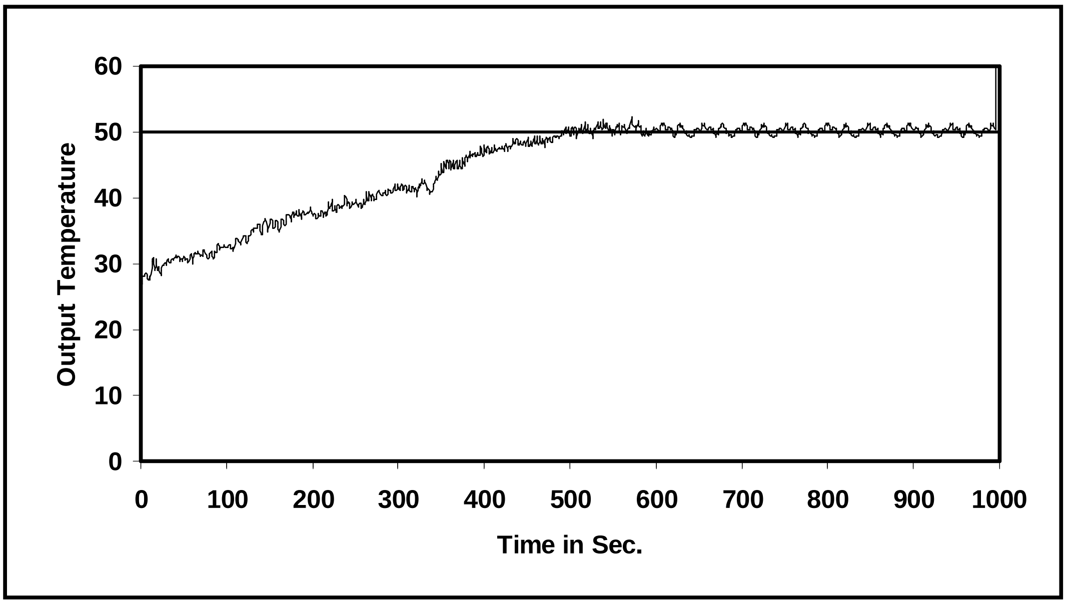

Figure (10-a): The Real time closed loop time response of the water temperature with PI-controller

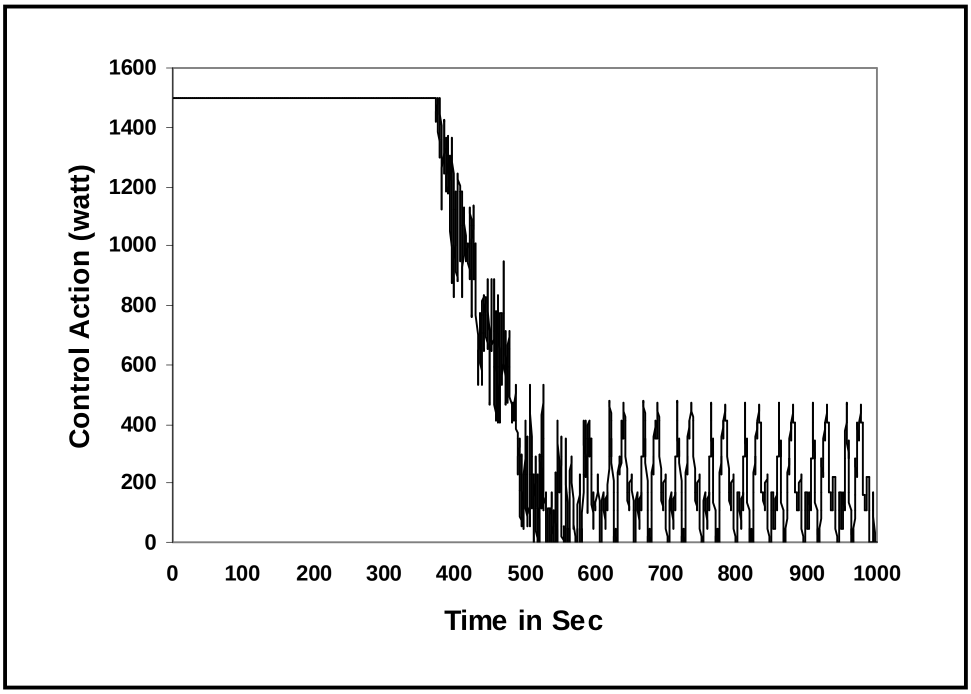

Figure (10-b): The Real Time heater control action

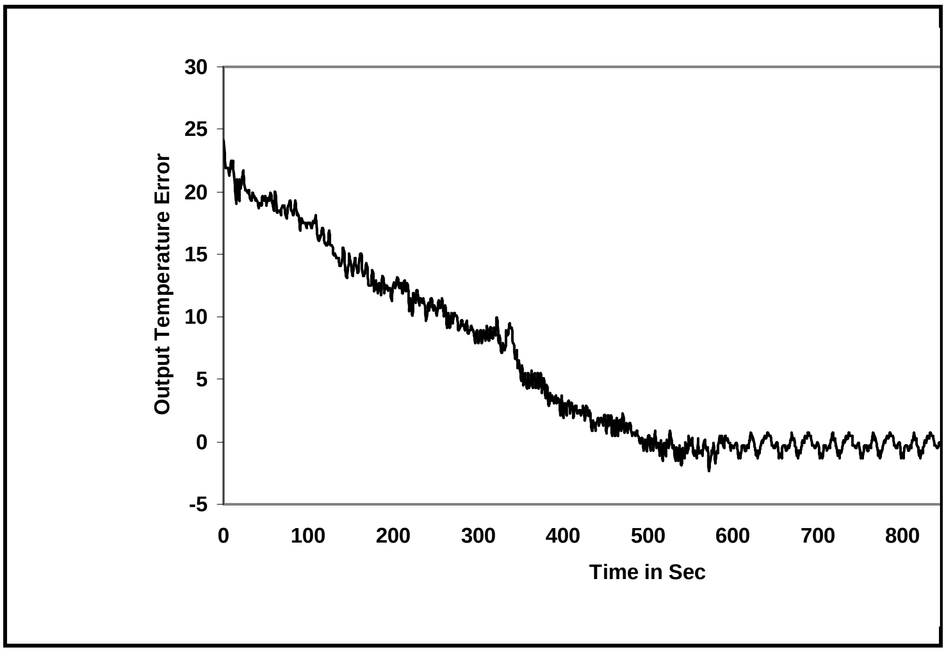

Figure (10-c): The Error between the desired temperature and the water temperature

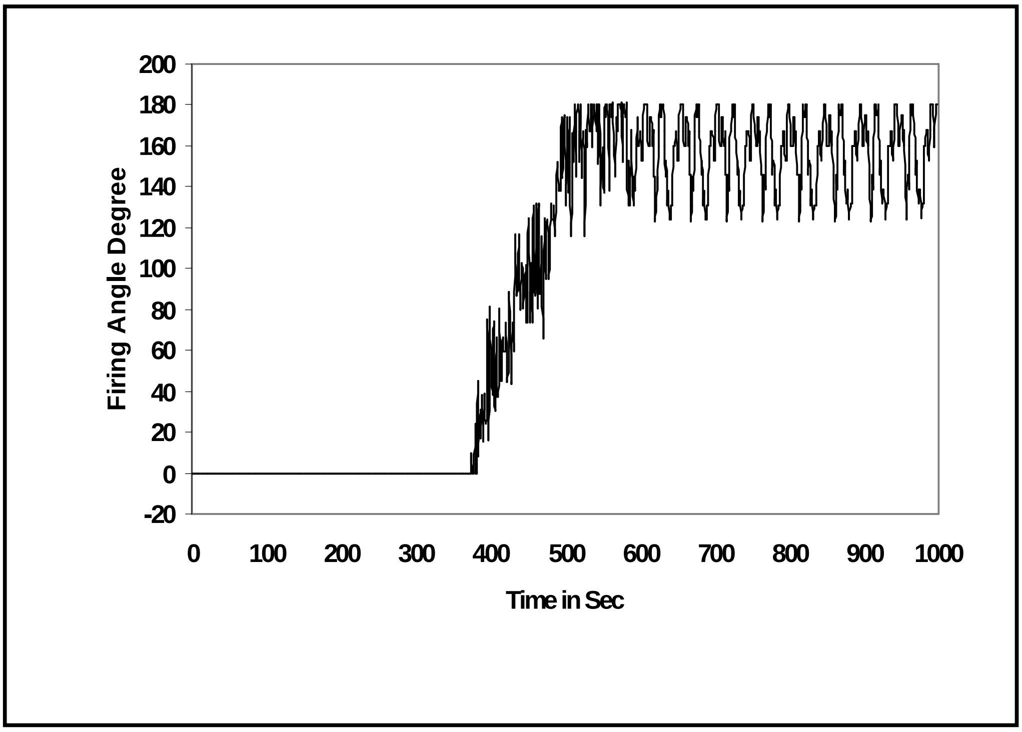

Figure (10-d): Firing angle degree of Traic device