# Design a Liquid Temperature Controller. Application for Heat Transfer System.

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***Abstract:*** *In this work, a water temperature control system in a Pirex tank is designed for teaching purposes. Students can use this system to conduct experiments for subjects in the field of automatic control. Our first task is to build mathematical model based on physical laws. After the system has been installed completely, the model parameters are identified experimentally based on the unit pulse response. Water temperature control system required to reach to the desired temperature set-point in a certain range of time and to avoid overshooting and steady-state error. Therefore, the PID controller and one neural intelligent controller are designed. Finally, experimental results show that the control system works stably and the settling short time.*

**Keywords: -** *PID, neural controller, water temperature control, heat transfer, delay.*

## I. INTRODUCTION

Following the development of the kiln temperature control system that was successfully built [1-6]. And now the water temperature control system is made using the equipment that is available in the lab of our major. A way to adjust parameters in PID controller is based on Ziegler–Nichols method [7-10]. This method uses plant and reference transfer functions to determine the PID parameters. In all fields of industry and civil, there are always variables of heat process using for in production processes. Water temperature control is one of the most widely used processes in academic laboratories and industries, for example, temperature control in thermal power plants, heating system in factories and in the health field. Its application in the production of a variety of products is common in process industries. While significant number of works, in industry and academic, has been studied on water bath temperature control [11-14], it still continues to elicit interest because of its critical roles in the quality of products and safety.

## II. TEMPERATURE CONTROL SYSTEM

### A. *Describe the thermal process*

The major components of the studying system are water tank, electric heating resistance (R=30Ω, $P_{max}$ = 1,6KW), sensor PT100, pump, flow meter, and the single-phase AC-AC converter. The physical size of the Pirex tank is 1 liter. The heating element is fixed inside the Pirex tank. The aim of this process (Fig.1) is to control the water temperature in a Pirex tank to reach to set-point, and to be kept constant at desired value. A temperature sensor is used for the measurement of the water temperature inside the tank. The output of the sensor which is proportional to the temperature is feedback to the controller to stabilize the set value. The water is taken from the general tap water for the experimental building through a centrifugal pump and is introduced into a circuit. During its forced circulation, the water reaches the Pirex tank, where it can be heated by varying the intensity of the electric current through a resistor. From the Pirex tank, the water go out. The outgoing flow is equal to the inlet flow. The flow can be adjusted through valve and measured by means of flow-meter. The value of the controlled quantity is acquired through a PT100 probe.

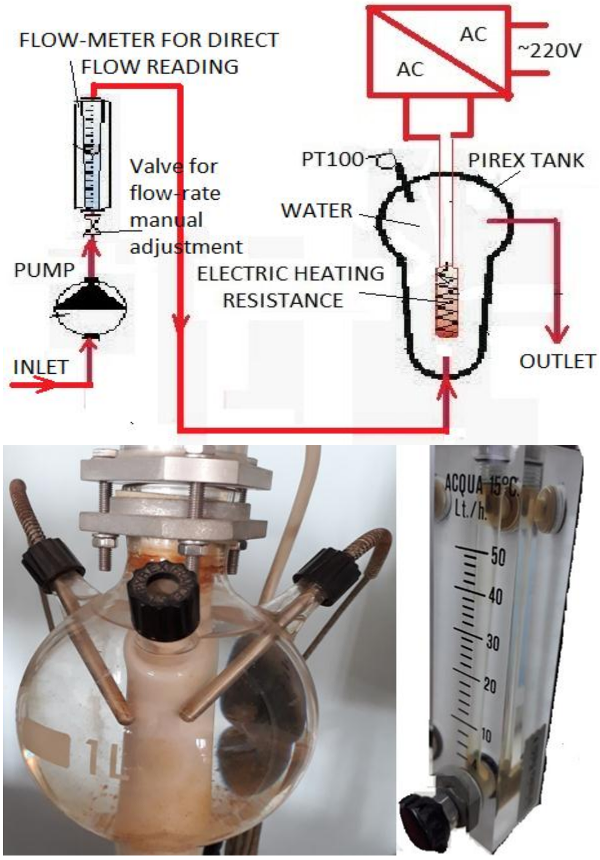


**Fig.1: The system model**

### B. *Thermal model of the water tank*

To consider the underlying physics of the water tank, it is assumed that the tank is insulated to eliminate heat loss to the surrounding air. It is at a uniform temperature. Thus, a single temperature is used to describe the temperature of the water inside the tank and of the outflowing water. Defining the system variables. The heat transfer equation for the process of transferring heat from the heating wire to water is:

$$\Delta T = R_T . q \tag{1}$$

with
$q$ is heat flow rate, kJ/s
$\Delta T$ is temperature difference, $^0$C
$R_T$ is thermal resistance, $^0$C s /kJ
$T_o$ is steady state temperature of inflowing water, $^0$C
$T_i$ is steady state temperature of outflowing water, $^0$C
$L$ is steady state water flow rate, kg/s
$m$ is mass of water in tank, kg
$C$ is specific heat of water, kJ/kg $^0$C
$C_T = mC$ is thermal capacitance, kJ/$^0$C
$Q$ is steady state heat input rate, kJ/s

Equation of thermal equilibrium in a unit of time is:

$$C_T \frac{dT}{dt} = (T_i - T_0) LC + Q(t-\tau)$$
$$C_T \frac{dT}{dt} = (T_i - T_0) \frac{1}{R_T} + Q(t-\tau)$$
$$\frac{\Delta T}{Q} = \frac{R_T}{R_T C_T s + 1} e^{-\tau s} = \frac{K}{Ts+1} e^{-\tau s}$$
(2)

Note that, the time constant of the system is:

$$R_T C_T = T \tag{3}$$

The constrained condition of the control function is:

$$0\% \le Q \le 100\% \tag{4}$$

with *0%*, *100%* are the under and upper limit of the supplied power respectively (W).

### *C. Parameter identification of the system*

In this experiment, we will derive a model for the thermal dynamics of the water tank based on the step response data recorded. That is, we will fit a model to the data without any consideration of the underlying physics of the system. Examination of the recorded data indicates that the thermal dynamics of the water tank are approximately first order with delayed time. Therefore, we will fit a transfer function to the data of the form shown below. In order to identify the parameter of the system, a step response is obtained as shown in Fig. 2, where the type of input is step function with amplitude of 70% of the power and the sampling time is $T_s = 1s$

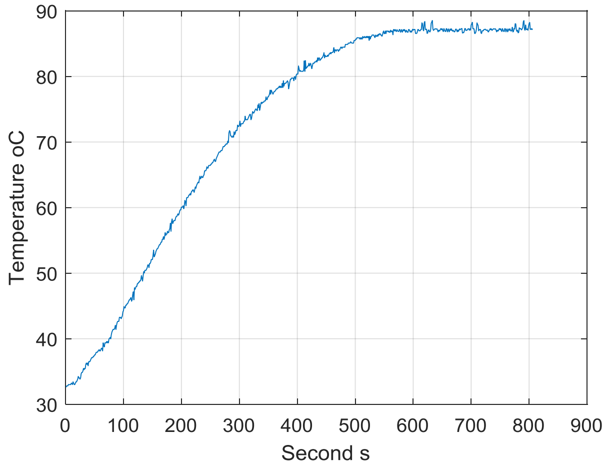


**Fig. 2. Step response of the water tank.**

From inspection of the given step response data, the ambient temperature (initial water temperature) appear to be approximately 33 degrees C, while the steady-state water temperature appears to be about 86 degrees C. Based on the step response and using System Identification Toolbox in Matlab, the process model is obtained as follows:

$$G(s) = \frac{K}{Ts+1} e^{-\tau s} = \frac{131,72}{240,1s+1} e^{-30s} \tag{5}$$

where $K$ is the static transfer coefficient, $\tau$ is the delayed time (s), $T$ is the time constant of system (s)

### *D. PID Controller Design*

There are many methods to adjust PID controller [8–10]. For simplicity, it can be adjusted the PID gains automatically using the 'Tune...' button (requires Simulink Control Design). This method will be used to initially determine the PID parameters. We can also use other methods like Ziegler – Nichols, genetic algorithm, and PSO to compare with each other. The PID controller is designed as follows:

$$u(t) = K_P + K_I \int e dt + K_D \frac{de}{dt} \tag{6}$$

where $K_P$ =1.25, $K_I$ =0.022 and $K_D$ = 0.001.

The controller is converted into discrete-time model as follows by using trapezoidal approximation for the integral.

$$u(n) = K_P e(n) + K_I \frac{T_s}{2} \sum_1^n [e(n) + e(n-1)] + \frac{K_D}{T_s}[e(n) - e(n-1)] \tag{7}$$

$$u(n) = u(n-1) + \left[K_P + K_I \frac{T_s}{2} + \frac{K_D}{T_s}\right] e(n) + \left[-K_P + K_I \frac{T_s}{2} - \frac{2K_D}{T_s}\right] e(n-1) + \frac{K_D}{T_s} e(n-2) \tag{8}$$

where $T_s = 1s$ is the sampling time.

### E. Smart controller design

The one neural controller has ability to make plant stable because of its nonlinearity. In addition, training algorithm enables the controller to adapt with changes of plant or noise. The one neural controller, having 3 inputs and 1 output, is shown in Fig 3. The inputs of neural network ($e_P$, $e_I$, $e_D$) are created by proportion, integration and derivation of error $e$.

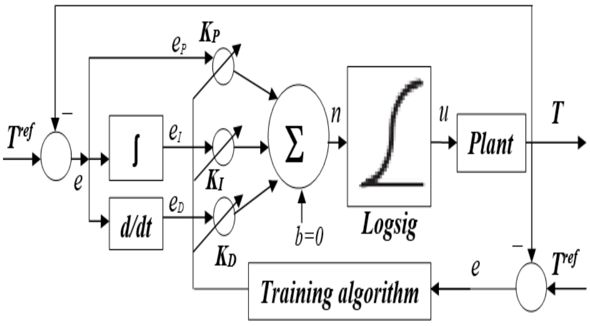


**Fig. 3: One neural controller**

$$u = Logsig(K_P e_P + K_I e_I + K_D e_D) \quad (9)$$

The objective function:

$$J = \frac{1}{2}e^2 = \frac{1}{2}(T^{ref} - T)^2 \rightarrow \min \quad (10)$$

The weights, PID controller parameters, can be adjusted by using the algorithm of gradient descent. The update rules for these control parameters are expressed as:

$$K_P = K_P - \eta_P \frac{\partial J}{\partial K_P} = K_P - \eta_P \frac{\partial J}{\partial y}\frac{\partial y}{\partial u}\frac{\partial u}{\partial K_P} =$$

$$= K_P + \eta_{Pu} e f'(u) e_P \quad (11)$$

$$K_I = K_I - \eta_I \frac{\partial J}{\partial K_I} = K_I - \eta_I \frac{\partial J}{\partial y}\frac{\partial y}{\partial u}\frac{\partial u}{\partial K_I} =$$

$$= K_I + \eta_{Iu} e f'(u) e_I$$

(12)

$$K_D = K_D - \eta_D \frac{\partial J}{\partial K_D} = K_D - \eta_D \frac{\partial J}{\partial y}\frac{\partial y}{\partial u}\frac{\partial u}{\partial K_D} =$$

$$= K_D + \eta_{Du} e f'(u) e_D \quad (13)$$

where, $\eta$ are the sensitivity of the response being a design parameter, the learning rates chosen 0.01 respectively.

Conduct partial derivative analysis of expressions, we have rule of change of weights of PID-neural controller

## III. EXPERIMENTAL RESULTS

A PID control strategy, based on a deduced model, is proposed for implementing a thermal process currently employed in industrial applications, and the tests can be performed in highly realistic conditions. The designed system consists of a Pirex tank, made of glass, a 30 Ω resistance, a temperature sensor PT100, an Arduino Uno-R3, a triac 40A and 220 V–50 Hz power supply.

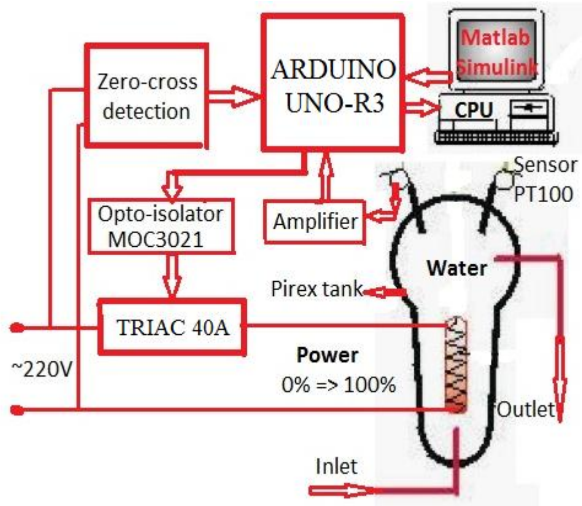


**Fig. 4: Block diagram of experimental setup**

The test circuit uses a small power Triac with incandescent lamp while running with 1600w load will use Triac 40A. Arduino is used to control a Triac's gate in the phase angle control circuit using Arduino.

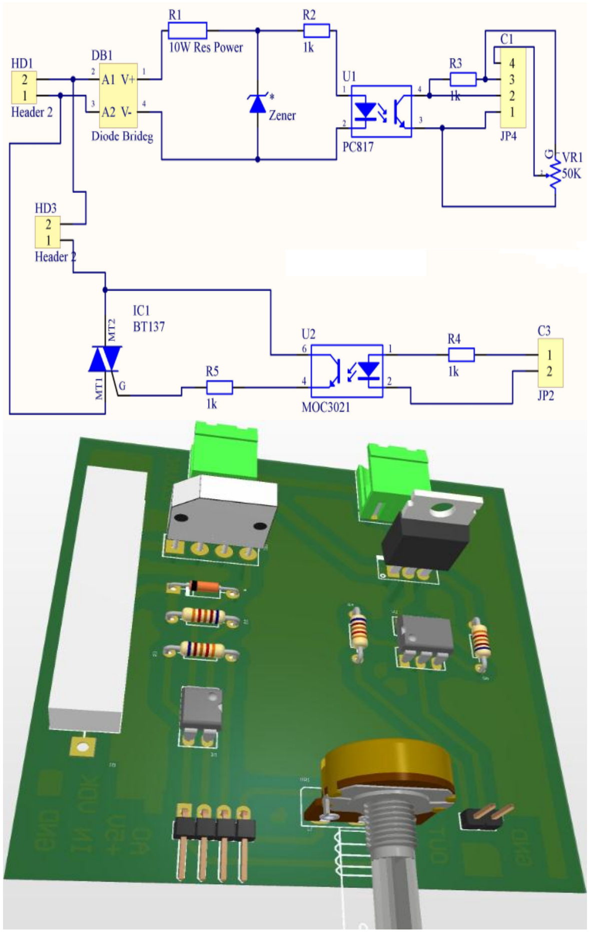


**Fig. 5: The block diagram of phase-angle control**

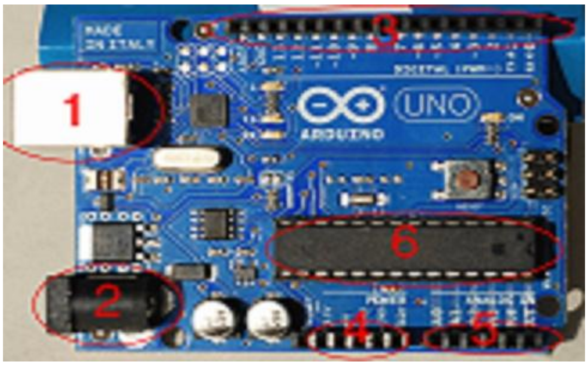

**Fig. 6: Modul Arduino UNO R3 with the Block diagram of phase-angle control**

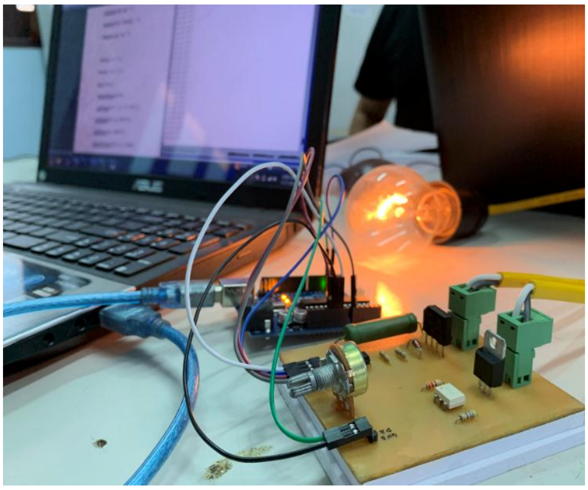

**Fig. 7: Test with incandescent lamp**

***Arduino code for phase-angle control circuit.***

```
unsigned int val = 0;
unsigned int TimeDL = 0;
unsigned int vol = 0;
#define IN_D 2
#define OUT_D 3
void setup() {
  Serial.begin(9600);
  pinMode(OUT_D, OUTPUT);
  pinMode(IN_D, INPUT);
 pinMode(A0, INPUT);
 digitalWrite(OUT_D, LOW);
 attachInterrupt(0, cross_zero, FALLING);
}
void cross_zero()
{
     delayMicroseconds(TimeDL);
     digitalWrite(OUT_D, HIGH);
     delayMicroseconds(100);
     digitalWrite(OUT_D, LOW);
}
void loop()
{
  val = analogRead(A0);
  TimeDL = (int)val*10;
  if(TimeDL >= 9500)
  {
   TimeDL = 9500;
  }
  vol = 220-(TimeDL*0.024);
  Serial.print("Voltage: ");
  Serial.print(vol);
  Serial.print(" V ");
  Serial.print("\n");
}
```

More details about the experiment and its results can be found at: https://www.youtube.com/watch?v=Fp0YAEU3Hlo

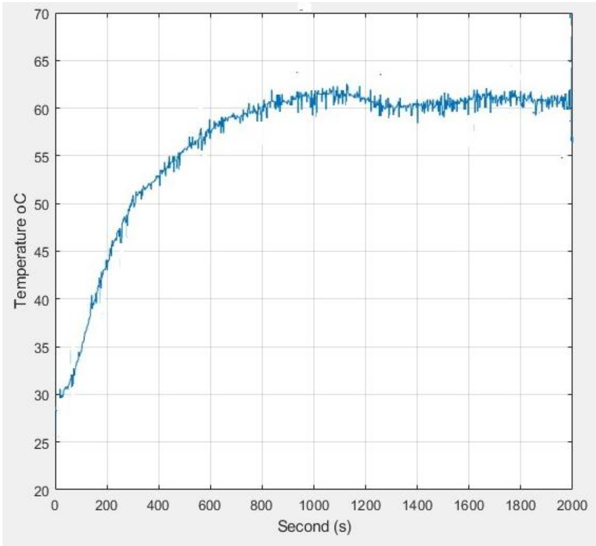


**Fig. 8: Experimental result of PID controller**

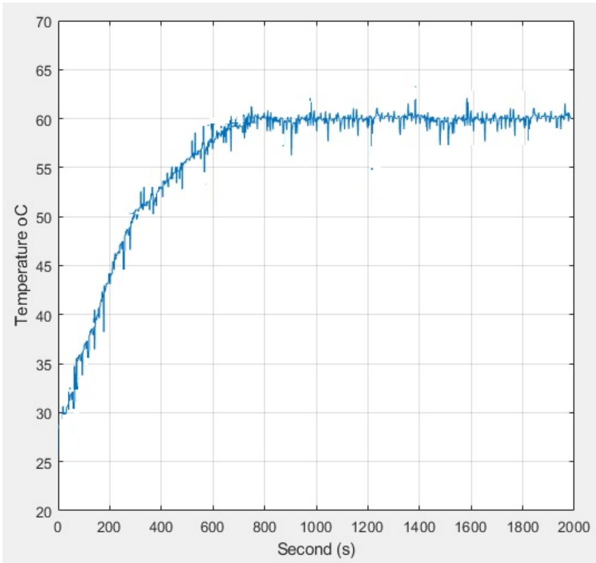


**Fig. 9: Experimental result of one neural controller**

**Remarks**

The experimental results for two cases are shown in Fig. 8 and Fig. 9. The settling times of closed-loop systems produced by the one neural, and PID controllers are 770, and 800 seconds, respectively. The overshoots in percentage made by these controllers are 1.5%, and 6.6%, respectively.

## IV. CONCLUSIONS

In the paper, the one neural controller is used to control a thermal process. The controller parameters are adjusted automatically, on-line, to overcome the disturbances and parameter variations. Experimental tests for the water tank in the laboratory show that the network controller provides very good performance in comparison with the PID. The advantage of the proposed controller is simple and practical to implement, ensure the stability of system and have relative lower requirements for precision of model of object. In addition, it uses the logsig trigger function to ensure the constrained condition of the control function.

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