A Study on PID Control with Indirect Liquid/Steam Heating

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Abstract: - The purpose of this experimental study is to reach homogeneous temperature control effect on the heat plate. In this research, the heat plate is kept constant temperature by the state of dual-phases, i.e., the state of phase change between liquid and steam, so that together with a single-point PID temperature controller only, the homogeneous temperature condition can easily be achieved with a smaller range of variation. The liquid-vapor region can stably predict the temperature for specific pressure and the specific working fluid. The experimental results show that, as far as the homogeneous temperature is concerned, the best result we got for the temperature variation is within ±0.5℃, which is superior to other researches. The system identification can discover the similar system to reach as high as 96.46% of transfer function.

Keywords:- PID control, Homogeneous temperature, System identification, Phase equilibrium, Temperature control, Semi-conductor

1 Introduction

The research can be applied directly to the semi-conductor oxidation processing equipment and the compression manufacturing process of PCB laminates. It can also be modified to use on the temperature control of powder injection molding (PIM) and micro-injection molding, etc. By dual-phase, it is much easy to maintain homogeneous temperature control of heat plate.

The latent heat will be absorbed or released when the phase change between the liquid and vapor, and the system is kept at constant temperature. In other words, the whole range is kept at a constant temperature on each constant pressure line in the wet region as shown in Fig. 1. The liquid-vapor region can stably predict the temperature for specific pressure and the specific working fluid. The controllable temperature is related directly to the working fluid.

Up to now, most manufacturing processes with homogeneous temperature control requirement use multiple-points PID control. The common difficulties encountered are the set-up of control parameters and the effectiveness of homogeneous temperature. Recent researches tried to maintain homogeneous temperature control of heat plate by a single phase, either liquid or gas.

Guibe, 1992 [1] developed a Rapid thermal processing system for single wafer processing by combining a parameter estimator and a long-range predictive PID controller. Laczik, 1996[2] showed that the magnitude of the defect etching of the commercial (100) LEC InP wafers could be virtually eliminated by an initial low temperature anneal.

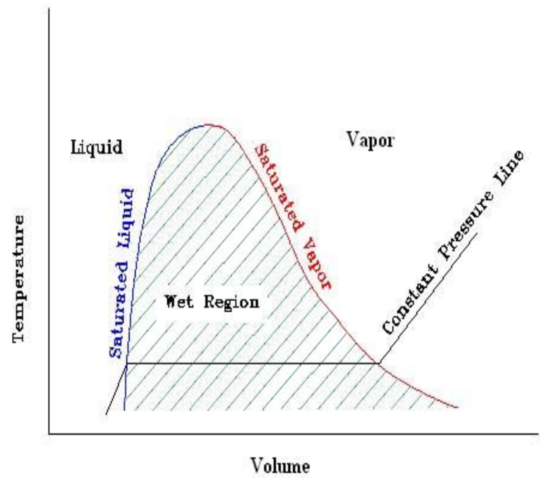

Fig. 1 The temperature change in the saturation dome for pure water.

The isothermal plate is useful to prevent a Si-based wafer or microstructure cracking, some heat treatments such as annealing or tempering process is necessary. During these processes, how to keep the plate stable in uniform temperature is especially important. Bertran, 2001 [3] showed the need to anneal anemometric structures of Si/SiC, C/SiC and C/SiN to improve their mechanical properties. Carpenter, 2006 [4] showed a 26.6% chromium white iron microstructure need the heat treatment cycle, which is similar to a commercially, including an annealing and a tempering process.

To make the PID controlled systems more user-friendly, effective innovation and more intelligent, many techniques are studied. Anders, 1999[5] presents an interactive tool for rapid system identification by step responses analysis with the graphical user interface. Krajewski, 2004 [6] Designed PI controllers with a normalized process model by developing MATLAB programs to find the loci, which can be exploited for tuning purposes and robustness analysis, of constant stability margins and crossover frequency in the parameter space.

Ang, 2005[7] presents a modern overview of functionalities and tuning methods including system identification and "intelligent" techniques in software based PID systems helps automate the entire design and tuning process to a useful degree.

In this paper, we present the performances of the homogeneous plate in experiments. The result shows the temperature of the plate is measured by 9 thermocouples which distribute evenly on the circumference and the central point of the plate when the steady state reached. With the latent heat characteristic of the water, we can make the temperature of the plate to be homogeneous and stable.

Postalcioglu, 2006[9] presents Graphical User Interface (GUI) based control of the temperature using autotuning PID Controller, which is efficient in advance student learning. The aim of computer based education is to develop the learning capacity of students and increase the teaching efficiency with computer based technology. A MatLab-based GUI program has been implemented to the oven for the temperature control.

Data communication link is established between a digital signal processing card and a computer, where the computer hosts a GUI for the digital signal processing card. For the system two kinds of software is applied. One of them is microcontroller software and the other is computer software. This software is corresponded by RS-232 protocol. This experimental system can give an efficient way for students to understand the main of process dynamics and prepares students for the challenges of the professional world where the computer has a significant place.

Sabry, 2006[10] showed the gas-dynamic equations are used to simulate a two phase flow of natural gas and condensed droplets through a convergent-divergent nozzle. A modified nucleation theory is used to estimate the nucleation coefficient and the nucleation rate. A numerical technique is used to solve the governing equations. The results obtained here show that increasing the correction coefficient as well as increasing the low initial pressure (P_o from 1 - 5 bar) delayed the zone of condensation towards the nozzle exit, while at moderate initial pressure (P_o from 10 - 30 bar) the observed shock condensation moves towards the nozzle throat.

Martin Foltin 2006[11] used a new type of adaptive control, based on the closed-loop response recognition is proposed. This approach tries to mimic the behavior of an expert, who has experience with the particular controlled system. The adaptive system updates the controller parameters according to the changes of system behavior. The algorithm uses a knowledge-based system, which evaluates the closed-loop response shape after the decay of the transient response or after only a part of it, and computes corrections of controller parameters. Because the main problem of such a control structure consists in designing of the knowledge-base, they focused them interest on the design of an automatic procedure for the knowledge-base generating.

Sandro Sautta 2006[12] used data mining techniques presented in the literature are usually used for prediction and they are tested on well known benchmark problems. System identification is a practical engineering problem and an abdicative task which is affected by several kinds of modeling assumptions and measurement errors. Therefore, system identification is supported by multiple-model reasoning strategies. The objective of this work is to study the use of data mining techniques for system identification. One goal is to improve views of model-space topologies. The presence of clusters of models having the same characteristics, thereby defining model classes, is an example of useful topological information. Distance metrics add knowledge related to cluster dissimilarity. Engineers are thus better able to improve decision making for system identification.

Boonruang Marungsri 2006[13] used dynamic parameters of induction motors can be roughly estimated through conventional tests (no load test, block rotor test and retardation test) and core loss is neglected in the dynamic behaviors analysis. Due to the complication of dynamic behaviors of induction motors, inaccuracy of transient characteristics may obtain when using these dynamic parameters. In order to improving accuracy of dynamic behaviors analysis, however, the inclusion of core loss in the machine model needs to be re-addressed and an intelligent approach to estimated dynamic parameters needs to be adopted. The simulation results from dynamic parameters including RC obtained by the GA in comparison with the experimental results are convinced the effectiveness for this aim. All the simulation results with taking core loss into account show the effectiveness of each technique for parameter identification of induction motor. However, high accuracy and precisely with shortest time for calculation are the key for indicate the most effective searching technique. Due to shortest calculation time, dynamic parameters identification using GA technique may be the most effectiveness searching techniques for induction motor compare with Tabu Search (TS) and Adaptive Tabu Search (ATS) techniques.

Yang, Jiann-Shiou 2006[14] presents the PI/PID control of a binary distillation column via a genetic searching algorithm (GSA). The time-domain design criterion, expressed as an integral of the squared error, is reformulated in the frequency-domain using the Parseval's relation and Pade approximation. A genetic algorithm is then used to search over the stability region in the controller parameter space for the best settings to minimize the design criterion. Our results indicate that the genetic algorithm can provide better solutions for the PI/PID control schemes as compared to those using the single-loop and multi-loop Ziegler-Nichols tuning methods. We also found that the GSA is easier to use than traditional optimization techniques. In addition, no knowledge of complex mathematics is required to use the GSA effectively.

The increase of both initial pressure and correction coefficient leads to a rapid appearance of sub-cooling, the process becomes more non-equilibrium and the zone of spontaneous condensation is shifted downstream towards a region with larger sub-cooling. The increase of both initial pressure and the correction coefficient besides the decrease of condensation coefficient cause a rapid decay of shock condensation, rapid growth of droplets in the initial stage of condensation and slower further downstream.

Kostic, 2008[15] presents common practice to approximate temperature distribution and heat flux as unidirectional for heterogeneous mixtures if exposed to “over-all unidirectional” boundary conditions. This approach has been used to model and to arrive at the effective (or over-all average) thermal conductivity of heterogeneous mixtures (nanofluids). It is shown here, however, that due to the heterogeneity of system structure and properties the temperature distribution and heat flow will not be unidirectional (one-dimensional) and the errors due to such unrealistic (physically impossible) approximation may be much higher than anticipated. Wacker, 2008[16] showed Firstly the authors explain the nature of contracts between primary suppliers of gas and local suppliers. They then describe and investigate an effect observed frequently in the field of gas volume and flow control. Instead of running a straight line, the volume controller opens or closes the control valve dramatically at the end of the accounting period.

The effect turns out to be caused by a relative deviation of the measured value of the gas flow rate from the actual value, and it is explained by solving an easy differential equation. Rounding errors occurring during necessary calculations may lead to the same effect. In section 2 of their paper the authors introduce a more general linear differential equation to describe various kinds of perturbations simultaneously: relative and absolute deviations of the measured values from the actual values of the gas flow rate and pulses disturbing the pulses counting the standard volume flown so far.

Seyedkazemi, 2008[17] presents an optimal PID controller in view of controller location in the plant is proposed. To adjust the parameters of the controller a fitness function in terms of transient and steady state parts of response and control energy of characteristics of system which are function of controller location, is introduced. A genetic algorithm is employed to minimize the fitness function to achieve a satisfactory response for system. The results are validated by some simulations.

2 Problem Formulations

A material physical state can be presented by its state equation. A state equation of a gas is

$$\Phi(P,V,T,n) = 0 \qquad (1)$$

The ideal gas state equation under low pressure or high temperature is

$$P \cdot V = n \cdot R \cdot T \qquad (2)$$

Where T is absolute temperature and R the universal gas constant

Boyle’s law state that under constant temperature

$$PV = K \qquad (3)$$

K1 is a proportional constant relating to the total amount of gas.

The rising pressure inside the tank will lead to a rising saturation temperature in the working fluid. By the working fluid, the controllable temperature range on the homogenous temperature plate is enlarged. PID will amplify the error message and controlled body to have quicker reaction, the output will response quickly with the input. Integrating function makes steady-state error to zero, while differential function improves the transient response.

The PID control becomes the most in common use control method in industry. Heat adds to saturated water, the liquid will absorb the energy and change to gas state without temperature variation. And the temperature of the two-phase mixture will not change. One can use the phase change principle as the temperature control mechanism. The experimental parameters are temperature, pressure, heat and phase change in this study.

3 Experiment Device

The measured experimental results are used to decide the system transfer function. After the form of the transfer function is chosen, the software can identify the system stability or change parameters to imitate different results. The system identification used in present study is in toolbox of Matlab [8].

A 304 type stainless cylindrical tank formed by using the argon welds for sealing, its size is 640 mm x 205 mm x 8mm, Teflon Resin for sealing between the tank and the homogeneous temperature plate. The whole tank is well sealed and no vapor will leak from the tank. Fig. 2 and Fig.3 are device explore view plot of the experiment.

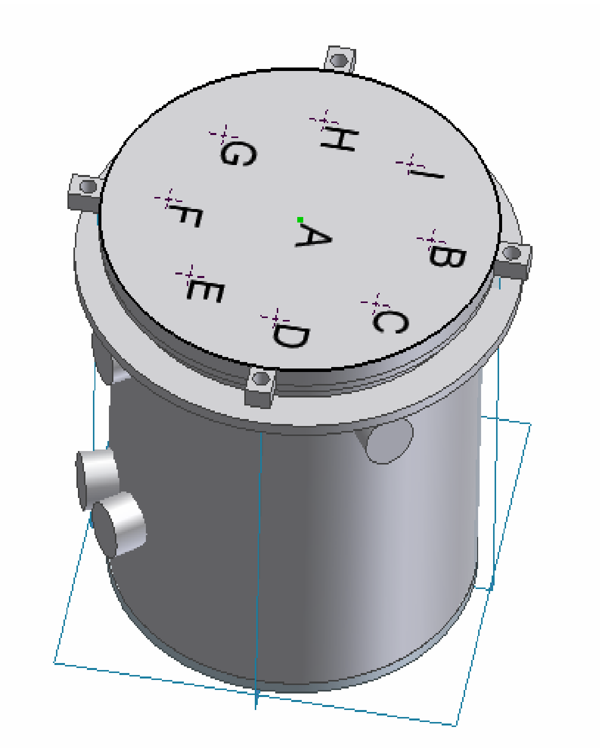

Fig. 2 The measured temperature on the plate.

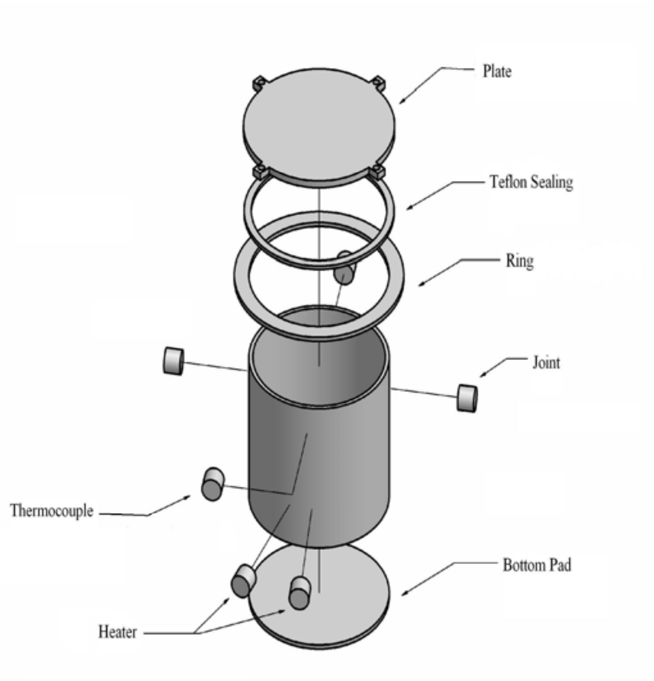

Fig. 3 The experiment device explore view plot.

Fig. 4 and Fig 5 show the measured tank temperature and the PID feedback temperature.

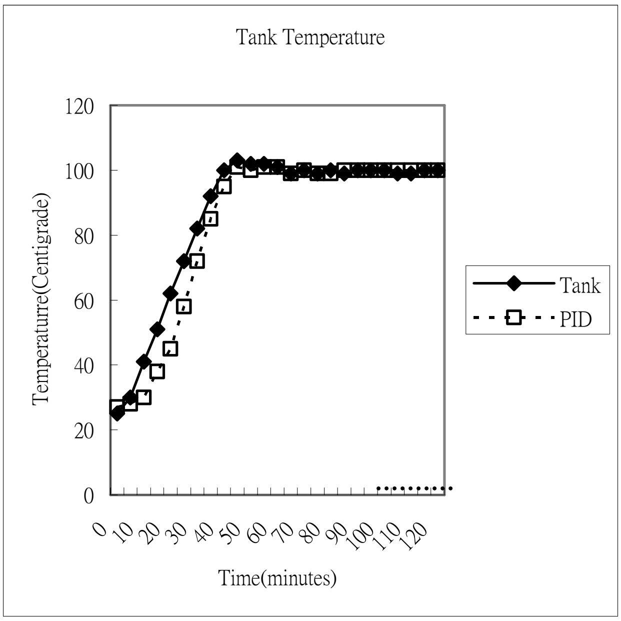

Fig. 4 The measured temperature (tank temperature：—◆—
and the PID feedback temperature： -□-)

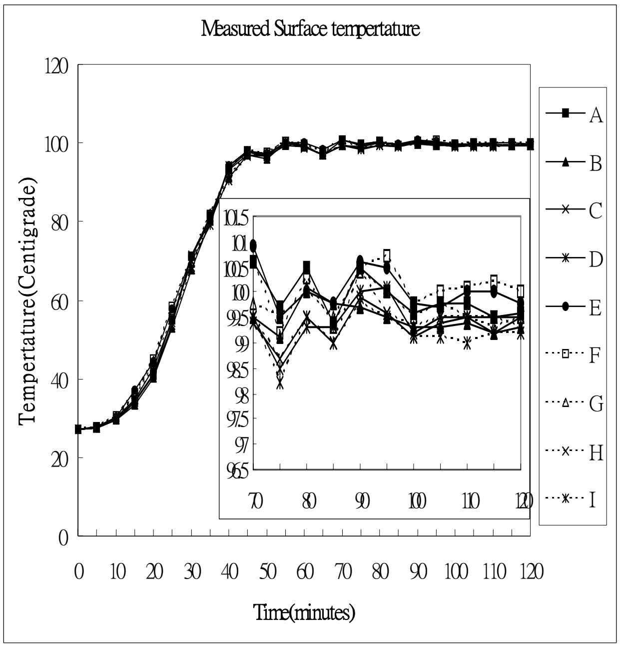

Fig. 5 The temperature of the plate is measured by 9 thermal couples

4 PID Controller

The PID parameters are self-adjust by intelligent regulator in this experiment. The sv is the settled temperature, pv the feedback temperature from the thermocouple. The K-type thermal couple uses the Seebeck effect as temperature sensor. The K-type Thermocouple thermometers are designed to supply accurate temperature readings in the higher temperature ranges (-50.0 to 900°C or -58.0 to 1650°F).

Silicon Carbide (SiC) heating elements can usually make use for furnace which temperature from 600℃-1600℃. It can be directly used in an air atmosphere without any protection atmosphere and is chosen as heater in present study. A pressure safety valve will release container pressure higher than 0.3546375MPa for security.

A PID controller catches the measured temperature on the plate. It also set the water level in the cylindrical tank and measured the vapor pressure, which must be less than 0.34323275MPa inside the tank. The measured temperatures around point E and F are the higher than any other measured points. The PID feedback temperatures are set around points E and F. By controlling the higher temperature, the whole plate temperature will be more homogeneous and heats always transfer from the higher temperature the lower one.

The thermocouple is used in the vapor to measure the steam temperature. After heats up 62 minutes, the feedback temperature overlaps the steam temperature. The convergent temperature of nine points on the plate is extremely close to the PID controller the temperature, and the average temperature is in 100℃.

The more quantity vapor inside the tank, the more quantity of heat stores up, and each measured temperature fluctuation on the entire plate is smaller. When the temperature sensory element measured the temperature has reached the set value, the controller immediately stops heating up the order. But the homogeneous plate still receives the energy, which the heater generated before the stop order, and its temperature will rise continuous after a Period of time.

5 The Effect of Thickness

In Fig.6 the plate thickness also is important key factor on temperature control during heat transfer. The plate thickness of 6 mm and 8 mm are tested.

The thermal energy all fast process 6mm stainless steel plate, and then disperses mainly in the air. Less transmission energy is stored in the steel plate, which leads to the variation temperature distribution at these 9 measuring points, and the plate is hardly reaches the homogeneous temperature distribution. But the 8mm thickness stainless steel plate will be in a homogeneous temperature distribution after 52 minutes heating.

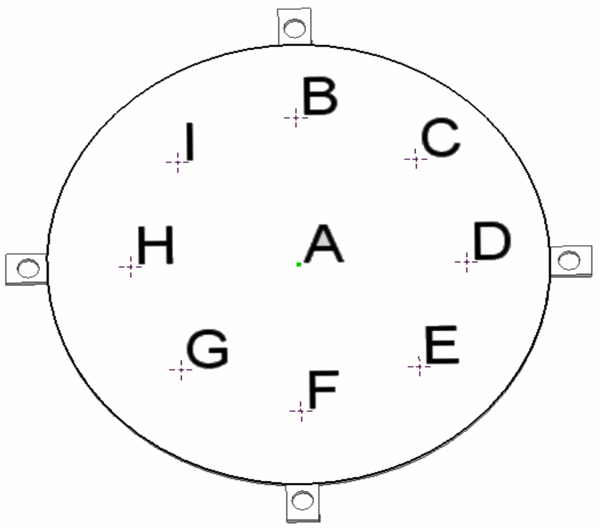

Fig. 6 The measured nine points on the plate.

The plate thickness higher than 8mm is able to reach the homogeneous temperature distribution, and more responding time is needed for a thicker plate to reach the homogeneous temperature distribution under same heater.

6 System Identification

The mathematical model of output error model is

$$y(k) = \frac{B(q)}{f(q)} u(k) + e(k) \tag{4}$$

Where $y(k)$ is the output signal, $u(k)$ the input signal and $e(k)$ the disturbance. And the transfer function is:

$$B(q) = b_1 q^{-1} + b_2 q^{-2} + \cdots + b_n q^{-n} \tag{5}$$

$$f(q) = 1 + f_1 q^{-1} + f_2 q^{-2} + \cdots + f_n q^{-n} \tag{6}$$

The disturbance model enters the output signal directly as $y(k)$ ， It is the Output Error model. Setting input time-domain data, choosing the output model, then system simulation and Finds out transfer function, the zeros and the poles. System identification also checks the stability of the transfer function.

The input of the system identification is the heat energy of the heater, and the output is the feedback temperature of the homogeneous plate temperature. The system identification can get six pairs of the transfer function based upon the OE model.

The second order transfer function

$$B(q) = 0.1025q^{-1} - 0.02638q^{-2} \tag{7}$$

$$F(q) = 1 - 1.598q^{-1} + 0.6427q^{-2} \tag{8}$$

The third order transfer function

$$B(q) = 0.1625q^{-1} + 0.03133q^{-2} \tag{9}$$

$$F(q) = 1 - 0.4066q^{-1} - 0.5329q^{-2} - 0.5924q^{-3} + 0.6524q^{-4} \tag{10}$$

The fourth order transfer function

$$B(q) = 0.1625q^{-1} + 0.03133q^{-2} \tag{11}$$

$$F(q) = 1 - 0.4066q^{-1} - 0.5329q^{-2} - 0.5924q^{-3} + 0.6524q^{-4} \tag{12}$$

The fiveth order transfer function

$$B(q) = 0.06112q^{-1} - 0.03339q^{-2} \tag{13}$$

$$F(q) = 1 - 1.456q^{-1} - 0.4278q^{-2} + 1.444q^{-3} + 0.1584q^{-4} - 1.376q^{-5} + 0.6839q^{-6} \tag{14}$$

The sixth order transfer function

$$B(q) = 0.06112q^{-1} - 0.03339q^{-2} \tag{15}$$

$$F(q) = 1 - 1.456q^{-1} - 0.4278q^{-2} + 1.444q^{-3} + 0.1584q^{-4} - 1.376q^{-5} + 0.6839q^{-6} \tag{16}$$

The seventh order transfer function

$$B(q) = -0.007467q^{-1} - 0.003922q^{-2} \tag{17}$$

$$F(q) = 1 - 0.9307q^{-1} - 0.5453q^{-2} + 0.2155q^{-3} + 0.3716q^{-4} - 0.008385q^{-5} - 0.1218q^{-6} + 0.01351q^{-7} \tag{18}$$

Neglecting the environmental atmosphere disturbance, let $e(k) = 0$. The heat energy generated by heater is the input of the system, and the output, $B(q)$ and $f(q)$, represents the feedback temperature of the homogeneous plate temperature. Fig. 7~11 are the output of the identification system.

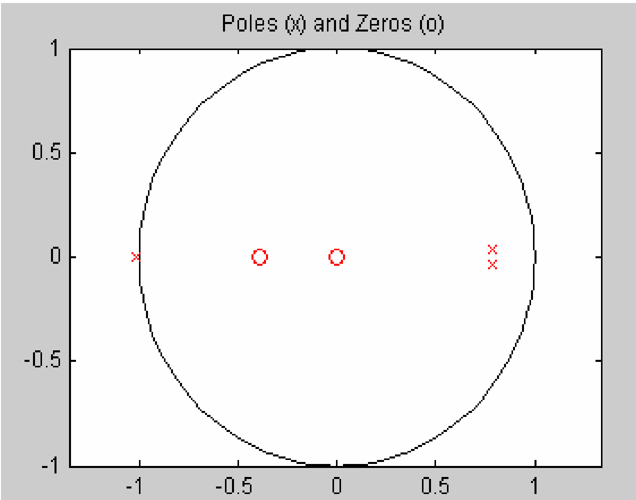

Fig. 7.1 Poles and Zeros of 3rd order system

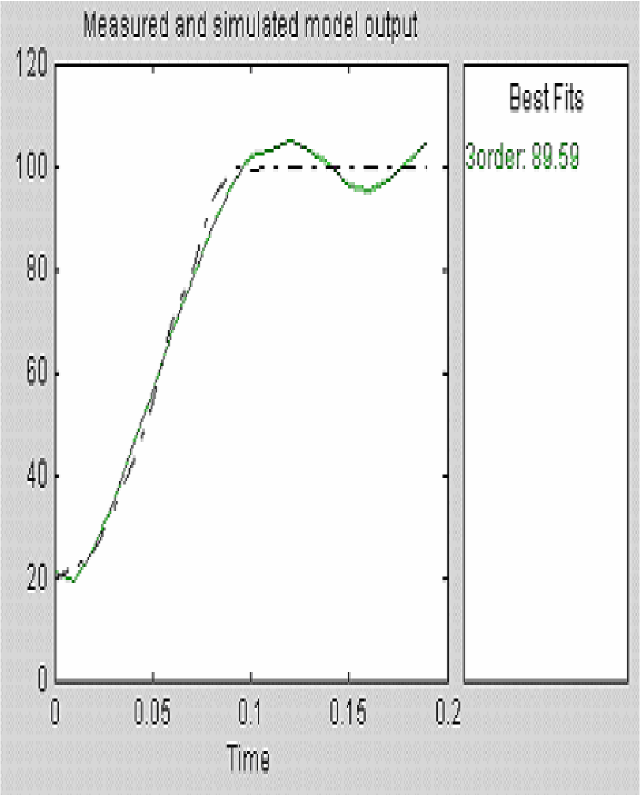

Fig. 7.2 Experiment results (measured temperature： ——— and simulated output temperature： -·-·-·-) of 3rd order system

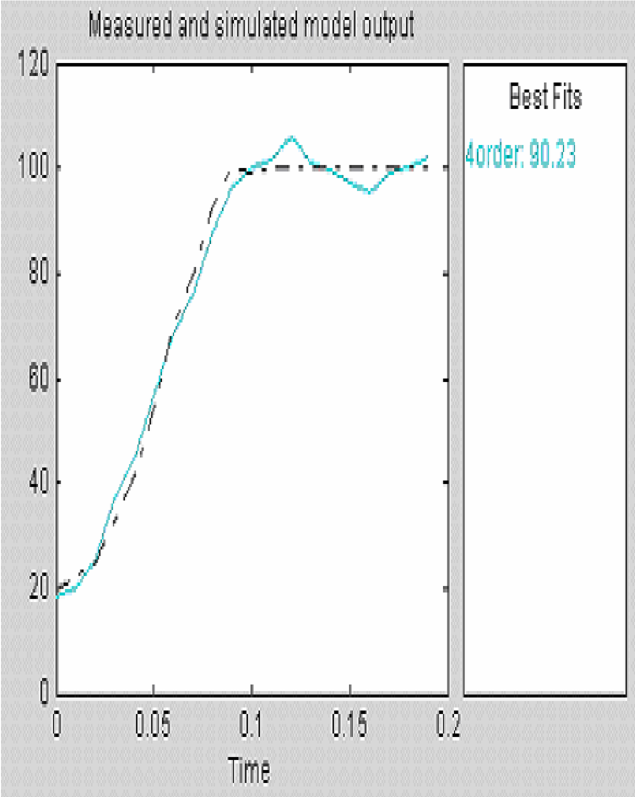

Fig. 8.2 Experiment results (measured temperature： ——— and simulated output temperature： -·-·-·-) of 4th order system

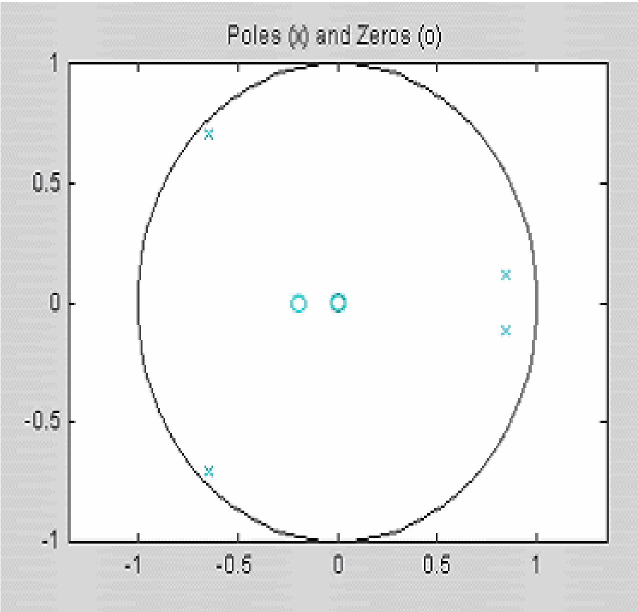

Fig. 8.1 Poles and Zeros of 4th order system

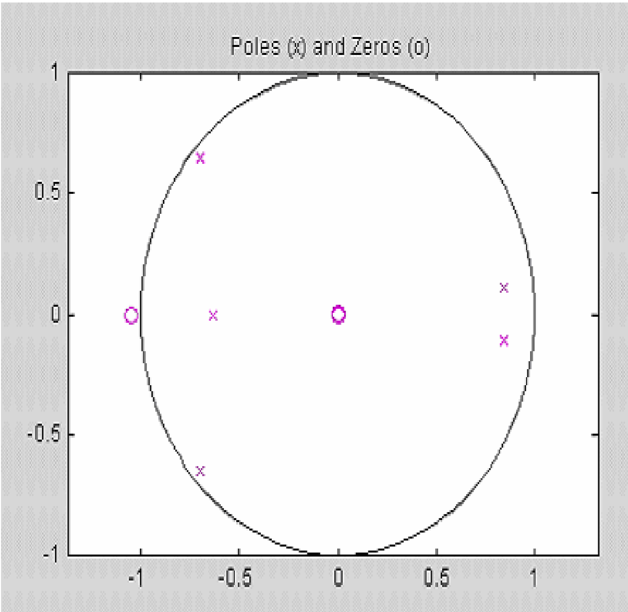

Fig. 9.1 Poles and Zeros of 5th order system

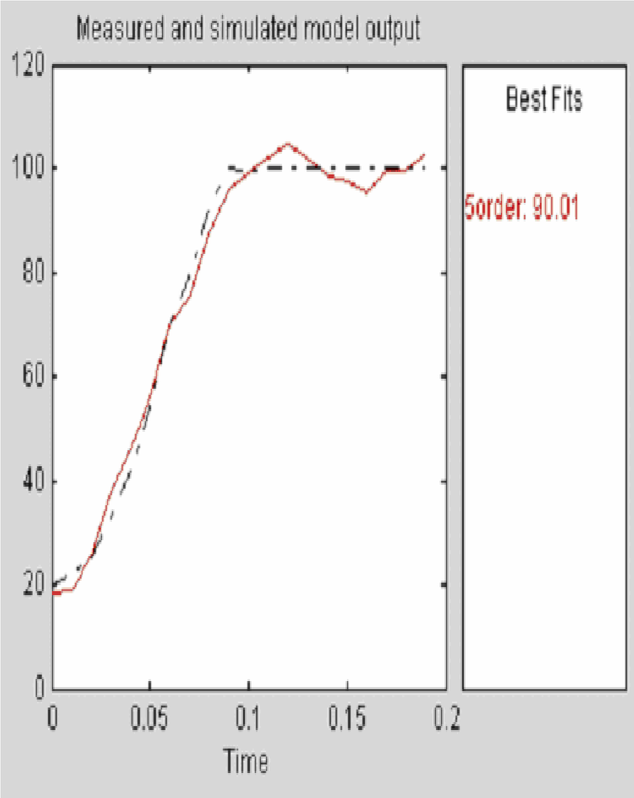

Fig. 9.2 Experiment results (measured temperature： ——— and simulated output temperature： -·-·-·-) of 5th order system

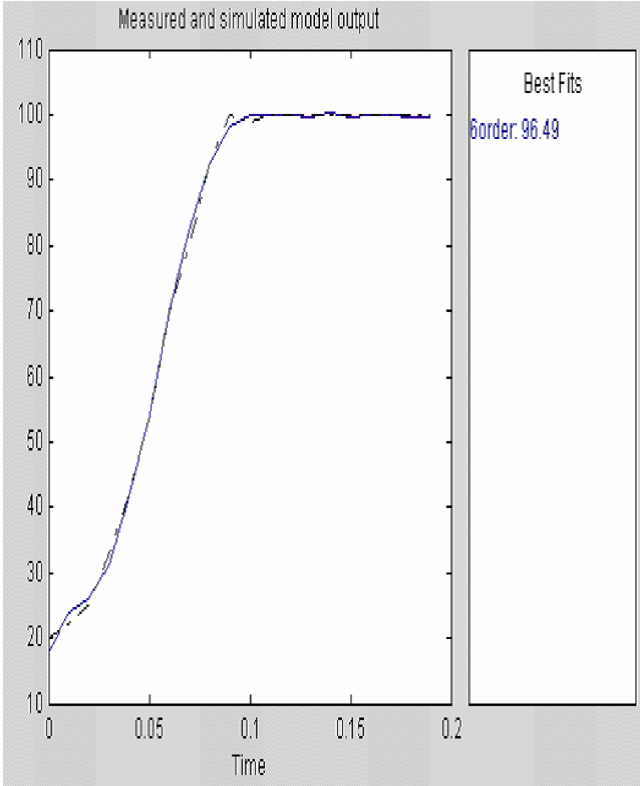

Fig. 10.2 Experiment results (measured temperature： ——— and simulated output temperature： -·-·-·-) of the 6th order system

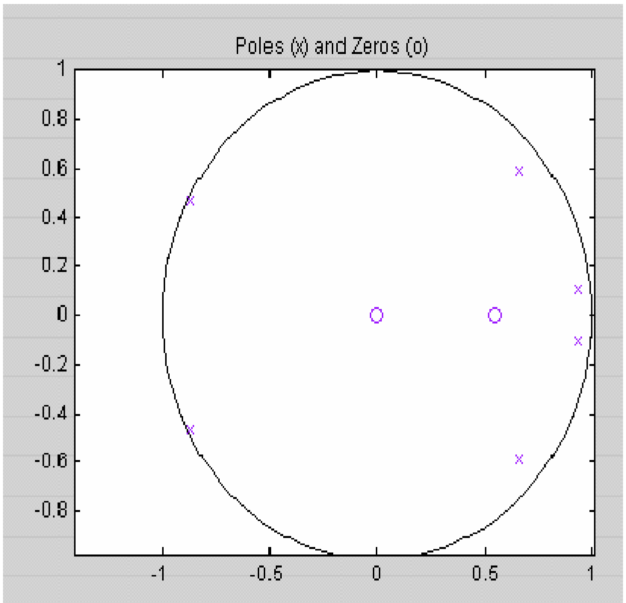

Fig. 10.1 Poles and Zeros of the 6th order system

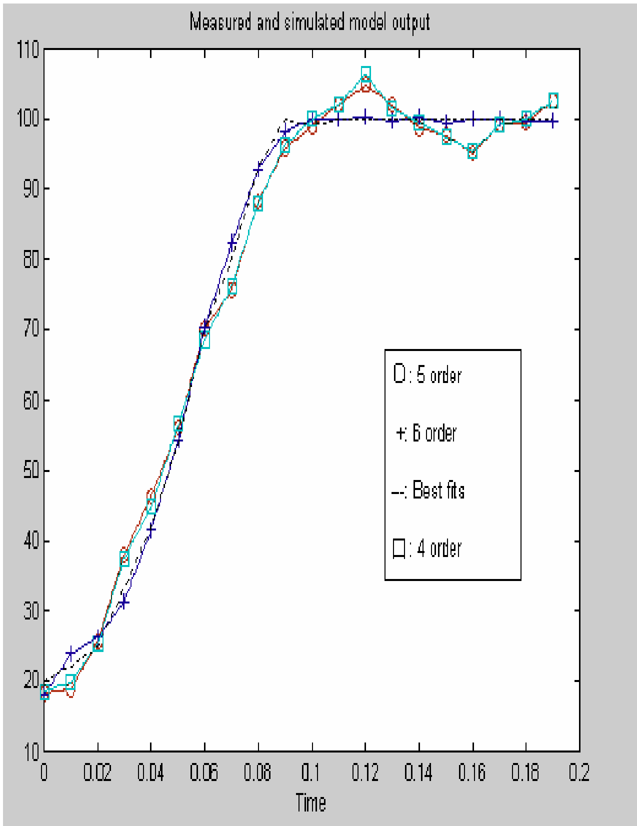

Fig. 11 Experiment results and simulated output temperature of the 4~6th order system

The OE Model identifies six groups of transfer function, its analog output all reaches as high as above 90% in Fig. 11. All systems less than seventh order transfer function is stable, but the seventh order transfer function will lead to unstable for a pole excluded the circle. Using the six order transfer function, the system identification reaches as high as 96.46% simulation in Fig. 10.2.

Although the sixth order transfer function system is uncommon in general PID controls, but the identification system is off-line operation, and the sixth order transfer function is preferred in this experiment.

7 Conclusions

The main goal of present paper is to control entire temperature to be homogeneous distribute on the plate, which is exposed to environmental disturbance. The homogeneous temperature distribution can be achieved by the latent heat reserved in vapor state and heating the plate.

The optimal controls data is with board thick 8mm and controller tolerance under 0.5 ℃, which is superior to the general commercial products. The system identification reaches as high as 96.46% simulation of the computer and the experiments, and it saves the correlation the resources and the time.

Acknowledgment

The present investigation was supported by National Science Council of Taiwan under granted NSC-97-2221-E-253-014-

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