LabVIEW Based DC Motor and Temperature Control Using PID Controller

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Abstract— LabVIEW is a graphical programming language. LabVIEW provides the flexibility of integration of data acquisition software/hardware with the process control application software for automated test and measurement applications. In this paper, an effort is made to control the speed of the DC motor and figure out the design process of a PID temperature controlling system of the electromagnetic oven using LabVIEW software. By LabVIEW-aided PID controller, the parameters are adjusted to control the motor speed and to control the temperature of Electromagnetic oven. Design of controller by applying several methods in analyzing controlled parameters to tune parameter in order to obtain the best process response.

Keywords— LabVIEW, DC Motor, Electromagnetic oven Temperature Control, PID controller, PID tuning method.

I.　INTRODUCTION

Virtual instrument is a computer instrument system. The system is based on the computer including a lot of hardware equipment and the consumer design the virtual panel and procedure to achieve the testing and controlling aim. In recent years, virtual instrument technology has been applied extensively in various fields, such as industrial control, communication, automation electric power and electronic and industrial production [15]. DC motors have been popular in the industry control area for a long time, because they have many good characteristics, for example: high start torque characteristic, high response performance, easier to be linear control etc. There are different control approaches which depend on the different performance of motors. The basic property of DC motor is that speed can be adjusted by varying the terminal voltage. Tuning of PID parameters should be done to get the optimal response. This paper is to design PID controller to supervise and control the speed response of the DC motor with the virtual instrument graphic monitor software LabVIEW and also describes a simulation that involves designing, building, and demonstrating a regulatory control system. There are many algorithms/methods proposed in literature for tuning of PID controller such as Process reaction curve, Ziegler Nichols method, Tyreus and Luyben. Lab-VIEW is the graphical development environment for creating flexible and scalable test, measurement, and control applications rapidly and at minimal cost. The structure of this paper is mainly divided into the

- Mathematic model of DC motor and electromagnetic oven
- PID control theory and Tuning Algorithm
- Lab view software simulation results

II.　MATHEMATICAL MODEL OF DC MOTOR AND ELECTROMAGNETIC OVEN

DC motor system is a separately excited DC motor, which is often used to the velocity tuning and the position adjustment. The control equivalent circuit of the DC motor using the armature voltage control method [21] is shown in Fig 1.
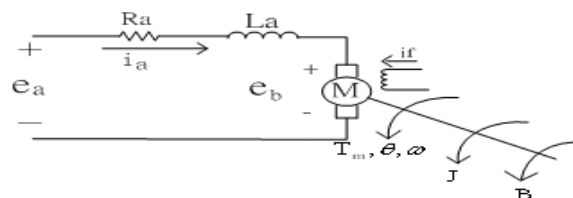

FIG 1. THE CONTROL EQUIVALENT CIRCUIT OF THE DC MOTOR.

where
R_a : Armature resistance
L_a : Armature inductance
i_a : Armature current

i_f : Field current
e_a : Input voltage
e_b : Back electromotive force (EMF)
T_m: Motor torque
$\omega\square$: An angular velocity of rotor
J: rotating inertial measurement of motor bearing
B: a damping coefficient

$$G(s) = \frac{\Omega(s)}{E_a(s)} = \frac{K_T}{(L_a s + R_a)(Js+B) + K_b K_T} \qquad (1)$$

Nowadays, the electromagnetic ovens are used for heating the component assembly of electronic manufacturing. Electromagnetic oven [13] that gives off a constant amount of heat transfers electrical energy by induction from a coil of wire into a metal vessel. The surface temperature of the electromagnetic oven is regulated by varying the amount of cooling it receives. A small electric fan is placed directly in line with the electromagnetic oven so that cool air is forced over it. The amount of heat transfer from the oven is directly proportional to the rate of airflow over it. The system monitors the surface temperature of the element and controls it by varying the speed of the cooling fan as shown in Fig 2.
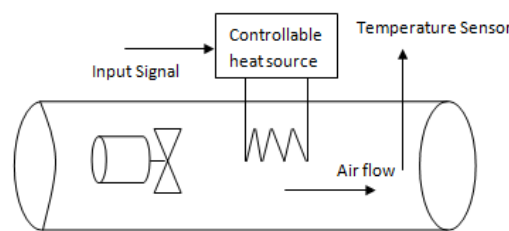

Fig 2. Heat Transfer System

Inside the oven, there is the electrical current controller for electromagnetic lamp [11] and thermocouples are used to perform temperature measurement. The mathematical model of the electromagnetic oven process can be investigated via theory of heat transfer and system identification with linearization. The electromagnetic oven process has the delay time so transfer function from input (the voltage applied to the heating element) to the output (the temperature as seen by the thermocouple) is approximately of the following form [4].

$$\frac{T_0(s)}{P(s)} = H_0(s) = \frac{K \exp(-sT_d)}{\tau s + 1} \qquad (2)$$

where
$T_0(s)$ - observed or desired temperature,
P(s)   - power input (lamp),
K   - gain
τ - time constant,
T_d - time delay,
K, T_d & τ all depend on the speed of the air flow, which changes the transport lag from the heater to the measured output as well as various heat transfer coefficients. It is extremely prevalent in process control applications.

III.   PID CONTROL THEORY AND TUNING ALGORITHM
The development of PID control theories has already 60 years so far, PID control has been one of the control system design method of the longest history. However, this method is still extensively used now [20].The structure of PID controller is simple, it is the most extensive control method to be used in industry so far. The PID controller is mainly to adjust an appropriate proportional gain (K_P), integral gain (K_I), and differential gain (K_D) to achieve the optimal control performance. The PID controller system block diagram of this paper is shown in Fig 3.
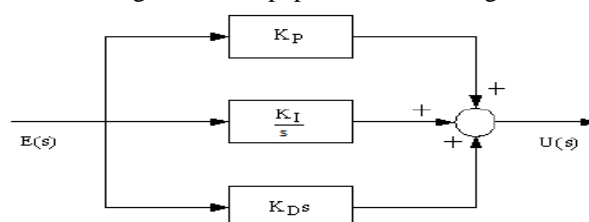

Fig 3. PID controller system block diagram.

The relationship between the input e(t) and output u(t) can be formulated in the following,

$$U(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt} \qquad (3)$$

The transfer function is expressed as follows

$$C(s) = K_P + \frac{K_I}{s} + K_D s = \frac{U(s)}{E(s)} \qquad (4)$$

The DC motor speed control using PID controller system block diagram is shown in Fig 4.and PID electromagnetic oven temperature control system block diagram is shown in Fig 5.
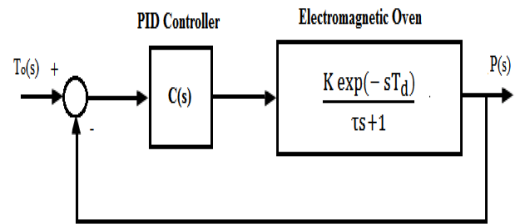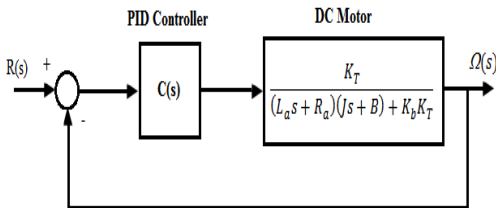

Fig. 4 PID DC motor speed control system block diagram   Fig. 5 PID electromagnetic oven temperature control system block diagram.

There are many methods proposed for tuning of PID controller. We have used the following four methods for tuning [18].

- Process reaction curve (Open-loop)
- Ziegler Nichols method (Closed-loop)
- Tyreus and Luyben

Process reaction curve (Open-loop): This is a manual procedure which is based on measuring the step response of the system .The input variable r(t) is changed from r_0 to r_1 ;the output c(t) is monitored carefully and the step response recorded on a chart recorder in Fig 6. Here r(t) should be as small as possible. On the recorded output, draw a tangent to enable the following measurements:
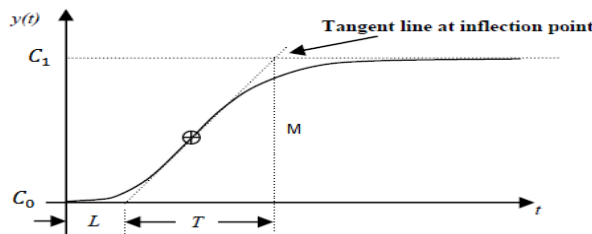

Fig. 6 shows step response of the plant.

- Effective time delay in the system response 'L';
- Recorded output change M=$C_1 - C_0$;
- Measurement of 'T';
- P = percent change in correction unit
- M (measured variable) = percent of full scale range
- R (reaction rate) = maximum gradient of the graph

$$R = \frac{M}{T}$$

Empirical relationships in terms of K_P, K_I, K_D for P, PI, and PID are by process reaction curve is given in Table.1
Table.1 shows process reaction curve parameters.

Type of controller	K_P	K_I	K_D	τ_I	τ_D
P	$\frac{P}{RL}$	-	-	-	-
PI	$\frac{0.9P}{RL}$	$\frac{1}{3.33L}$	-	3.33L	-
PID	$\frac{1.2P}{RL}$	$\frac{1}{2L}$	0.5L	2L	0.5L

Ziegler Nichols method (Closed-loop): Ziegler- Nichols is a type of continuous cycling method for controller tuning. The term continuous cycling refers to a continuous oscillation with constant amplitude and is based on the trial-and-error procedure of changing the proportional gain (K_P). K_P is reduced from larger value till the point at which the system goes to unstable state i.e. the point at which the continuous oscillations occurs. Thus the gain at which system starts oscillating is noted as ultimate gain (K_u) and period of oscillations is ultimate time period (K_u). It allows us to use the ultimate gain value, Ku, and the ultimate period of oscillation (P_u) to calculate K_c. These two parameters, K_u and P_u are used to find the loop-tuning constants of the controller (P, PI, or PID) using the formula tabulated in Table 2.

Controller	K_P	τ_I	τ_D
P	$0.5K_u$	∞	0
PI	$0.45K_u$	$\dfrac{P_u}{1.2}$	0
PID	$0.6K_u$	$\dfrac{P_u}{2}$	$\dfrac{P_u}{8}$

Table 2. Shows Ziegler Nichols parameters.

The advantage of this method is that it is a proven online method and includes dynamics of whole process, which gives a more accurate picture of how the system is behaving. The disadvantage is that it upsets the process, uses trial and error method and has a very aggressive tuning. This closed-loop tuning method is limited to tuning processes that cannot run in an open-loop environment.

Tyreus and Luyben: A modification to the above Ziegler-Nichols tuning parameters was made by Tyreus and Luyben shown in Table.3

Type of controller	K_P	τ_I	τ_D
PI	$\dfrac{K_u}{3.2}$	$2.2P_u$	
PID	$\dfrac{K_u}{2.2}$	$2.2P_u$	$\dfrac{P_u}{6.3}$

Table.3 shows Tyreus and Luyben parameters.

IV.   SIMULATION RESULTS

CASE-I for DC MOTOR
Simulations Results for Z-N calculations:
A typical procedure to tune a PID controller would be
 a) First use a proportional controller with a gain of 1 and take the step response as shown in Fig.7
 b) Keep increasing /decreasing Kc until the response has some overshoot. And sustained oscillations are there at Kc=1.1084 as shown in Fig.8
 c) Calculating ultimate gain (K_u) and then Calculate the ultimate period of oscillation, (P_u) from Fig.9
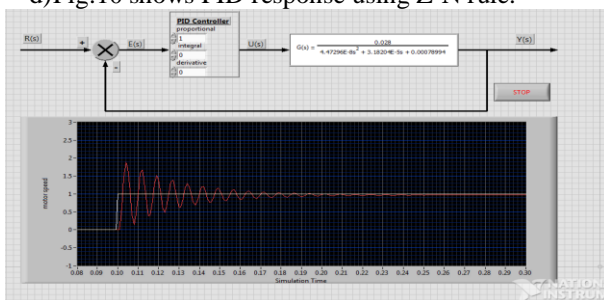 d) Fig.10 shows PID response using Z-N rule.

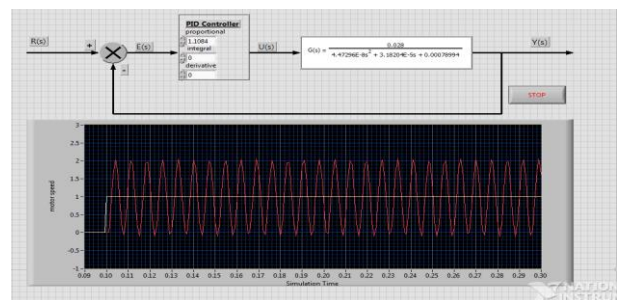**Fig.7 Step response for** $(K_P = 1, K_I = 0, K_D = 0)$

Fig.8 Step response
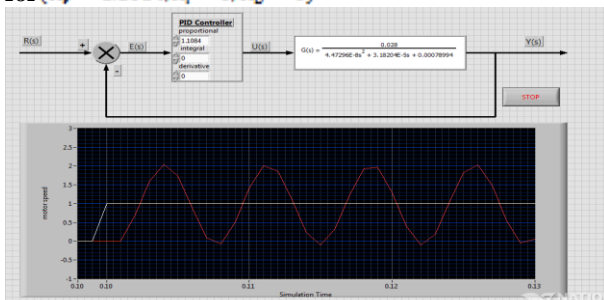**for** $(K_P = 1.1084, K_I = 0, K_D = 0)$

Fig.9 calculating the ultimate period of oscillation (P_u)
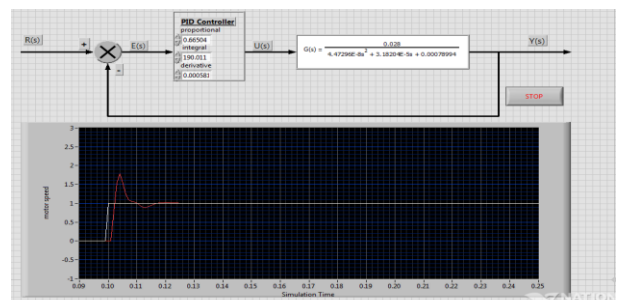**From here we got**

Fig.10 Step response for PID controller.

$$K_u = 1.1084$$
$$P_u = 0.007$$

Then according to Z-N tuning rule, by using ultimate gain and ultimate period PID gains K_P, K_I and K_I obtained using relation $K_I = K_P/\tau_I$ and $K_D = K_P * \tau_D$ [14] for DC motor is shown in Table.4

Controller	K_P	K_I	K_D
PID	0.6650	190.011	0.0005819

Table.4 Simulated results for   Ziegler Nichols.

PID controller transfer function for DC motor using Ziegler Nichols tuning method is shown in Eqn. 5

$$= \frac{0.0005819\, S^2 + 0.66504S + 190.0114}{S} \tag{5}$$

Simulations Results for Tyreus and Luyben calculations:
According to Tyreus and Luyben tuning method step response for PID gains for DC motor is shown in Table.5. and PID controller transfer function for DC motor using Tyreus and Luyben tuning method is shown in Eqn.6

$$= \frac{0.000559S^2 + 0.50381S + 32.715466}{S} \tag{6}$$

Controller	K_P	K_I	K_D
PID	0.50381	32.7154	0.000559

Table.5 Simulated results for   Tyreus and Luyben.

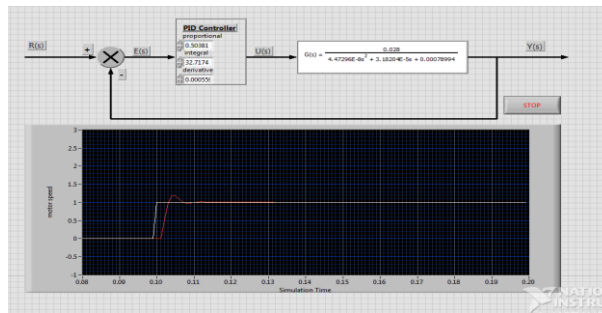PID response using Tyreus and Luyben calculations is shown in Fig.11

Fig.11 Step response for proportional plus integral plus derivative controller for$(K_P = 0.5038, K_I = 32.7154, K_D = 0.000559)$

It has been observed that by Tyreus and Luyben method results in less oscillation at the control system response. Less oscillations means better controllability, robustness and less sensitivity to change in system condition.
Ziegler-Nichols and Tyreus and Luyben tuning algorithms and step response specifications are tabulated in Table 6.

Tuning algorithm / Response specification	Ziegler-Nichols	Tyreus and Luyben
Damping ratio	0.46	0.97
Peak overshoot	30.25	6.60
Phase margin	105.18	151.55
Peak time (s)	0.006	0.01
Peak value	1.30	1.07
Gain margin	∞	∞
Rise time (s)	0.002	0.004
Settling time (s)	0.025	0.03

Table.6 comparison of Ziegler-Nichols and Tyreus and Luyben

From the simulation results tabulated in Table.6 it is concluded that by step response specifications using Tyreus and Luyben tuning algorithm damping ratio, peak overshoot, peak value and phase margin is better but all other parameter are nearly same as compared to Ziegler-Nichols. So from here Tyreus and Luyben tuning algorithm results in less

oscillation at the control system response. Less oscillations means better controllability, and less sensitivity to change in system condition.

CASE- II for ELECTROMAGNETIC OVEN
CASE (i): Transfer Function of electromagnetic oven with time delay as of Eqn.7 is taken as of following form

$$H_O(s) = \frac{3\,exp\,(-4s)}{2s+1} \tag{7}$$

Modified Ziegler-Nichols tuning method given in section has been used to tune the PID controller parameters. With the tuned parameter having value is
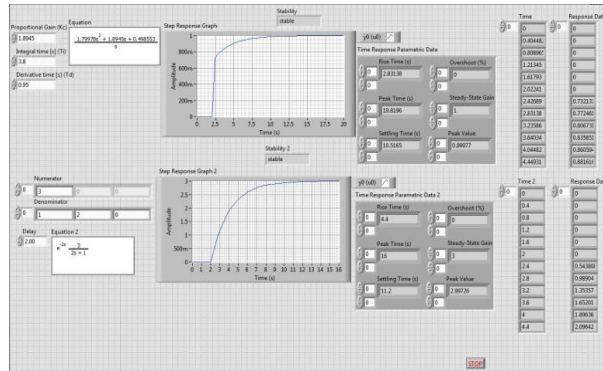K_C= 1.8945, T_I = 3.8, T_D = 0.95 and, T_f = 0

Fig 12. Screenshot of LabVIEW Front Panel

In Fig.12 lower step time response curve shows without PID controller tuning and upper response shows with PID controller tuning. Table.7 shows the response value of the electromagnetic oven with and without PID controller. The temperature control system can quickly achieve stability with steady state error is no more than 0.2% and overshoot is equal to 0%.

Response Value	Open loop controller tuning	With PID controller tuning
Rise time (s)	4.4	2.83138
Peak time (s)	16	19.8196
Settling time (s)	11.2	10.5165
Peak value	2.99726	0.99977
Overshoot (%)	0	0
Steady-state gain	3	1

Table.7 response data for electromagnetic oven

Therefore, we can say that the system can quickly reach the stability with high accuracy in a short time.

CASE (ii):
A generalized 1st order standard Transfer Function as given in LabVIEW and A Pade approximation for time delay is used to represent the time delay of the process because the control design(CD) Feedback function in LabVIEW works correctly only if there are only rational transfer functions in the feedback loop.
In this case the hit and trial method has been used to tune the PID controller parameters, the tuned parameter value is
K_C = 1, T_I = 4, T_D = 0, T_f = 0, K = 3, τ = 2, T_d = 1
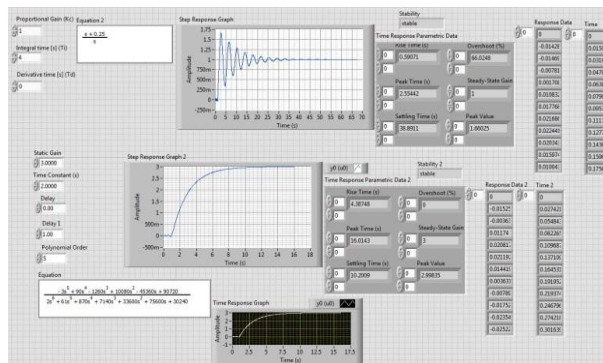

Fig 13. Screenshot of LabVIEW Front Panel When 1st order generalized Transfer Function

When we increased the delay time, again we used hit and trial method to tune the PID controller. In this case we take controller parameters as $K_C = 1$, $T_I = 5$, $T_D = 0$, $T_f = 0$, $K = 3$, $\tau = 11$, $T_d = 4$
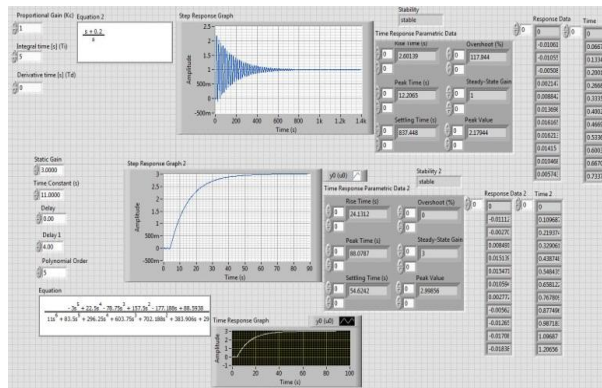

Fig 14. Screenshot of LabVIEW Front Panel When 1st order generalized Transfer Function

In the generalized 1st order standard transfer function one can able to see the stability response by changing the value of K_C, T_I and T_D. Step response obtained by simulation control system as shown in Fig 14 shows the stability of the system respectively. The temperature control system always stable without PID tuning except at few static point and time constant. With PID controller tuning system performance increased and stable but settling time increased. Therefore, the electromagnetic oven control system will have low efficiency with the Pade approximation.

V. CONCLUSIONS

In this paper PID controller is designed using LabVIEW. Graphical representation of program gives us clear understanding about the structure and data flow. LabVIEW is a debugging tool. It is better for control application while MATLAB is better for data manipulation. Execution time is better in LabVIEW and survey ability is better in LabVIEW than MATLAB. So we use LabVIEW for DC motor speed control. Tyreus and Luyben method results in less oscillation at the control system response. Less oscillations means better controllability and less sensitivity to change in system condition. This technique can be extended to other types of motors. The parameters of PID controller can also be tuned by using Fuzzy logic or Genetic Algorithm (GA).

The system offers successful simulation of a practical example of PID temperature control. This simulation shows that the system has such characteristics as temperature auto-control. It also find big stability fluctuation between standard 1st order system and general system. With the LabVIEW professional development system or application builder, it can build stand-alone executable by taking standard transfer function. Time of system has been reduced greatly, compared with the system constructed by traditional instrument, it has such advantages as stabilizing the temperature in a short time, even with good performance and flexibility. So it is find that virtual instruments have the good flexibility and powerful functions in the application of the measurement system, which means it is a good choice in the design of industrial control system with high measuring precision, easily manipulation, high accuracy, better stability etc.

REFERENCES

[1] National Instruments, "*LabVIEW Graphical Programming*", 2011.
[2] National Instruments, "*LabVIEW Course LV1 & LV2*", 2011.
[3] www.ni.com/control toolkit, 2011.
[4] Graham C. Goodwin, Stefan F. Graebe, Mario E. Salgado, "*Control System Design*", Prentice Hall Publication pp. 70-73, 2002.
[5] Spoelder, H.J.W., "*Virtual instrumentation and virtual environment*", IEEE instrumentation and measurement magazine, 2(3), 14–19, 1999.
[6] Goldberg, H., "*What is virtual instrumentation*", IEEE instrumentation and measurement magazine, pp. 10–13, 2000.
[7] Johnson, G.W., Jennings R., "*LabVIEW Graphical Programming*", McGraw-Hill press, New York, pp. 90-101, 2001.
[8] F.L.Lv and Z.Z.Chen, "*The design of temperature detecting system based on LabVIEW*", Microcomputer Information, 23(3), 170–172, 2007.
[9] W.Jiang, F.Yuan, "*Design of temperature control system based on LabVIEW environment*", Foreign Electronic Measurement Technology, 23(3), 8–10, 2004.
[10] Zhang Lin, Song Yin, "*Design of PID Temperature Controlling System Based on Virtual Instrument Technique*", The Eighth International Conference on Electronic Measurement and Instruments, 2005.
[11] A. A. Rodriguez et al, "*Description of a Modeling, Simulation, Animation, and Real-Time Control (MoSART) Environment for a Class of Electromechanical System resources* ", IEEE Trans. Educ., 48(3), pp-359-374, 2005.
[12] Saco, R., Pires, E., Godfrid, C., "*Real Time Controlled Laboratory Plant for Control Education*", IEEE Frontiers in Education Conference, pp. T2D12 – T2D16, 2002.

[13] Lin, C. A., Jan, Y. K., *"Control system design for a rapid thermal processing system"*, *IEEE Transactions on Control System Technology,* Vol. 9, Issue 1, pp.122-129, 2001.

[14] Lab VIEW PID Control Toolset User Manual, National Instruments, 2001. Liau, J. C., A Study of Lab VIEW Aided in DC Motor Speed Monitoring System. National Taiwan Ocean University Department of Mechanical & Mechatronic Engineering, 2000.

[15] Lab VIEW Basics I Course Manual, National Instruments, 1999.

[16] The Design of PID Controllers using Ziegler Nichols Tuning Brian R Copeland (March 2008)

[17] Using the Lab VIEW PID Control Toolkit with the Lab VIEW Control Design and Simulation Module Sep 2009

[18] Control Engineering by K.P Ramachandran. Wiley Precise Textbook, 2011.

[19] Classical PID Control by Graham C. Goodwin, Stefan F. Graebe, Mario E. Salgado (Control System Design, Prentice Hall PTR)

[20] PID Control of Continuous Processes by John W. Webb Ronald A. Reis.

[21] PC-based PID Speed Control in DC Motor.

[22] Guoshing Huang, Shuocheng Lee, Department of Electronic Engineering, National Chin-Yi University of Technology, 35, Lane 215, Chung-Shan Rd., Sec. 1, Taiping, Taichung, Taiwan, 41111, ROC E-mail:hgs@ncut.edu.tw

[23] "Getting in tune with Ziegler-Nichols," Thomas R. Kurfess, PhD, in the Academic Viewpoint column, Control Engineering magazine, Feb 2007 issue, p. 28, http://www.controleng.com/.

[24] A more recent survey that covers the Ziegler-Nichols and Kappa-Tau tuning rules: "Automatic Tuning of PID Controllers," Karl J. Åström & Tore Hägglund, Chapter 52, The Control Handbook, IEEE/CRC Press, 1995, William S. Levine ed.

[25] PID Example: DC Motor Speed Control
"ACT Ziegler-Nichols Tuning," http://ourworld.compuserve.com/homepages/ACTGMBH/zn.htm