COMPARISON BETWEEN ZIEGLER-NICHOLS AND COHEN-COON METHOD FOR CONTROLLER TUNINGS

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A thesis submitted in fulfillment
of the requirements for the award of the degree of
Bachelor of Chemical Engineering

Faculty of Chemical & Natural Resources Engineering
University College of Engineering & Technology Malaysia

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DECLARATION

I declare that this thesis entitled *"Comparison Between Ziegler-Nichols & Cohen-Coon Methods For Controller Tunings"* is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date	:	22 NOVEMBER 2006

Special dedication to my beloved mother, father, brothers and sisters

ACKNOWLEDGMENT

In preparing this thesis, I was in contact with many people who have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Miss Noorlisa Binti Harun for her encouragement, guidance, critics and supervision. I also very thankful to my lecturers for their support, knowledge, advices and motivation to finish this thesis. Without their continued support and interest, this thesis would not have been the same as presented here.

I am also like to show my gratitude and appreciation to University College of Engineering and Technology Malaysia (KUKTEM), for giving me the opportunity to deliver this thesis.

My sincere appreciation and grateful also extends to my mother; Madam Fauziah Rozali, my father; Mr. Mohd Noris Mansor, brothers and sisters and finally to others who have provided assistance at various occasions. Besides that, I would like to thank to my entire fellows friends for their support and guidance. Thanks a lot for your contribution.

ABSTRACT

Proportional-Integral-Derivative (PID) controllers are the predominant types of feedback control. PID controller is widely used in industry due to their simplicity and easy to tuning. For controller tuning, the PID parameters are tuned by any conventional method in order to assure a good reference signal to the closed loop system is obtained by filtering appropriately the set-point step signal. This study is conducted to get the optimum PID controller parameters (K_c, τ_I, τ_D) for first order process model. Two well known methods; Ziegler-Nichols (Z-N) method and Cohen-Coon (C-C) are used to tune controller. Both methods are compared to get the optimum condition for the process model with one-quarter decay ratio at minimum settling time and minimum largest error. The responses for both methods are analyzed using Simulink in MATLAB software. Block diagram for the process model with controllers was created for simulation process. *Kc*= 16.667, τ_I =6.283 and τ_D =1.571 are optimum parameters setting for Ziegler-Nichols method and the minimum largest error as 0.582 and minimum settling time equal with 11.8s in sample 11. For Cohen-Coon method, *Kc*= 14.703, τ_I =3.622 and τ_D =0.541 are optimum parameters setting. The minimum largest error and minimum settling time from response in sample 39 are 0.4914 and 12.2s. The results indicated that responses using Cohen-Coon tuning are slightly better than those with the Ziegler-Nichols settings method.

ABSTRAK

Kawalan perkadaran-pengamiran-perkadaran (PID) adalah pengawal "feedback" yang dominan. Kawalan PID digunakan secara meluas didalam industri kerana ianya mudah dan senang untuk diselaraskan. Untuk mengawal penyelarasan, parameter PID akan diselaraskan dengan mengunakan pelbagai peraturan konvensional yang ada bagi memastikan respon yang baik digunakan dalam sistem gelung tertutup dengan mencapai isyarat titik set yang ditentukan. Kajian ini dijalankan untuk mendapatkan parameter-parameter (K_c, τ_I, τ_D) kawalan PID yang optimum bagi proses model arahan pertama. Dua peraturan yang sangat dikenali;peraturan Ziegler-Nichols dan peraturan Cohen-Coon digunakan untuk pelarasan kawalan PID. Kedua-dua peraturan dibandingkan untuk mendapat keadaan yang optimum bagi proses model dengan suku "decay ratio" pada ketetapan masa yang minima dan kesilapan besar yang minima. Respon yang terhasil dari kedua-dua peraturan akan di analisis dengan menggunakan aplikasi "Simulink" didalam perisian "MATLAB". Gambarajah blok untuk proses model serta kawalan dibina untuk proses simulasi. *Kc*= 16.667, τ_I =6.283 dan τ_D =1.571 ada parameter-parameter yang optimum bagi peraturan Z-N dengan kesilapan besar minima 0.582 dan ketetapan masa minima, 11.8s dalam sampel 11. Bagi peraturan C-C; *Kc*= 14.703, τ_I =3.622 dan τ_D =0.541 adalah parameter-parameter optimum. Ketetapan masa dan kesilapan besar yang minima dalam sampel 39 adalah 0.4914 dan 12.2s. Keputusan menunjukkan, respon yang menggunakan penyelarasan Cohen-Coon adalah lebih baik dari penyelarasan yang dibuat dalam Ziegler-Nichols.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

MATLAB	-	Matrix Laboratory
Kc	-	Controller Parameter of Proportional
τ_I	-	Controller Parameter of Integral
τ_D	-	Controller Parameter of Derivative
DR	-	Decay Ratio
α	-	The Height of First Peak
γ	-	The Height of Second Peak
P	-	Period of Oscillation
t_r	-	The Time the Process Output Takes To First Reach
t_p	-	Time Required For the Output to Reach First Maximum Value
t_s	-	Settling Time
K	-	The Output Steady State Divided By the Input Step Change
τ	-	Effective Time Constant
t_d	-	Dead Time
M	-	Amplitude Ratio of The System's Response
Kcu	-	1/M
ωco	-	Crossover Frequency
Pu	-	$\frac{2\pi}{\omega_{co}}$

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent years the performance requirements for process plants have become increasingly difficult to satisfy. Stronger competition, tougher environmental and safety regulation, and rapidly changing economic condition have been key factors in tightening product quality specifications. A further complication is that modern plants have become more difficult to operate because of trend toward complex integrated processes.

Process control has become increasingly important in the process industries as a consequence of global competition, rapidly changing economic conditions, and more stringent environmental and safety regulations. Process control is also a critical concern in the development of more flexible and more complex processes for manufacturing high value added products. One of the complex and difficult in process control is control tuning. Control tuning is the major key issue to operate the plant. Process tuning is a key role in ensuring that the plant performance satisfies the operating objectives.

Controller tuning inevitably involves a tradeoff between performance and robustness. The performance goals of excellent set-point tracking and disturbance rejection should be balanced against the robustness goal of stable operation over a wide range of conditions.

Before started the tuning, it is general to make various reason and criteria for selecting which controller type will be adequate for which application. In control tuning, feedback control was used. Feedback control is that the controlled variable is measured and the measurement is used to adjust the manipulated variable and the disturbance variable is not measured [1]. This controller is used to make tuning in process control. The selection made on the basis of the general characteristics of the different feedback controllers are the most practical.

It have three major type of feedback controller, the controller are proportional controller (P), proportional-integral controller (PI) and proportional-integral-derivative controller (PID). P controller only can achieve acceptable offset with moderate value and it only used for gas pressure and liquid-level control. For provide sufficiently small steady-state errors PI controller will be used. Consequently, integral control mode make the speed of the closed-loop system remains satisfactory despite the slowdown of flow system response in PI controller. The combination of the process, the feedback controller, and the instrumentation is referred to as a feedback control loop or a closed-loop system [1].

To increase the speed of the closed-loop response and retain robustness, PID controller is used. PID controllers are widely used in industrial practice more than 60 years. The development went from pneumatic through analogue to digital controllers, but the control algorithm is in fact are same. The PID controller is a standard and proved solution for the most of industrial control applications. In spite of this fact, there is not some standard and generally accepted method for PID controller design and tuning based on known process model.

Over the years, there are many formulas derived to tune the PID controller for adjusted parameters and achieved optimum value. There are three parameters must be tuning to achieved optimum value. The table 1.1 shows the parameters are considered in PID controller

Table 1.1: Parameters Of PID Controller

SYMBOL	PARAMETER
Kc	Proportional
τ_I	Integral
τ_D	Derivative

After PID controller has been selected, there are need approaches to use for tuning a controller and get the optimum parameters. It have many approaches for tuning and general approaches are use simple criteria such as the one-quarter decay ratio, minimum settling time, minimum largest error and so on. It provides multiple solutions with simple and easily implement table on actual process rather than use the approach is rather cumbersome and relies heavily on the mathematical model like time integral performance criteria such as integral of the squared error (ISE), integral of the absolute value of the error (IAE) or integral of the time-weighted absolute error (ITAE) and semi empirical rules.

Two controller tuning relations were published by Ziegler and Nichols (1942) and Cohen and Coon (1953) are used were develop to provide closed-loop responses that have one-quarter decay ratio with minimum settling time and minimum largest error [2]

Abnormal process operation can occur for a variety of reason, including equipment problems, instrumentation malfunctions, and unusual disturbances. Severe abnormal situations can have serious consequences such as even forcing a plant shutdown. It have been estimated that improved handling control tuning could result in savings of $10 billion U.S Dollar each year to the U.S petrochemical industry [1]. That mean, controls tuning are important activities.

1.2 Problem Statement

The controller tuning problem gives an effect on closed-loop stability and overall process control. It difficult to find the simple and easy implement table approach for tune the parameters. It also difficult to achieved the optimum parameter in controller tuning with method to minimize the largest error and settling time. To develop a good performance controller tuning method is also hard.

1.3 Objective

The aim of this study is to

- To get the optimum Kc, τ_I , & τ_D to control a given process
- To tune the feedback controller using Cohen-Coon & Ziegler-Nichols method
- To compare the performance criterion between Cohen-Coon & Ziegler-Nichols method for the selection and the tuning of the controller.

1.4 Scope

To achieve the objective of this research, there are four scopes that have been identified:

- Select first order model for process control tuning
- Control the process using proportional-integral-derivative controller (PID controller)
- Determine the beat optimum PID controller parameter.

- Tune PID controller using Cohen-Coon & Ziegler-Nichols method
- Calculate the error.
- Compare the performance of Cohen-Coon & Ziegler-Nichols method

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Proportional-integral-derivative (PID) controllers are the predominant types of feedback control. PID controller is widely used in industry due to their simplicity and easy to tuning. The output of PID controller is a linear combination of the input, the derivative of the input and the integral of the input. It is widely used and enjoys significant popularity because it is simple, effective and robust.

One of the reason why this is so is the existence of tuning rules for finding suitable parameters for PID, rules that do not require any model of the plant to control. All that needed to apply such rules is to have a certain time response of the plant [3]. It will be use some method like Ziegler-Nichol, Cohen-Coon and Kappa-Tau rules or method.

2.2 Closing The Loop Control System

Systems that utilize feedback are called closed-loop control systems. The feedback is used to make decisions about changes to the control signal that drives the plant. An open-loop control system does not use feedback.

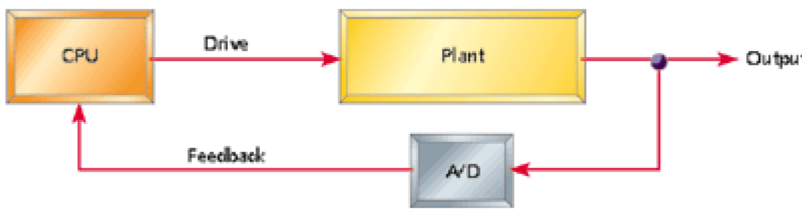

Figure 2.1: A Closed-Loop Control System

A basic closed-loop control system as shown in Figure 2.1 can describe a variety of control systems, including those driving elevators, thermostats, and cruise control.

Closed-loop control systems typically operate at a fixed frequency. The frequency of changes to the drive signal is usually the same as the sampling rate, and certainly not any faster [4]. After reading each new sample from the sensor, the software reacts to the plant's changed state by recalculating and adjusting the drive signal. The plant responds to this change, another sample is taken, and the cycle repeats. Eventually, the plant should reach the desired state and the software will cease making changes.

If feedback indicates that the temperature in plant is below desired set point, the thermostat will turn the heater on until the plant is at least that temperature [4]. The simple example like a car is going too quickly, the cruise control system can temporarily reduce the amount of fuel fed to the engine

An effective feedback control system is expected to be stable and capable of causing the system output ultimately to attain its desired set-point value for example [5]. The approach of this system output to desired set-point should neither be too sluggish, nor too oscillatory. It reveals three types of criteria by which closed loop system performance may be assessed in general.

- Stability Criteria
- Steady state Criteria
- Dynamic Response Criteria

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Figure 2.2 illustrates type of feedback response that raise depend on the process being controlled, choice of controller type and the controller parameters selected [5]. The best control systems are decided with the response for particular problem.

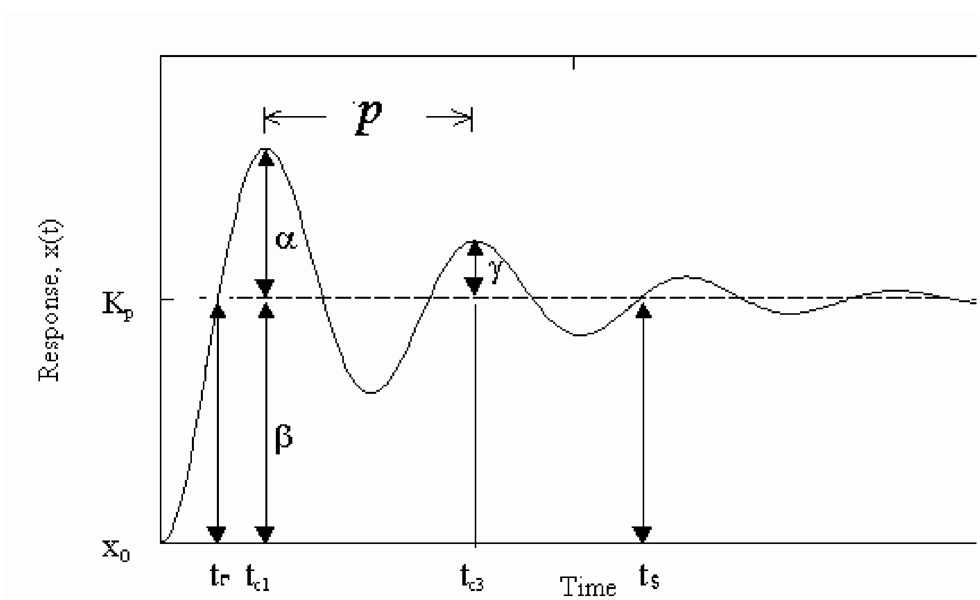

Figure 2.2: Type Of Feedback Response

- $\frac{\gamma}{\alpha} = DR$, a specified maximum decay ratio
- P, Period of oscillation.
- t_r, the time the process output takes to first reach the new steady state value and time to the first peak,
- t_p, the time required for the output to reach its first maximum value.
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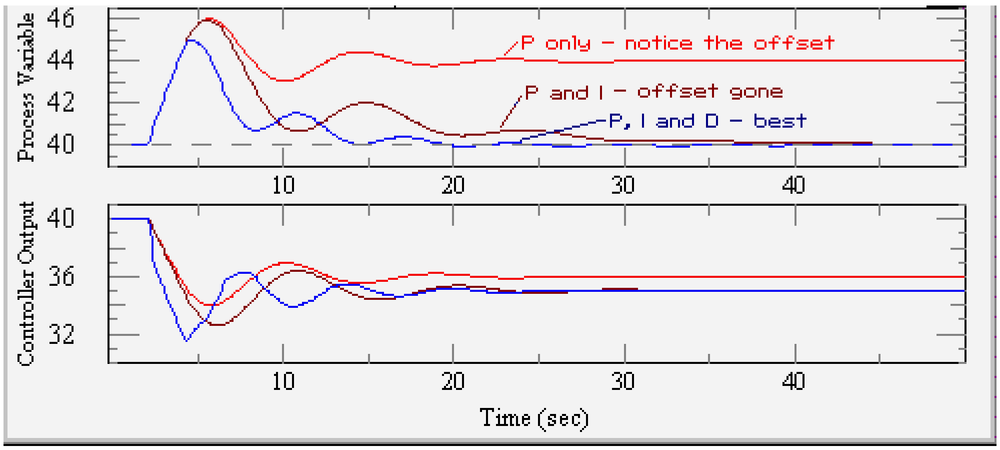
2.3 PID Controller

PID stands for Proportional, Integral, and Derivative. Controllers are designed to eliminate the need for continuous operator attention. Cruise control in a car and a plant thermostat are common examples of how controllers are used to automatically adjust some variable to hold the measurement at the set-point.

The set-point is where you would like the measurement to be. Error is defined as the difference between set-point and measurement. The variable being adjusted is called the manipulated variable which usually is equal to the output of the controller. The output of PID controllers will change in response to a change in measurement or set-point [6] From figure 2.3, it shows the different of P, PI and PID controllers.



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2.3.1 Proportional Action

The units of proportional action may be either percent Proportional Band *P* or Proportional Gain K_c, where

$$K_C = 100 / P \tag{2.1}$$

$$P = 100 / K_C \tag{2.2}$$

The proportional action should work on deviation or controlled variable depending on the user selection. The user should also be able to adjust the amount of proportional action applied to the set point.

Proportional Band setting should range from 1 to 10,000. If gain is used, the gain range should be from 0.01 to 100.

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There should be anti-reset windup logic so that the output of the integral term does not saturate into a limit when the controller output reaches that limit. The method of anti-reset windup should incorporate integral feedback. This allows the secondary measurement signal to be feeedback to the primary controller in cascade, feedforward, and constraint control systems, maximizing their effectiveness, operability, and robustness.

The controller should be capable of operation without integral action, through the application of an adjustable output bias.

2.4 Ziegler-Nichol Method (Z-N)

This pioneer method, also known as the close-loop or on-line tuning method was proposed by Ziegler and Nichols in 1942. Like all the other tuning methods, it consists of two steps:

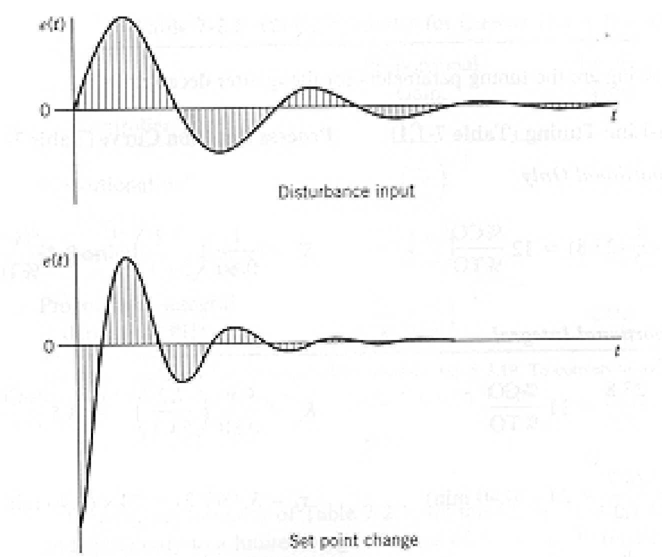
1. Determination of the dynamic characteristics, or personality, of the control loop
2. Estimation of the controller tuning parameters that produce a desired response for the dynamic characteristic determined in the first step, in other words, matching the personality of the controller to that of the other elements in the loop.

In this method the dynamic characteristic of the process are represented by the ultimate gain of a proportional controller and the ultimate period of oscillation of the loop. It usually determinate the ultimate gain and period from the actual process by the following procedure:

- Switch off the integral and derivative modes of the feedback controller so as to have a proportional controller.
- With the controller in automatic (i.e., the loop closed), increase the proportional gain (or reduce the proportional band) until the loop oscillates with constant amplitude. Record the value of the gain that produces sustained oscillation. To prevent the loop from going unstable, smaller increments in gain are made as the ultimate gain is approached.
- From a time recording of the controlled variable such as the figure below, the period of oscillation is measured and recorded as T the ultimate period.

For the desired response of the close loop, Z-N method specified a decay ratio of one-fourth. The decay ratio is the ratio of the amplitudes of two successive oscillations. It should be independent of the input to the system and should depend only on the roots of the characteristic equation for the loop [9].

The tuning relationship are intended to minimize the integral of the error, their use is referred to as minimum error integral tuning. However the integral of the error cannot be minimized directly, because a very large negative error would be the minimum. In Figure 2.4, it shows the error integrals for disturbance and for set point changes.



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The Z-N method is more robust because it does not require a specific process model. To tune a controller using the Z-N method the integral and derivative elements of the PID controller are ignored. The proportional element is used to find a Kc that will sustain oscillation. This value is considered the Kcu, or the ultimate gain. The period of oscillation is the Pu, or ultimate period. Consequently, Z-N settings are reasonable to applied in controller tuning using table 2.1.

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	P	PI	PID
K_c	$.5K_{cu}$	$.45K_{cu}$	$0.6K_{cu}$
τ_I	-	$P_u/1.2$	$P_u/2$
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$$G_{PRC(S)} = \frac{\overline{y_m}(s)}{\overline{c}(s)} \simeq \frac{Ke^{-td^s}}{\tau s+1} \tag{2.4}$$

C-C method used the approximated mode of equation 2.4 and estimated the value of the parameters K, τ, and t_d as indicated above. Then it derived expressions for the best controller settings using one-quarter decay ratio. From K, τ, and t_d the PID parameters are calculated from the following formulas [2].

$$Kc = (1/K)\,(\tau/t_d)\,(4/3 + t_d/(4\tau)) \qquad (2.5)$$

$$\tau_I = t_d\,(32 + 6t_d/\tau) / (13 + 8t_d/\tau) \qquad (2.6)$$

$$\tau_D = 4t_d / (11 + 2\,t_d/\tau) \qquad (2.7)$$

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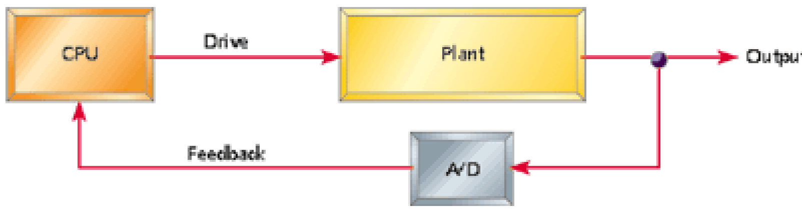

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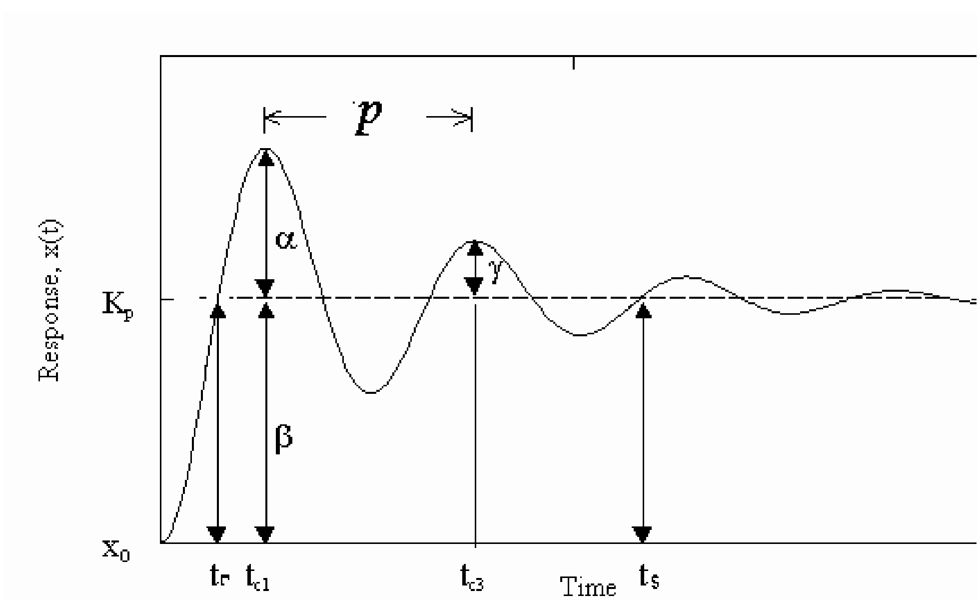

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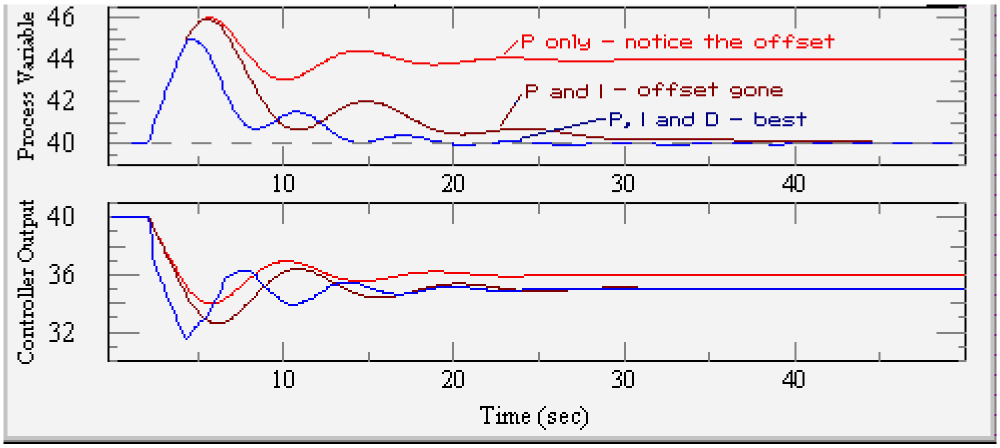

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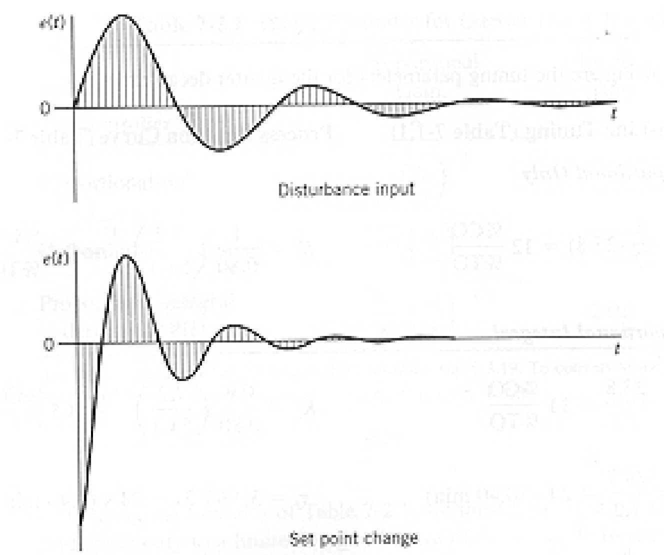

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$$G_{PRC(S)} = \frac{\overline{y_m}(s)}{\overline{c}(s)} \simeq \frac{Ke^{-td^s}}{\tau s + 1} \qquad (2.4)$$

C-C method used the approximated mode of equation 2.4 and estimated the value of the parameters K, τ, and t_d as indicated above. Then it derived expressions for the best controller settings using one-quarter decay ratio. From K, τ, and t_d the PID parameters are calculated from the following formulas [2].

$$Kc = (1/K)\,(\tau/t_d)\,(4/3 + t_d/(4\tau)) \qquad (2.5)$$

$$\tau_I = t_d\,(32 + 6t_d/\tau) / (13 + 8t_d/\tau) \qquad (2.6)$$

$$\tau_D = 4t_d / (11 + 2\,t_d/\tau) \qquad (2.7)$$