COMPARISION OF PERFORMANCE ANALYSIS OF DIFFERENT CONTROL STRUCTURES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FORTHE DEGREE OF

Bachelor of Technology
in
Electronics & Communication Engineering

By

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2012

CERTIFICATE

==

This is to certify that the work in this thesis entitled "**Comparison of Performance Analysis of Different Control Structures**" by Somjit Swain, Devendra Singh Mandavi and Arup Avishek Behera has been carried out under my supervision in partial fulfillment of the requirements for the degree of Bachelor of Technology in 'Electronics & Instrumentation' and 'Electronics & Communication' during session 2008-2012 in the Department of Electronics and Communication Engineering, National Institute of Technology, Rourkela.

Place:

Dated:

Prof. T.K.Dan
Dept. of ECE
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Somjit swain	Devendra Singh Mandavi	Arup Avishek Behera
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Abstract

Process control is a key part of almost every process operation. The features of a process are usually measured by process variables. The control of process variables is achieved by controllers. Process Engineers are often held responsible for different processes taking place in industries. These processes are generally of large scale and more complex. So, the role of process automation is more and more important in industries. Our prime objective is to design and tune various controllers and also analyze their performance. Implementing an effective control structure to control a process provide us various benefits like: better regulation of yield, better utilization of resources like energy, higher operating frequency, increased production and improved recording and reporting of process operations.

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Chapter 1: Introduction

Controller

In process control loops, a controller's job is to influence the control system via control signal so that the value of the cotrolled variable equals the value of the reference. Controller is rightly called the "Brain" of process control room. Controller generates a control signal to the final control element depending upon the deviation between the set point and the measured value of the cotrolled variable. The way in which the controller responds to deviation is called controller mode. The sensor, the transmitter, and the control valves are normally located around the process itself, while the controller is located on the panel or is residing as a program inside the computer memory.

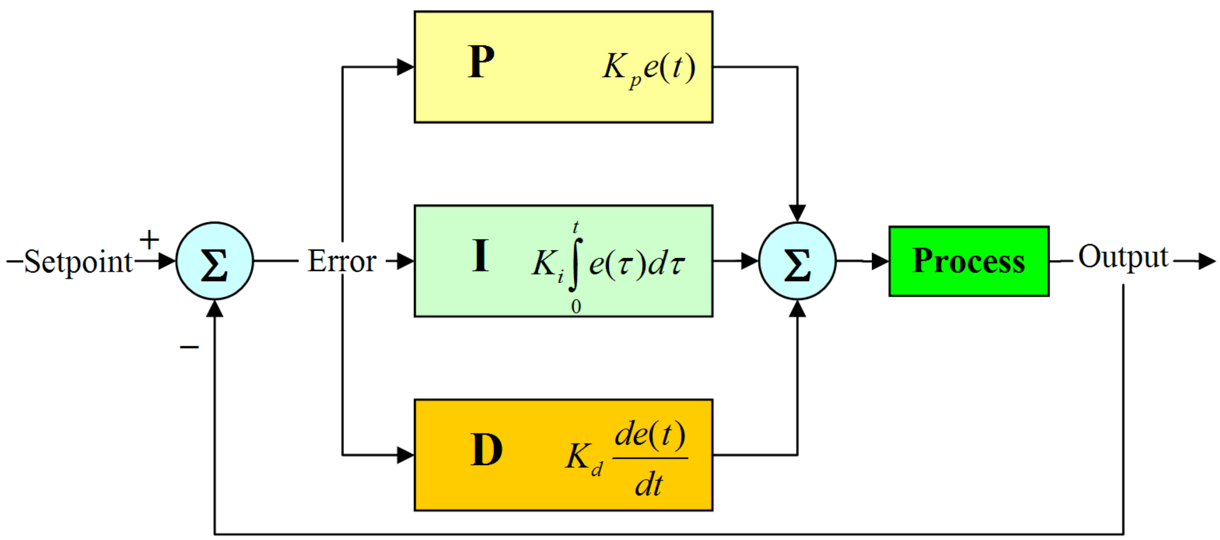

Figure 1 General Controller Structure

Chapter 2: Controllers

2.1. PID Controller Theory

The PID control scheme is named after its three correcting terms, whose constitutes the manipulated variable (MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining as the controller output, the final form of the PID algorithm is:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t)$$

Taking the Laplace transform we obtain

$$\frac{u(s)}{e(s)} = K_p(1 + \frac{1}{\tau_i s} + \tau_d s)$$

Where

K_p : Proportional gain, a tuning parameter

K_i: Integral gain, a tuning parameter

K_d: Derivative gain, a tuning parameter

e: Error = Set Point – Process value

t : Instantaneous time

τ_i : Integral time

τ_d: Derivative time

2.2. Proportional term

The proportional term is produced by an output value that is proportional to the current error value. The proportional response is adjusted by multiplying the error by a constant K_p, called the proportional gain constant.

The proportional term is given by:

$$u(t) = K_p e(t)$$

or

$$\frac{u(s)}{e(s)} = K_p$$

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable. Whereas , a small gain results in a small output response to a large input error and a less responsive or less sensitive controller. If the proportional gain is too low, the control action may be too small when responding to the system disturbances. Tuning theory and industrial practice indicates that, the proportional term should contribute to the bulk of the output change.

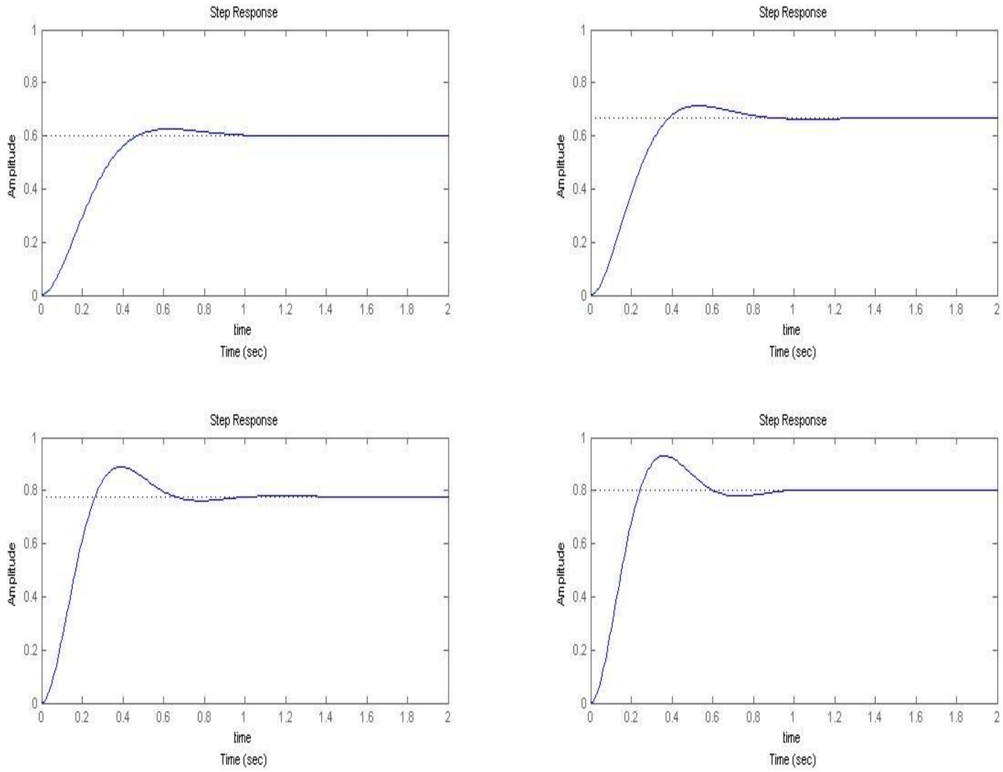

Figure 2: Only P controller by varying K_p

For the above figure we have taken the process transfer function to be

$$g_p(s) = \frac{1}{s^2 + 10s + 20}$$

And we took different values for $\mathbf{K_p}$ as 30,40,70,80. We can clearly see that with increase in the value of $\mathbf{K_p}$ the rise time decreased from 0.6 sec in first sub-image to 0.3 sec in the last sub-image. Similarly the overshoot increases and the steady state error decreases from 0.1 to 0.4 units. But there is small change in settling time.

2.3. Integral term

The contribution of the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain (K_i) and added to the controller output.

The integral term is given by:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau$$

or

$$\frac{u(s)}{e(s)} = K_p(1 + \frac{1}{\tau_i s})$$

The integral term accelerates the movement of the process towards the set point and eliminates the residual steady-state error which occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the set point value.

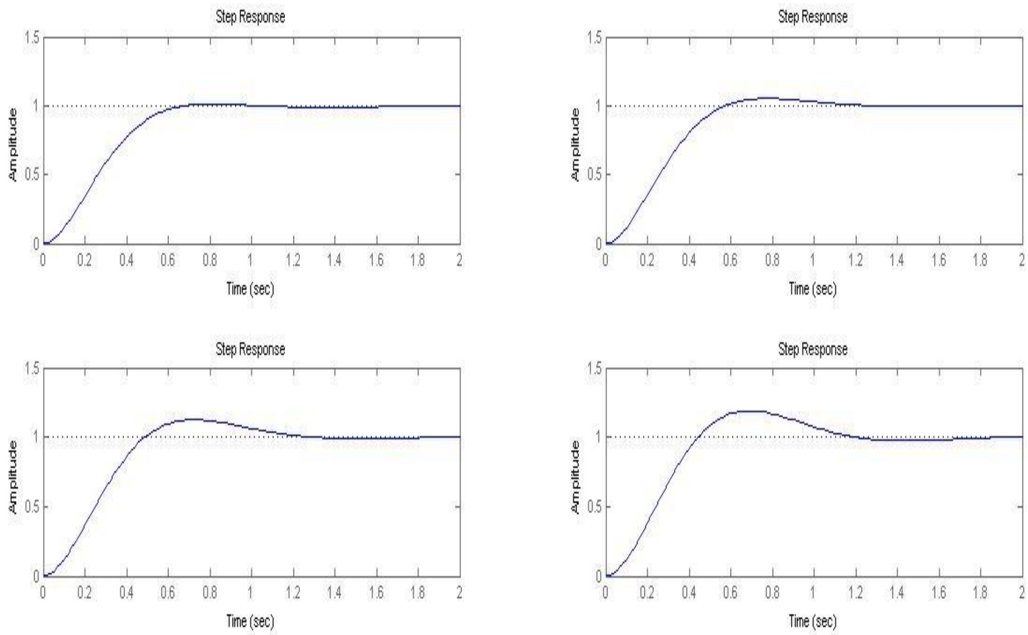

Figure 3 PI Controller by varying K_i

For the above figure we have taken the process transfer function to be

$$g_p(s) = \frac{1}{s^2 + 10s + 20}$$

And we took different K_i as 70, 80,100,120 keeping Kp fixed at 30. We can clearly see that with increase in the value of K_i the rise time decreases. Similarly the overshoot and steady state error increases. And there is significant decrease in settling time compared to only P controller.

2.4. Derivative term

The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain K_d. The amount of the contribution of the derivative term to the overall control action is termed as the derivative gain, K_d.

The derivative term is given by:

$$u(t) = K_p e(t) + K_d \frac{d}{dt} e(t)$$

or

$$\frac{u(s)}{e(s)} = K_p(1 + \tau_d s)$$

The derivative term slows the rate of change of the controller output. Derived control is used to reduce the magnitude of the overshoot formed by the integral component and improve the combined controller-process stability. However, the derivative term slows the transient response of the controller. Also, differentiation of a signal amplifies noise and thus this term in the controller is highly sensitive to noise in the error term, and can cause a process to become unstable if the noise and the derivative gain are sufficiently large. Hence an estimate to a differentiator with a limited bandwidth is more commonly used. This circuit is widely known as a phase-lead compensator.

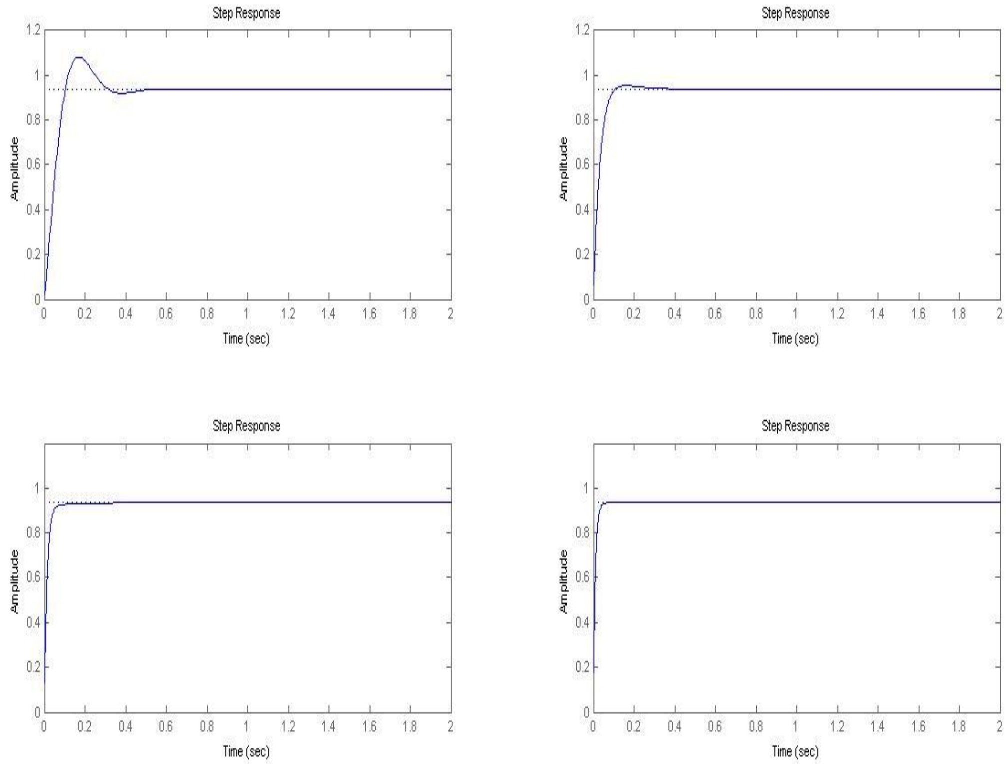

Figure 4 PD Controller by varying K_d

For the above figure we have taken the process transfer function to be

$$g_p(s) = \frac{1}{s^2 + 10s + 20}$$

And we took different K_d as 10,30,70,100 keeping K_p fixed at 300. We can clearly see that with increase in the value of K_d there is very small change in rise time , overshoot and settling time. But there is no change in steady state error.

2.5. PID Controller

PID controller is the mixture of proportional, integral and differential controller which can be tuned to obtain good results

The controller output of the PID algorithm is:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t)$$

Taking the Laplace transform we obtain

$$\frac{u(s)}{e(s)} = K_p(1 + \frac{1}{\tau_i s} + \tau_d s)$$

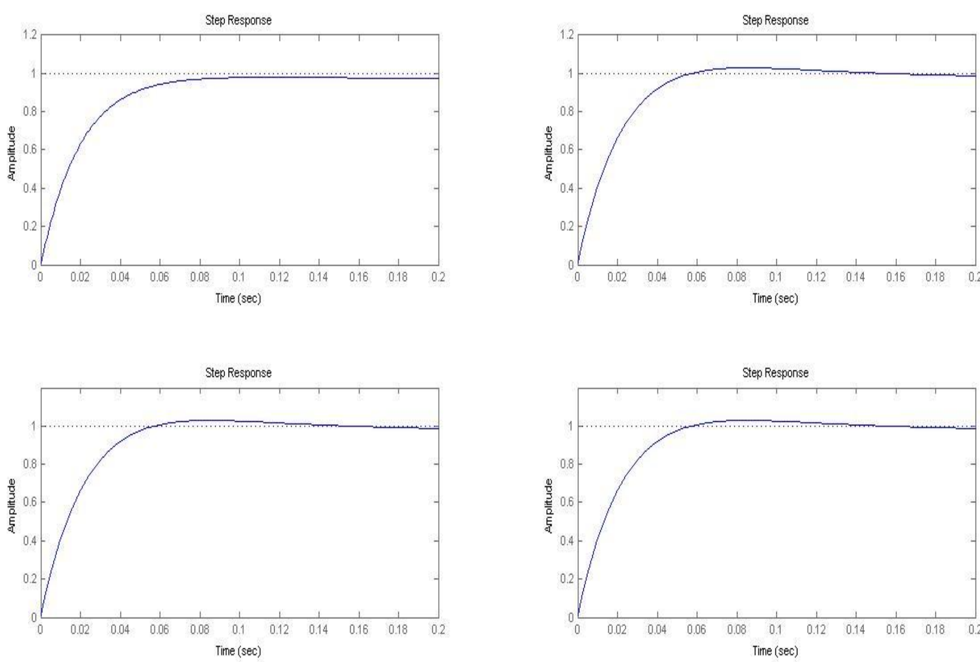

Figure 5 PID Controller by varying K_p

For the above figure we have taken the process transfer function to be

$$g_p(s) = \frac{1}{s^2 + 10s + 20}$$

We observed that combination of all P,I and D components produced astonishing results and settling time reduces to as low as 0.16 sec and steady state error is also reduced.

2.6. Comparison of P, PI and PID controllers

The process transfer function taken for comparison of the controllers is

$$g_p(s) = \frac{1}{s^2 + 10s + 20}$$

and K_p = 30, K_i=70 and K_d = 10

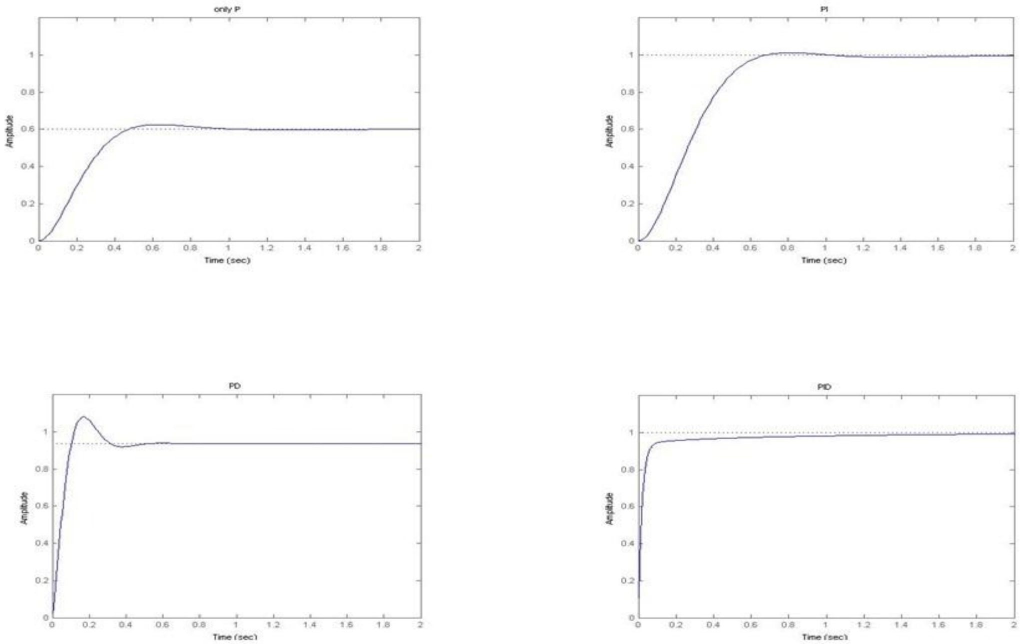

Figure 6 Only-P,PI,PD,PID responses

It can be easily concluded that the proportional term is maximum responsible for change in output , the integral term is responsible for decreasing the steady state error and the derivative term is responsible for decreasing the rise time and overall PID controller is responsible for better results due to decrease in settling time.

2.7. Examples of processes

2.7.1. Proportional Control of a first order process

Let us consider a process transfer function of a stirred tank-reactor. Where the manipulated variable is the heater power (kW) and the output is temperature (˚C)

$$g_p(s) = \frac{1}{5s+1}$$

Assuming a step input response and taking different values of Kp (1, 5, 10)

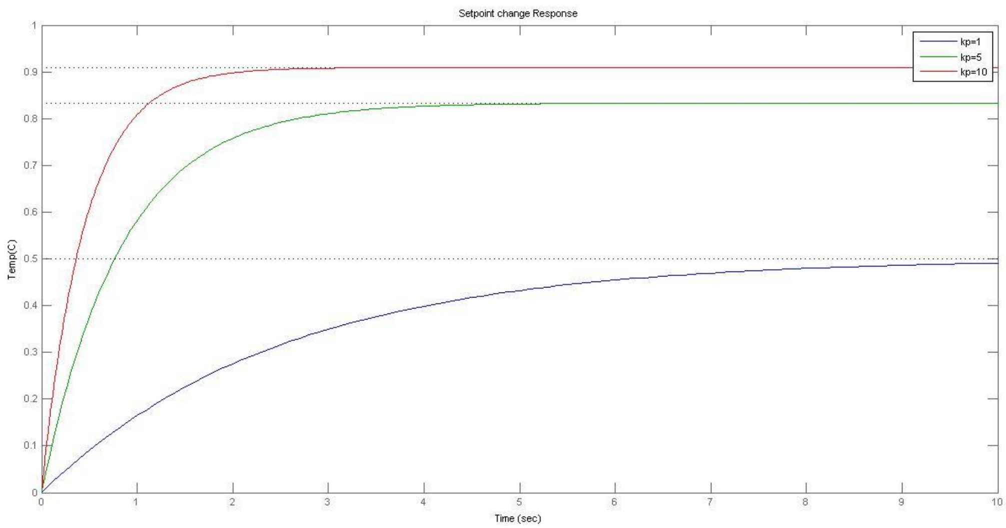

Figure 7 Proportional Control of a first order process by varying K_p (1,5,10)

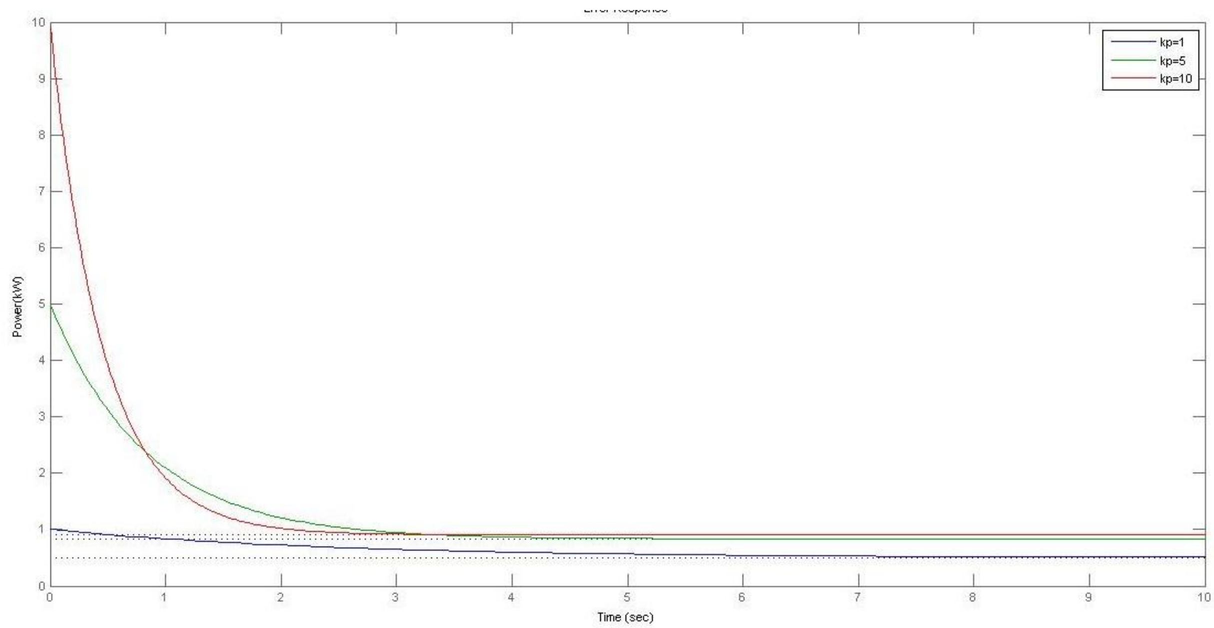

Figure 8 Error in Proportional Control of a first order process

It can be observed that increasing the K_p reduces the offset and speeds up the response. K_p can be increased up to a certain level beyond which the process will be unstable.

2.7.2. PI Control of a first order process

Let us consider a same process transfer function of a stirred tank-reactor. Where

$$g_p(s) = \frac{1}{5s+1}$$

Assuming a set point change of 1˙C and taking different values of τi (0.25,5) with fixed K_p=5 kW/˙C and simulating it we obtain the following figure

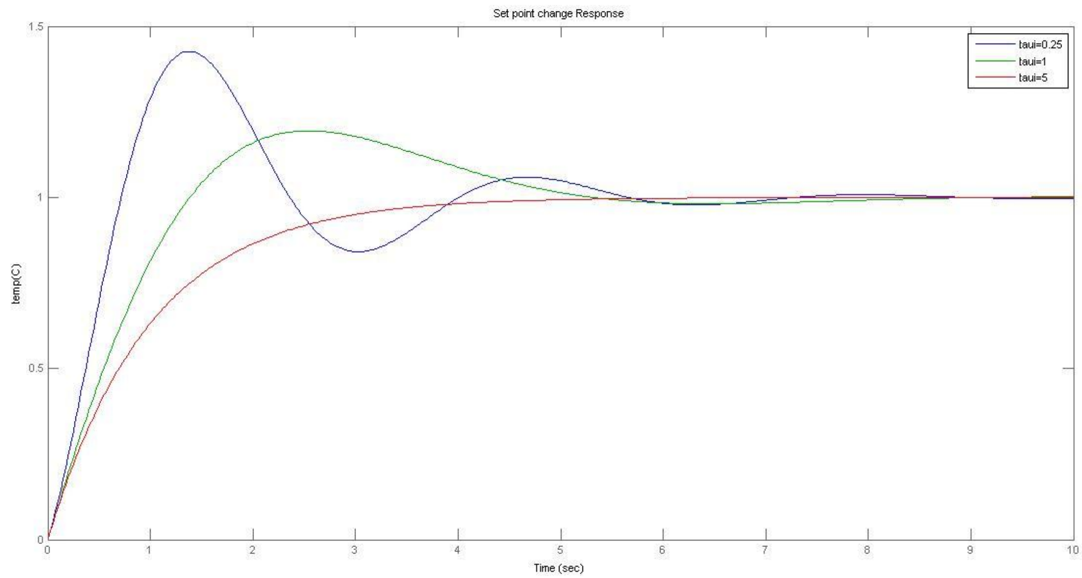

Figure 9 PI Control of a first order process by varying τ_i (0.25,1,5)

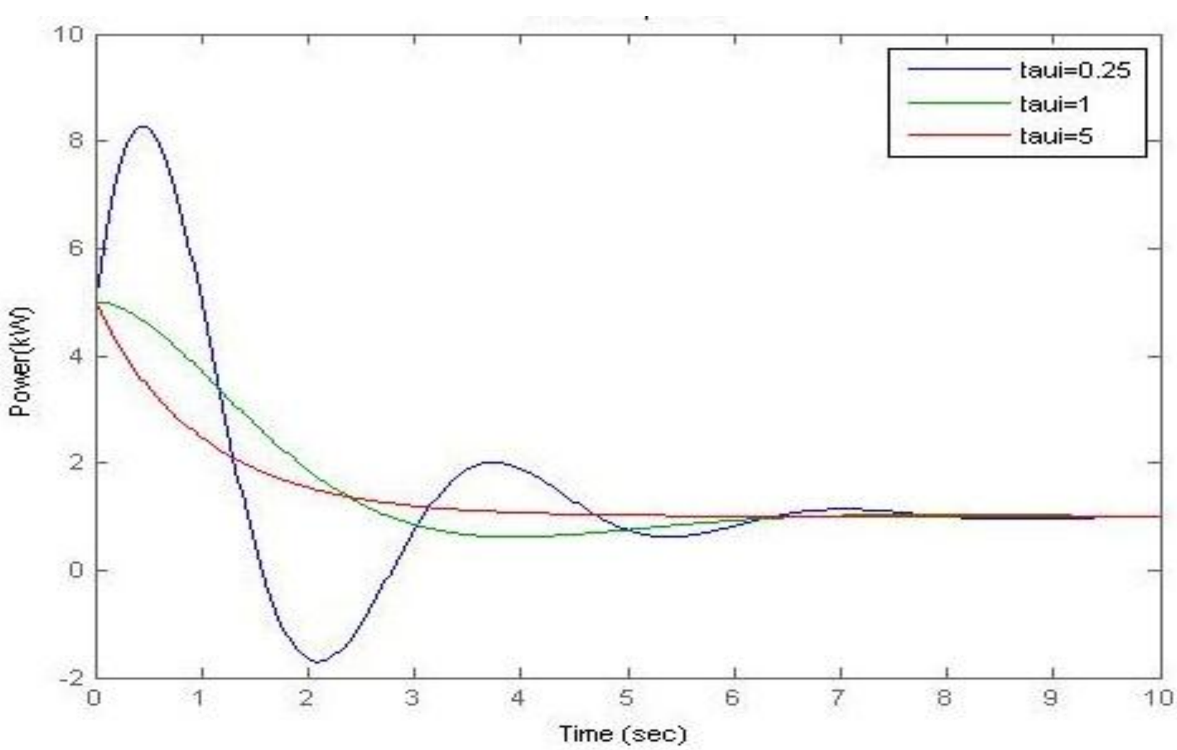

Figure 10 Error in PI Control of a first order process

We can see that for smaller integral time there is oscillatory performance for both manipulated input and controlled output. The oscillatory performance is viewed as unfavorable to process parameters.

2.7.3. P-only Control of a third order process

The process transfer function taken here is

$$g_p(s) = \frac{1}{s^3 + 6s^2 + 11s + 1}$$

And plotting the graphs for input and output with K_p (1,5,10)

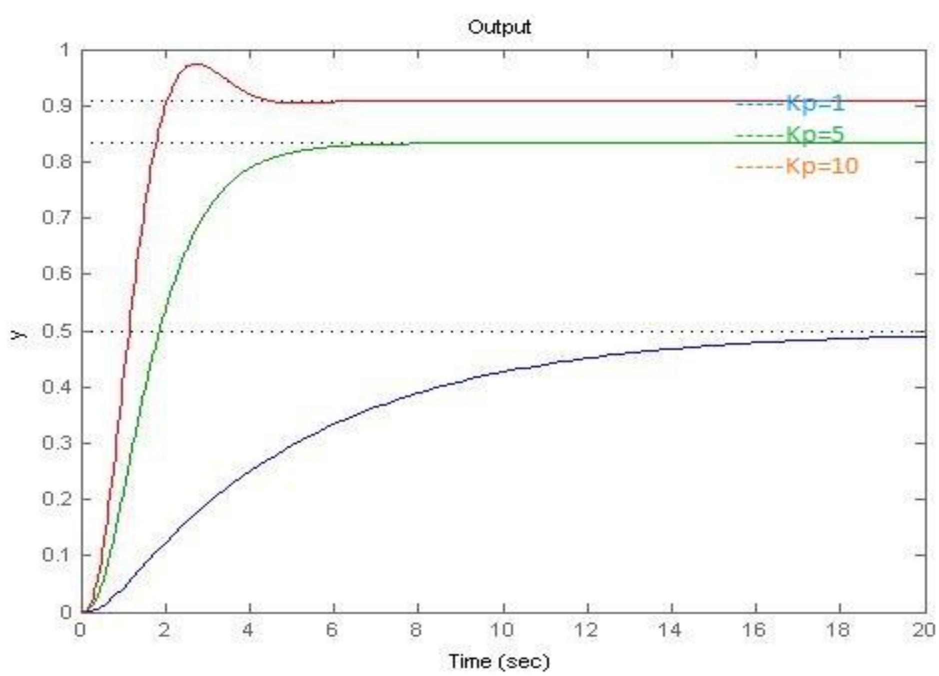

Figure 11 P-only Control of a third order process Kp = 1, 5,10

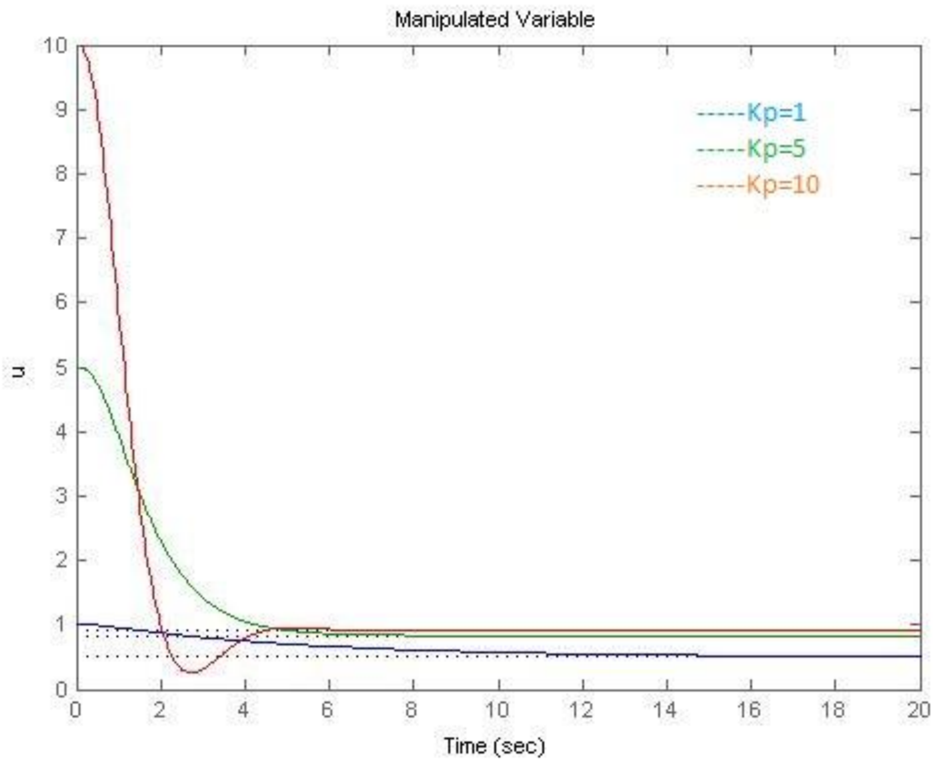

Figure 12 Error in PI Control of a first order process

2.8. Closed loop oscillation based tuning

There are three tuning parameters in a PID controller. If these are adjusted in random fashion then it may take a while for obtaining satisfactory performance. And also each tuning parameter will result in a different set of tuning parameter. Different kinds of algorithms have been developed for controller tuning. The first widely used algorithm for PID tuning was developed by Ziegler and Nichols in 1942.

2.8.1. Ziegler-Nichols Closed-loop method

Ziegler-Nichols Closed-loop method was the first proper algorithmic method for tuning the PID controllers. It is not widely used today because closed-loop behavior tends to be oscillatory and sensitive to uncertainty. We study this technique as it is the base for commonly used automatic tuning.

2.8.2. Steps for Ziegler-Nichols Closed-loop method tuning

- Taking P-only controller the magnitude of K_p is increased so as to get perfect oscillation
- The value of proportional gain obtained is termed as critical (or ultimate) gain, k_{cu} and peak-to-peak is called ultimate period P_u .

The process transfer function used to determine the tuning parameters is

$$g_p(s) = \frac{1}{(3s+1)(2s+1)(s+1)} = \frac{1}{6s^3 + 11s^2 + 6s + 1}$$

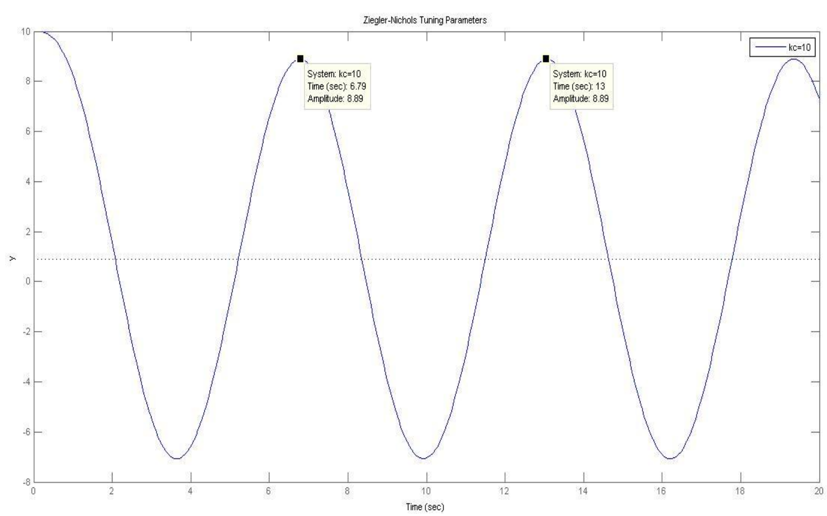

Figure 13 Determination of Ziegler-Nichols parameters

From the graph we obtained the values of K_{cu} = 10 & P_u=6.2 sec

2.8.3. Ziegler-Nichols Closed-loop method tuning

Ziegler-Nichols suggested tuning parameter rules that result in less oscillatory response and are less sensitive to change in process conditions.

Table 1 Ziegler-Nichols tuning parameters

Controller Type	K_c	τ_i	τ_d
P-only	$0.5K_{cu}$	----	----
PI	$0.45K_{cu}$	$P_u/1.2$	----
PID	$0.6K_{cu}$	$P_u/2$	$P_u/8$

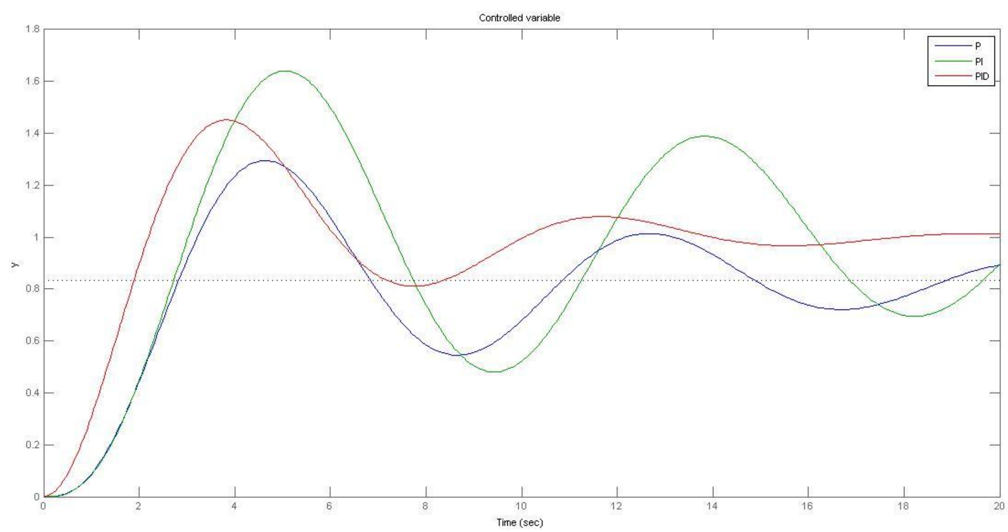

Figure 14 Comparison of Ziegler-Nichols P,PI,PID tuning rules of controlled variable

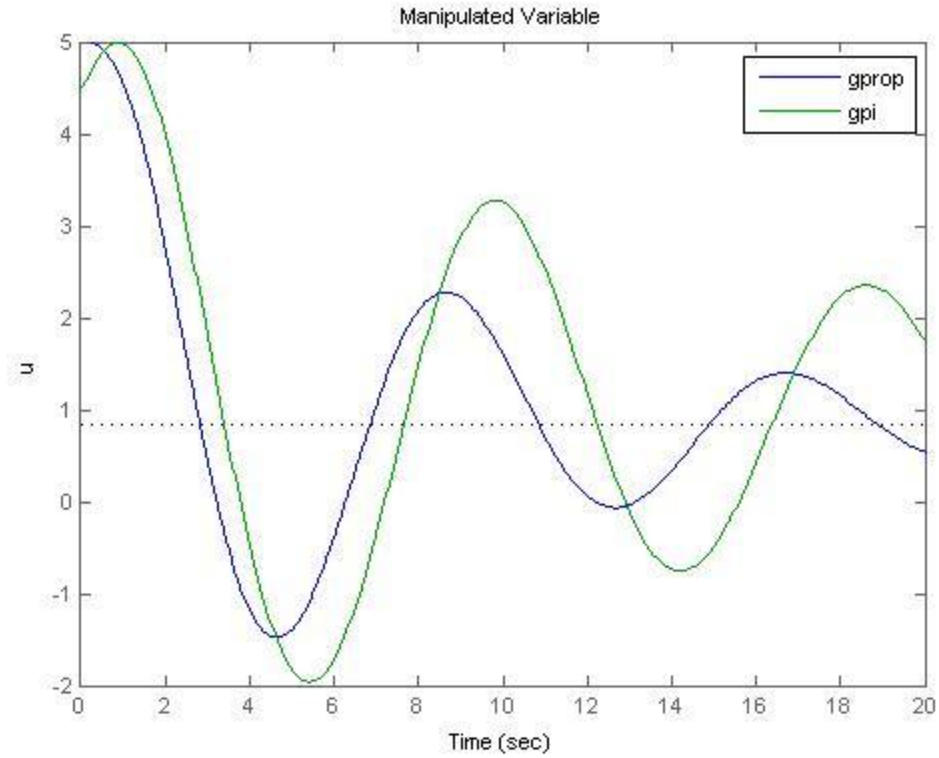

Figure 15 Comparison of Ziegler-Nichols P,PI,PID tuning rules of manipulated variable

Chapter 3: Control Structures

3.1. Cascade Control

In cascade control configuration, there is one manipulated variable and more than one measurement. It is an alternative to consider if direct feedback control using the primary variable is not satisfactory and a secondary variable measurement is available. Cascade control uses the output of primary controller to manipulate the set point of secondary controller.

The basic principle of cascade control is that if the secondary variable responds to the disturbance sooner than the primary variable. So, it provides a possibility to capture and nullify the effect of the disturbances before it propagates into the primary variable.

There are two measurements taken from the system and used in their respective control loops. In the outer loop, the controller output is the set point of the inner loop. The outer loop is called primary loop and the inner loop is called secondary loop. If the outer loop variable changes, it affects in the set point of inner loop. The inner loop experiences an error signal and produces a new output due to the change in set point. Cascade control provides better control of the outer loop variable than is accomplished by a single variable system. The main feature of cascade control is to divide an difficult control process into two portions; where by a secondary loop is formed around major disturbances, leaving only minor disturbances to be controlled by the primary controller.

3.1.1. Features of Cascade Control

- More than one measurement , but one manipulated variable
- Two feedback loops are nested
- The output of primary controller serves as the input for secondary controller

- Useful in case of eliminating effect of disturbances that move through the system slowly
- Increases stability characteristics
- Insensitive to modeling errors
- Variation of primary variable decreases
- The secondary controller eliminates the disturbances arising within the secondary loop before they affect the primary variable
- The proportional gain value of secondary controller is high, moreover , the offset value associated with proportional mode can be easily removed by integral action of primary controller.

3.1.2. Advantage of Cascade Control

- Better control of primary loop
- Faster recovery from disturbances
- Natural frequency of the system increase
- Effective magnitude of time lag decreases
- Dynamic performance increases

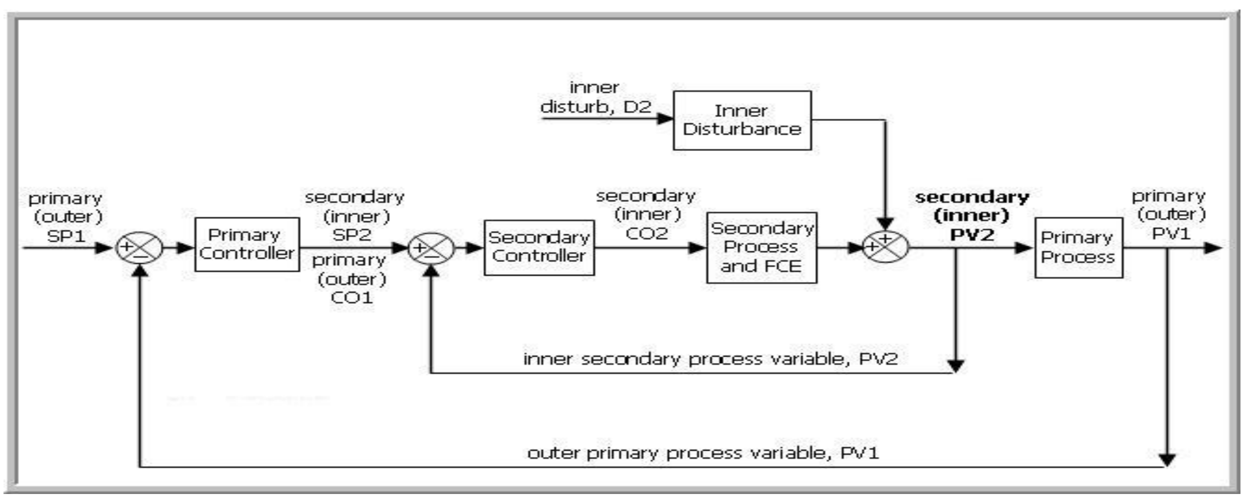

Figure 16 Block diagram of cascaded structure

3.2. FeedForward Control

The conventional feedback control loop can never achieve perfect control. It is difficult on the part of conventional loops to keep the set point at desired position continuously. This happens because a feedback controller reacts only after it detects a deviation in the value of the output from the desired set point. Unlike feedback systems, a feedforward control configuration measures disturbances directly and takes action to abolish its impact on the process output. Theoretically these controllers have potential for perfect control.

The control strategy of feedforward control , corrective action is taken in order to minimize the deviation of controlled variable which might can disturb the control variable. The signals which have the potential to upset the process are transmitted to the controller. The controller makes accurate computation on these signals and calculate the new values of the manipulated signals and send those values to the final control element, Therefore, the control variable remains unchanged in spite of change in load.

3.2.1. Features of Feedforward Control

- It is quite different from conventional feedback controllers(*P, PI, and PID*)
- It is a special purpose computing machine
- The effectiveness of the controller require through knowledge of the process model

3.2.2. Advantages of Feedforward Control

- It acts before the effect of a disturbance has been felt by the system
- Good for slow processes or with significant dead time
- It doesn’t introduce instability in the closed loop response.

3.2.3. Feedforward Control is used if

- The physical and chemical properties are well known.
- The variables in the equation can be easily measured.
- There is no significant process disturbance.
- The accuracy of measurement must be high.

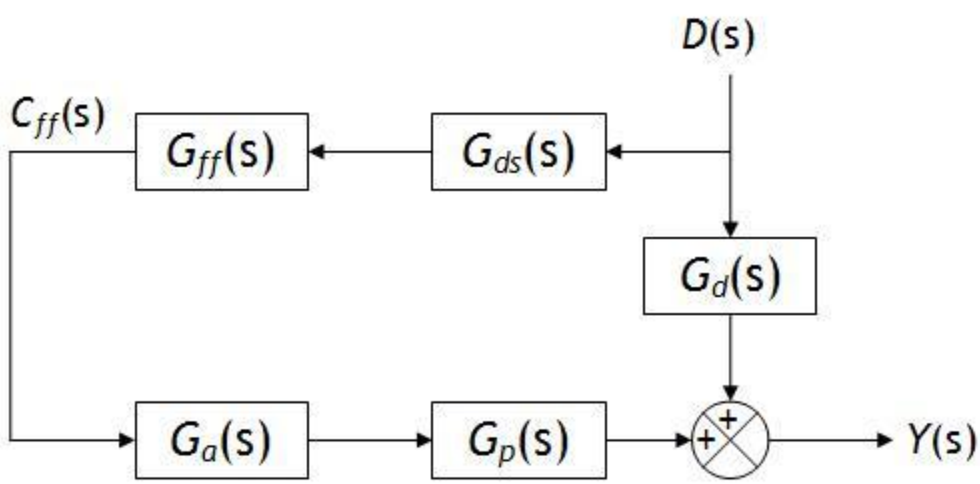

Figure 17 Block diagram of feedforward contro structure

3.3. Feedforward- Feedback Control

If we can measure the up-stream disturbances, then we can take anticipatory control action that nullifies the disturbance affecting the process. Feedforward control depends on the use of open loop inverses; hence it is susceptible to the impact of modeling errors. Thus, we can easily supplement feedforward control by some feedback control, so as to correct any miscalculation involved in the anticipatory control action inherent in feedforward control. The feedfoward control cancels the effect of the measured disturbance. Feedback acts as the system's watchdog .The effect of load change other than the measured disturbance will be corrected by the feedback system. Feedback alone must absorb the variations by feedback action only.

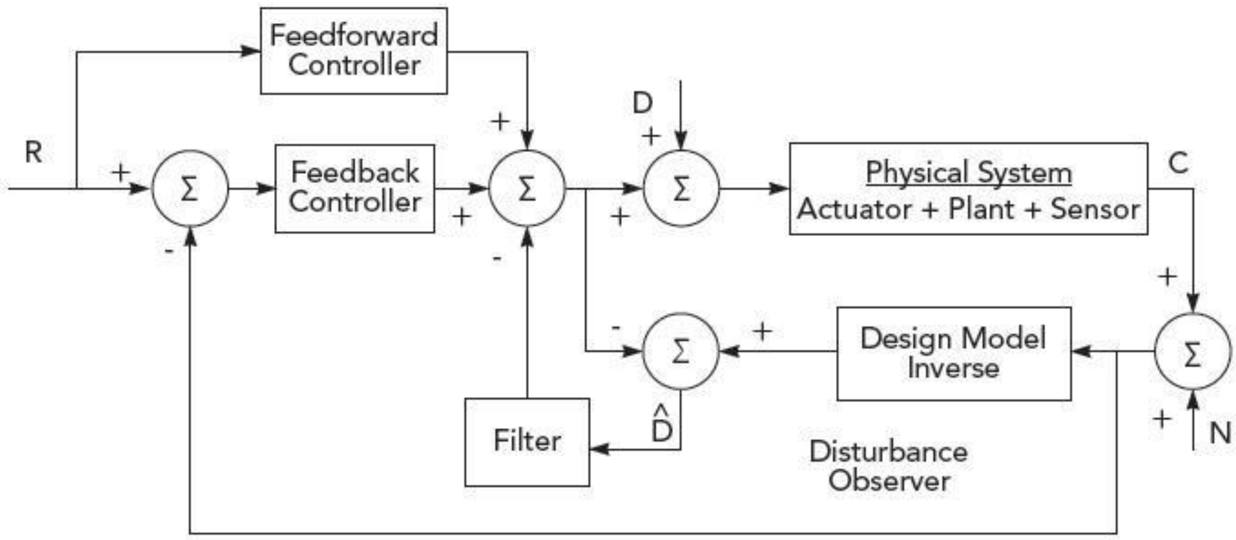

Figure 18 Block diagram of feedback-feedforward control structure

3.4. Comparison of cascade, simple feedback and feedforward-feedback structures

Let the transfer function of system be

$$G_{p1} = \frac{4}{(2s+1)(4s+1)}$$

$$G_{p2} = \frac{5}{(s+1)}$$

$$G_{l2} = \frac{1}{(3s+1)}$$

$$G_{c1} = Proportional\ controller$$

$G_{c2} = 4$

$G_{m1}=0.05$

$G_{m2}=0.2$

From the block diagram we can get

$$\frac{C_1}{R_1}_{cascade} = \frac{G_{c1}G_{c2}G_{p1}G_{p2}}{1 + G_{p2}G_{m2}G_{c2} + G_{p1}G_{p2}G_{c1}G_{c2}G_{m1}}$$

$$\frac{C_1}{R_1}_{simple\ feedback} = \frac{G_{c1}G_{c2}G_{p1}G_{p2}}{1 + G_{p1}G_{p2}G_{c1}G_{m1}}$$

$$\frac{e}{L_2}_{cascade} = \frac{-G_{l2}G_{p1}G_{m1}}{1 + G_{p2}G_{m2}G_{c2} + G_{p1}G_{p2}G_{c1}G_{c2}G_{m1}}$$

$$\frac{e}{L_2}_{cascade} = \frac{-G_{l2}G_{p1}G_{m1}}{1 + G_{p2}G_{m2}G_{c2} + G_{p1}G_{p2}G_{c1}G_{c2}G_{m1}}$$

$$\frac{e}{L_2}_{simple\ feedback} = \frac{-G_{l2}G_{p1}G_{m1}}{1 + G_{p1}G_{p2}G_{c1}G_{m1}}$$

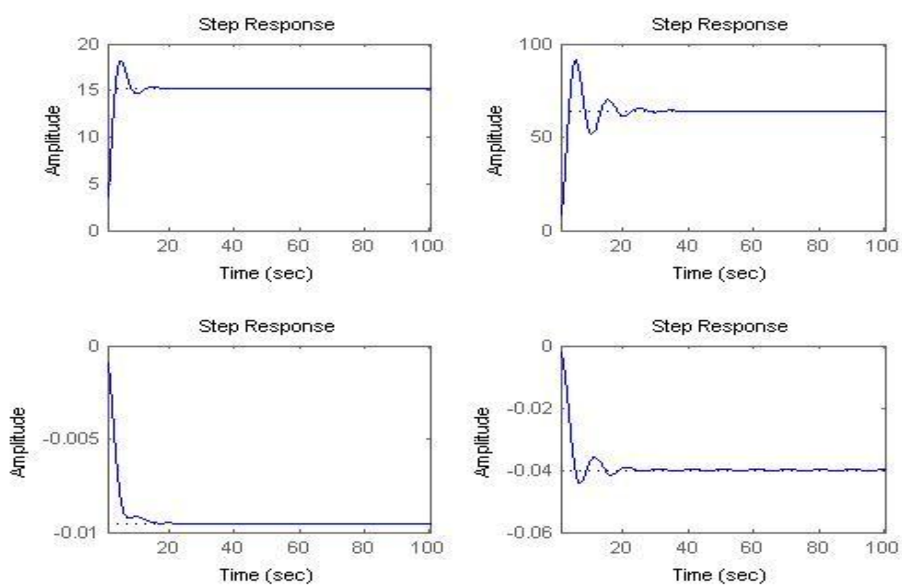

Figure 19 Step response of cascaded and simple feedback structures with their corresponding errors (K_p=4)

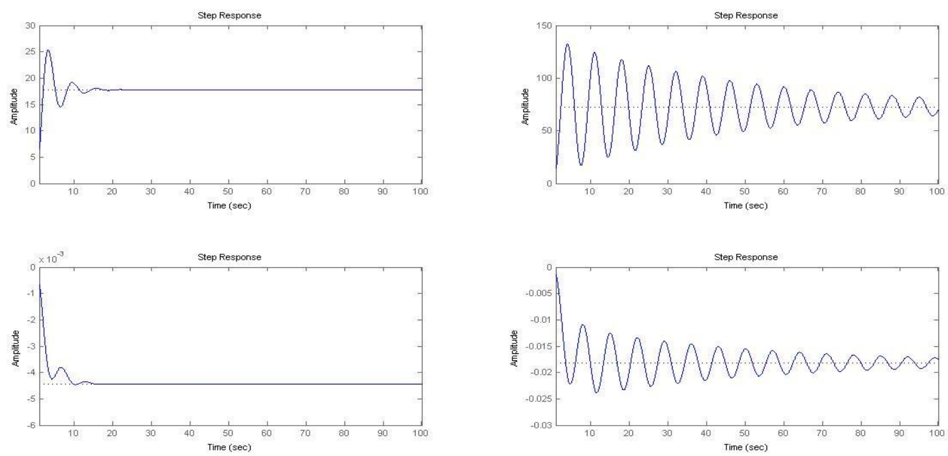

Figure 20 Step response of cascaded and simple feedback structures with their corresponding errors (K_p=10)

From the above figures we can conclude that cascade control provides better control of the outer loop variable than is accomplished by a single variable system and also error is also less.

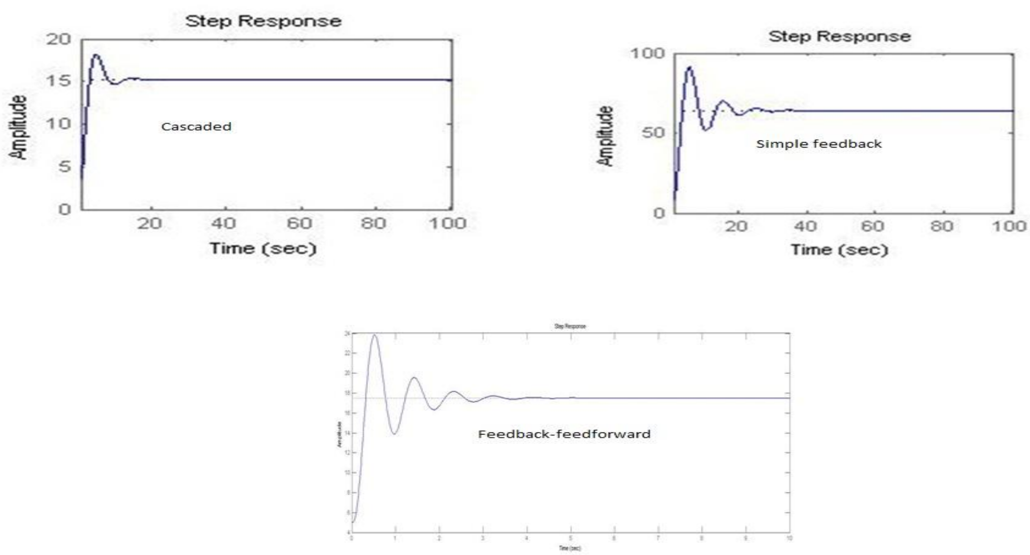

Figure 21 Comparison of cascaded, simple feedback and feedback-feedforward structures

The above figure clearly states that the best control structure in terms of performance (settling time) is feedback-feedforward(5 sec)followed by cascaded(20 sec) and simple feedback(40 sec)

Chapter 4: Internal Model Control

4.1. Internal Model Control

An internal model is a postulated neural process that simulates the response of the control system in order to estimate the outcome of a control command. Internal models can be controlled by either feed-forward or feedback control. Feed-forward control calculate its input into a system using only the current state and it's model of the system. It does not use feedback control. So, it cannot correct all errors in its control. In feedback control, some of the output of the system is fed back into the system's input and the system became capable to make adjustments or recompense for errors from its desired output. Two primary types of internal models have been projected: i) forward models and ii) inverse models. In simulations, models are often combined together to resolve more complex movement tasks.

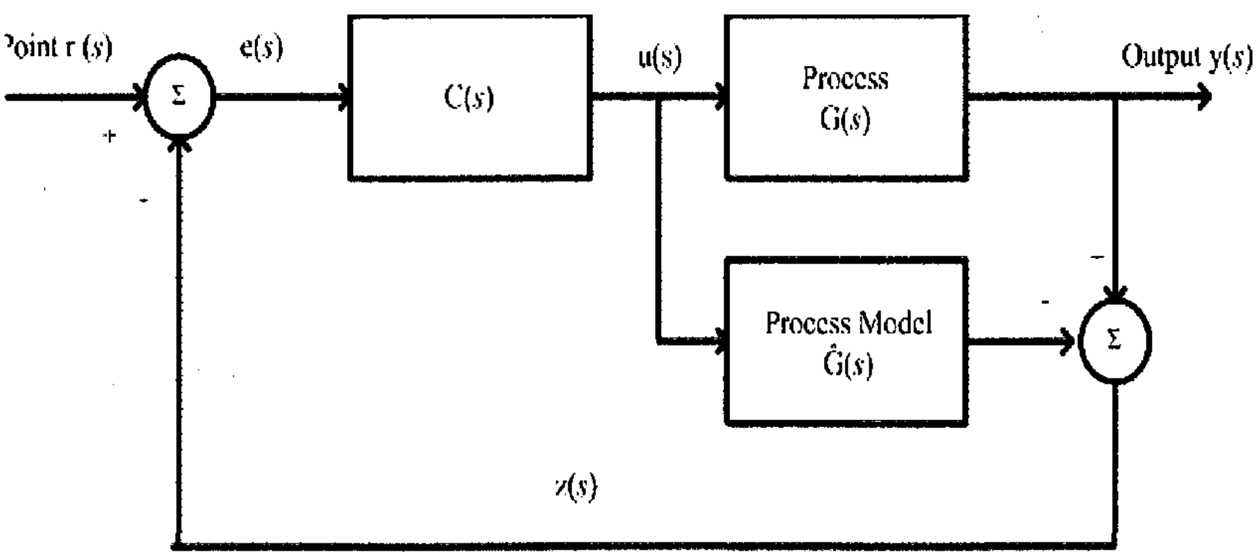

Figure 22 General IMC structure

4.2. IMC Background

The main advantage of IMC is that it provides a transparent framework for control system design and tuning. The IMC control structure can be formulated in the standard feedback control structure. For many processes, this will result in a standard PID controller. This is satisfying because we can use standard equipment and algorithms to implement an “advanced” control concept. The IMC design procedure is same as that of the open loop control design procedure.

A factorization of the process has been performed for which the resulting controller would be stable. If the controller is stable and the process is stable, then the overall controlled system is stable. In the design of IMC there is a restriction that the process must be stable. IMC is able to compensate for disturbances and model uncertainty, where as in case of open loop control design it is not possible.

Let us consider the closed loop response for IMC for the following process

$$g_p(s) = \frac{1.5(-s+1)}{(s+1)(4s+1)}$$

$$\breve{g}_p(s) = \frac{2}{5s+1}$$

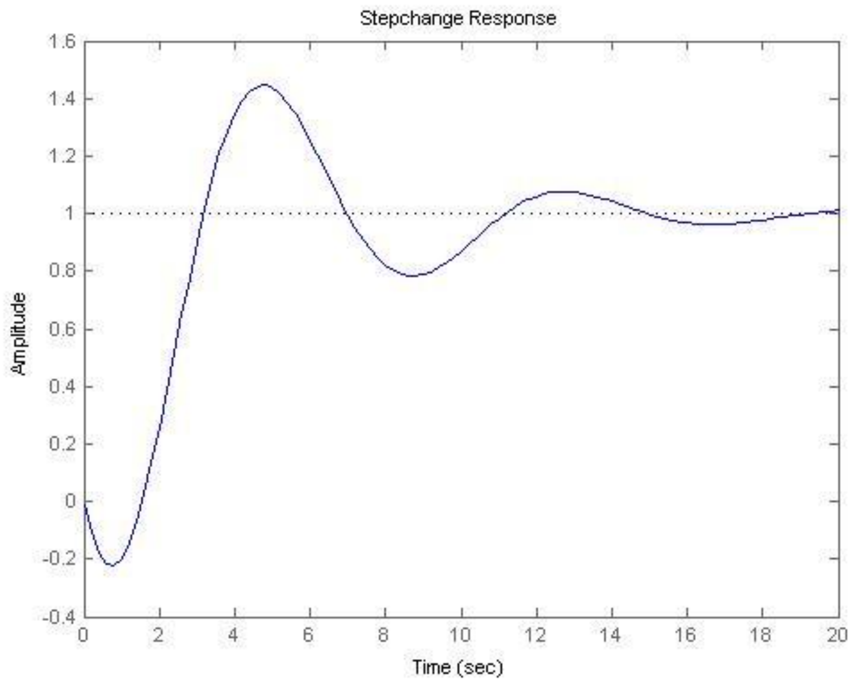

Figure 23 Step change response of an IMC controller

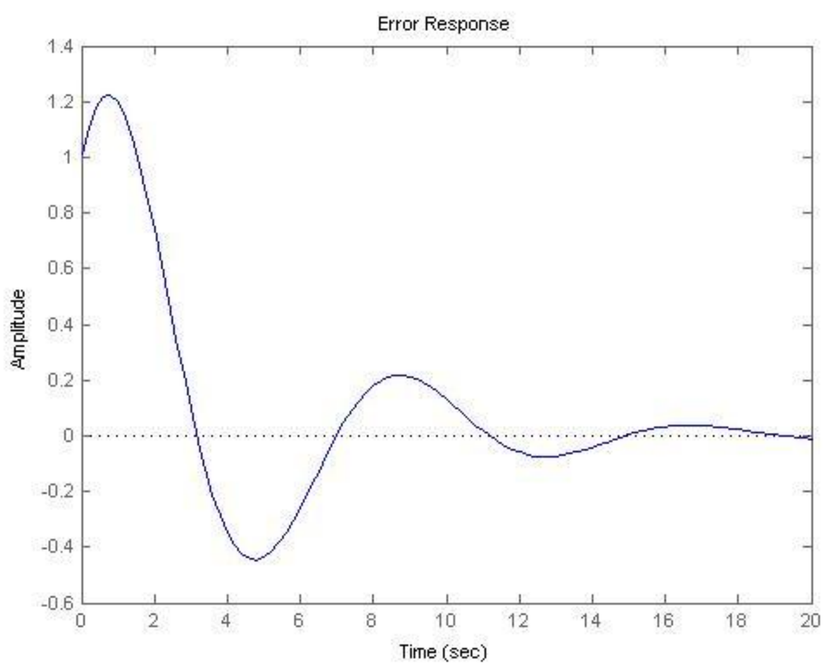

Figure 24 Error response of an IMC controller

The minimum value of λ that assures closed loop stability is found to be 0.9 in which there is perfect oscillations

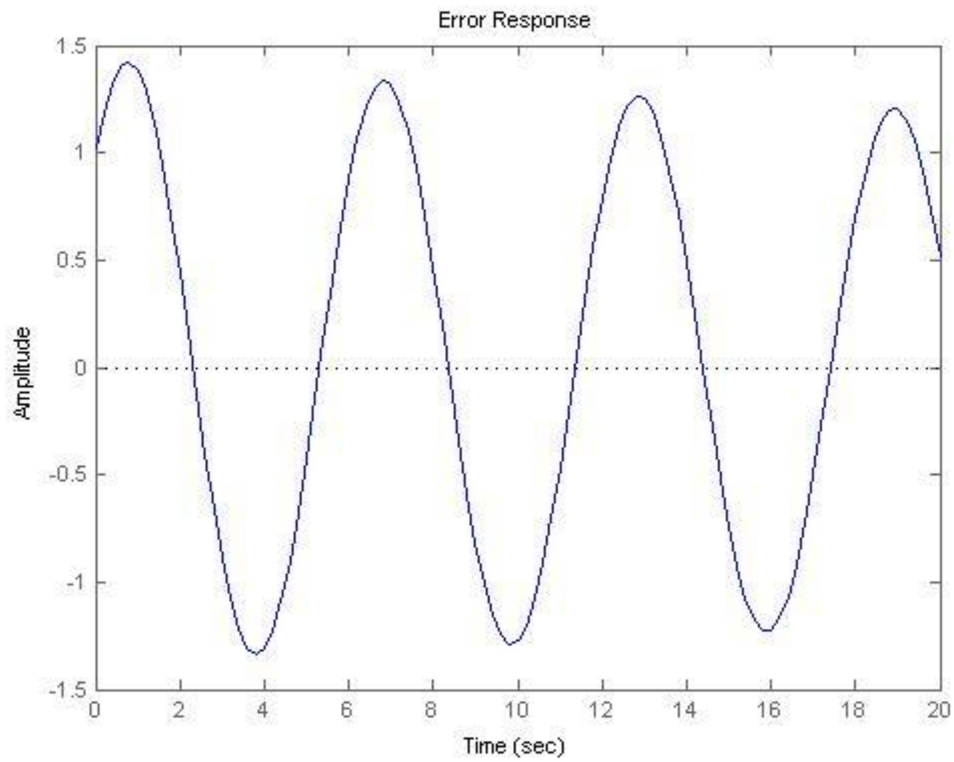

Figure 25 Minimum value of λ that assures closed loop stability

Chapter 5: Conclusion

Conclusion

It can be concluded that PID controller has all the necessary dynamics: fast reaction on change of the controller input(D mode), increase in control signal to lead error to zero(I mode) and suitable action inside control error area to eliminate oscillations (P mode)

Among the different control structures, the feedback-feedforward control structure faster in response

Table 2: Response of different parameters with increase in K_p, K_i, K_d

Parameter (increase)	**Rise time**	**Overshoot**	**Settling time**	**Steady-state error**
K_p	Decrease	Increase	Small change	Decrease
K_i	Decrease	Increase	Increase	Decrease significantly
K_d	Minor decrease	Minor decrease	Minor decrease	No change

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