A Comparison of Different Controllers to Control Various Parameters of Continuous Stirred Tank Reactor

A Thesis submitted in partial fulfilment of the
Requirements for the award of degree of

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In
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CERTIFICATE

I hereby declare that the work which is done in this thesis "A comparison of different controllers to control various parameters of continuous stirred tank reactor " in partial fulfillment of the requirement for award of degree of MASTER of ENGINEERING in **Electronics and Instrumentation Control** submitted in **Electrical and Instrumentation Department of Thapar University,Patiala** is an authentic record of my own work carried out under the supervision of **Dr. GagandeepKaur,Assistant Professor,EIED**

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university

Date: Rupinder Kaur
RUPINDER KAUR

This is here certifying that the above statement given by candidate is correct and true to best of my knowledge and belief.

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LIST OF ABBREVIATION

MV	Measured Value
S.P	Set Point
PID	Proportional Integral Derivative
MATLAB	Matrix Laboratory
FLC	Fuzzy Logic Controller
AI	Artificial Intelligence
ISE	Integral Square Error
IAE	Integral Absolute Error
ITAE	Integral Time Absolute Error
ITSE	Integral Time Square Error
CSTR	Continuously Stirred Tank Reactor
NB.	Negative Big
NM	Negative Medium
NS	Negative Small
ZO	Zero
PS	Positive Small
PM	Positive Medium

List of symbol

Kp	Proportional Gain
Kd	Derivative Gain
Ki	Integrative Gain
Tr	Rise time
Ts	Settling time
Mp	Peak overshoots

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RupinderKaur

ABSTRACT

Control of various parameters in a chemical plant is one of the major challenges in industry. This thesis considers a chemical reactor, and controls various parameters of the reactor using different controllers. The thesis also compares the performance of different controllers by time domain analysis like transient response and error analysis. The thesis models the chemical reactor, implements PID controller, feedback and feed forward controller, hybrid fuzzy controller to control various parameters of the chemical reactor.

CHAPTER 1

Introduction

1.1Overview

It is important to control different parameters while dealing with chemical process. The process can be exothermic or endothermic in nature, while designing a controller, it is better to understand the process very well. Model based controller and model less controller are two of the main controller architecture that can be used and implemented in a control loop. Different control loop demands different controllers, so the most important part of process control is to study the performance of the controller.

1.2Objective

The aim of this thesis is to compare the performances of various controllers in different control loops. The performance is evaluated in time domain. Two controllers, conventional controllers and fuzzy based controllers are used. Performance of both the controller is compared on the basis of their transient response. The objective of the controller is to control the temperature of the outgoing fluid to a desired set point.

1.3Introduction

Control theory is a branch of instrumentation engineering that deals with the behavior of dynamical systems. The external input of a system is called the reference or set point. When one or more output variables of a system need to follow a certain reference over time, a controller manipulates the inputs to a system to obtain the desired effect on the output of the system. The usual objective of control theory is to calculate solutions for the proper corrective action from the controller that result in system stability, that is, the system will hold the set point and not oscillate around it. The inputs and outputs of a continuous control system are generally related by nonlinear differential equations. A transfer function can sometimes be obtained by

(1) Finding a solution of the nonlinear differential equations,

(2) Linearizing the nonlinear differential equations at the resulting solution (i.e. trim point),

(3) Finding the Laplace Transform of the resulting linear differential equations, and

(4) Solving for the outputs in terms of the inputs in the Laplace domain.

The transfer function is also known as the system function or network function. The transfer function is a mathematical representation, in terms of spatial or temporal frequency, of the relation between the input and output of a linear time-invariant solution of the nonlinear differential equations describing the system. The key characteristic of control system is to interfere, to influence or to modify the process according to the requirement. Depending on whether a human body (the operator) is physically involved in the control system, they are divided into Manual Control and Automatic Control. Due to its efficiency, accuracy and reliability, automatic control is widely used in chemical processes. The aim of this section is to introduce the concept of control systems, what their function is and what *hardware* and *software* is required by them.

1.3.1 Functions of a Control System

- Measurement

  This is essentially an estimate or appraisal of the process being controlled by the system. In this example, this is achieved by the right hand of the operator.

- Comparison

  This is an examination of the likeness of the measured values and the desired values. This is carried out in the brain of the operator.

- Computation

  This is a calculated judgment that indicates how much the measured value and the desired values differ and what action and how much should be taken. In this example, the operator will calculate the difference between the desired temperature and the actual one. Accordingly the direction and amount of the adjustment of the valve are worked out and the order for this adjustment is sent to the left hand from the brain of the operator. If the outlet water temperature is lower, then the brain of the operator will tell the left hand to open the steam valve wider. If there is any disturbance, or variation of flow rate in water to the shower inlet, some adjustment must be made to keep the outlet water temperature at a desired value.

- Correction

  This is ultimately the materialization of the order for the adjustment. The left hand of the operator takes the necessary actions following the order from brain.

Of course, the manual operation has obvious disadvantages e.g. the accuracy and the continuous involvement of operators.

Although accuracy of the measurement could be improved by using an indicator, automatic control must be used to replace the operator. In industry, it is automatic control that is widely used.

1.3.2 Hardware of a Control System

Examining the automatic control system, it is found that it contains the following hardware.

- Sensor - a piece of equipment to measure system variables. It serves as the signal source in automatic control. These will be discussed at length in a later module.
- Controller - a piece of equipment to perform the functions of comparison and computation. The actions that a controller can take will be discussed at length in a later module.
- Control Element - a piece of equipment to perform the control action or to exert direct influence on the process. This element receives signals from the controller and performs some type of operation on the process. Generally the control element is simply a control valve.

1.3.3 Software of a Control System

Associated with a control system are a number of different types of variables.

First we have the Controlled Variable. This is the basic process value being regulated by the system. It is the one variable that we are especially interested in - the outlet water temperature in the example above. In feedback control the controlled variable is usually the measured variable. An important concept related to the controlled variable is the Set point. This is the predetermined desired value for the controlled variable. The objective of the control system is to regulate the controlled variable at its set point. To achieve the control objective there must be one or more variables we can alter or adjust. These are called the Manipulated Variables. In the above example this was the input hot water flow rate.

Conclusively, in the control system we adjust the manipulated variable to maintain the controlled variable at its set point. This meets the requirement of keeping the stability of the process and suppressing the influence of disturbances.

1.3.4 Basic Requirements

In order to control the process performance, we need a control system, which consists of a sensor, a controller and a final control element. Obviously, the sensor is a very important part of the control system. It monitors the process and serves as a signal source for the control system. In our previous discussion, we always assumed, there was some suitable measuring device available, but not all measuring devices can be used in automatic control. The basic requirements for a sensor used in a control loop are the abilities:

- to indicate the values of measured variables

The signals could be transmitted through either an electric circuit or a pneumatic pipeline, therefore, in order to transmit the signal, the sensors must have the ability to convert the measured variable values into either electric signals or pneumatic signals. The concept of the feedback loop to control the dynamic behaviour of the system: this is negative feedback, because the sensed value is subtracted from the desired value to create the error signal, which is amplified by the controller.

1.4 Closed Loop Control versus Open Loop Control

Although there are various types of controllers, most of them can be grouped into one of the two broad categories: closed loop and open loop controllers. The subsections below summarize the differentiation.

Closed Loop System

In a closed loop control system, the input variable is adjusted by the controller in order to minimize the error between the measured output variable and its set point. This control design is synonymous to feedback control, in which the deviations between the measured variable and a set point are fed back to the controller to generate appropriate control actions. The controller C takes the difference e between there reference and the output to change the inputs u to the system. This is shown in figure below. The output of the system y is fed back to the sensor, and the measured outputs go to the reference value

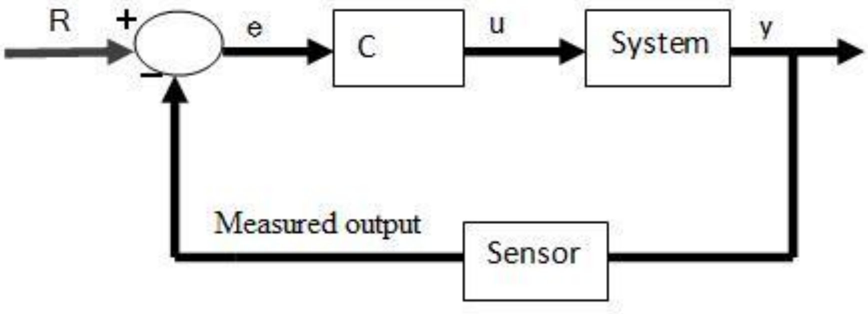

Figure 1.1 close loop system

1.4.1Open Loop System

On the other hand, any control system that does not use feedback information to adjust the process is classified as open loop control. In open loop control, the controller takes in one or several measured variables to generate control actions based on existing equations or models. Consider a CSTR reactor that needs to maintain a set reaction temperature by means of steam flow: A temperature sensor measures the product temperature, and this information is sent to a computer for processing. But instead of outputting a valve setting by using the error in temperature, the computer (controller) simply plugs the information into a predetermined equation to reach output valve setting. In other words, the valve setting is simply a function of product temperature.

Note that the open loop controller only uses the current state of the measured variable (product temperature) and a model to generate its control output (valve setting), as opposed to monitoring errors that have already taken place. As the result, the quality of the control system depends entirely upon the accuracy of the implemented model, which is challenging to develop. For this reason, feedback, or closed loop, controllers are generally recognized as the more reliable control system.

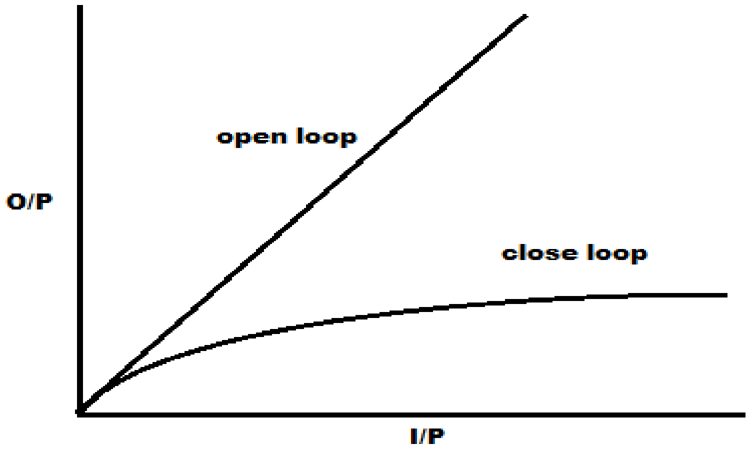

Figure 1.2 Response of open and close loopsystem

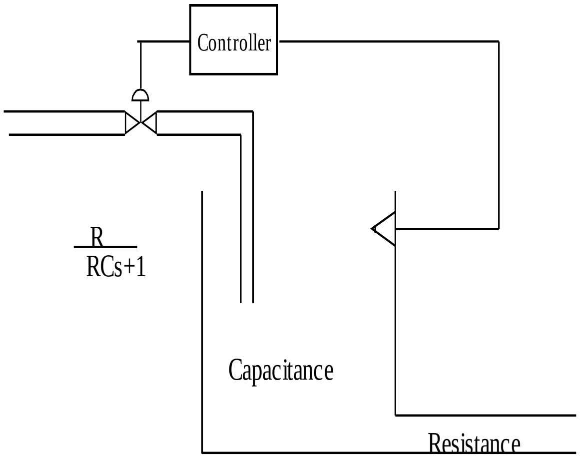

Figure 1.3 CSTR with close loop

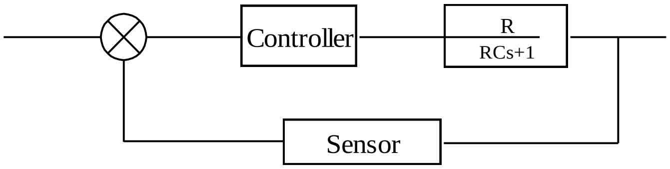

Figure 1.4 Block diagram of Close loop system

There are two main types of feedback control systems:

1. Negative feedback
2. Positive feedback

By definition, negative feedback is when a change (increase/decrease) in some variable results in an opposite change (decrease/increase) in a second variable. This is demonstrated in Figure 3 where a loop represents a variation toward a plus that triggers a correction toward the minus, and vice versa. Negative feedback leads to a tight control situation whereby the corrective action taken by the controller forces the controlled variable toward the set point, thus leading the system to oscillate around equilibrium.

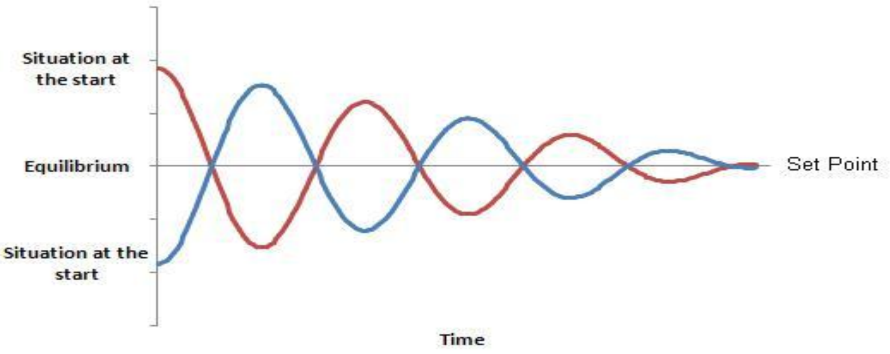

Figure 1.5(a) Response of negative feedback

1.4.2Positive Feedback

As opposed to negative feedback, positive feedback is when a change (increase/decrease) in some variable results in a subsequently similar change (increase/decrease) in a second variable. In some cases, positive feedback leads to an undesirable behavior whereby the system diverges away from equilibrium. This can cause the system to either run away toward infinity, risking an expansion or even an explosion, or run away toward zero, which leads to a total blocking of activities (Figure 5). In a positive feedback control system the set point and output values are added. In a negative feedback control the set point and output values are subtracted. As a rule negative feedback systems are more stable than positive feedback systems. Negative feedback also makes systems more immune to random variations in component values and inputs.

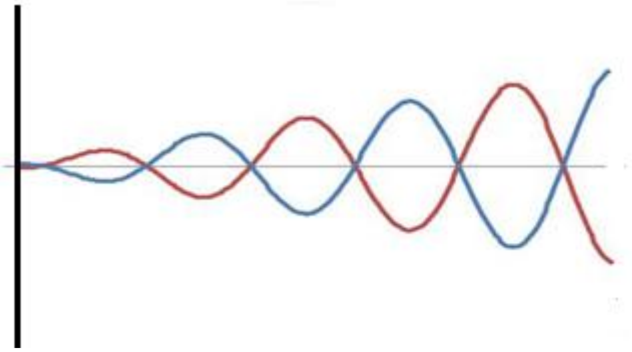

Figure 1.5(b) Response of negative feedback

This summarizes the basic operation of a feedback control system such as one would expect to find carrying out nearly all control operations on chemical plants and indeed in most other circumstances where control is required. The diagram below a feedback control loop. Notice that this extremely simple idea has a number of very convenient properties. The feedback control system seeks to bring the measured quantity to its required value or set point. The control system does not need to know why the measured value is not currently what is required, only that this is so. There are two possible causes of such a disparity:

- The system has been disturbed. This is the common situation for a chemical plant subject to all sorts of external upsets. However, the control system does not need to know what the source of the disturbance was.
- The set point has been changed. In the absence of external disturbance, a change in set point will introduce an error. The control system will act until the measured quantity reaches its new set point.

A control system of this sort should also handle simultaneous changes in set point and disturbances.

1.43 Feedback Control

In feedback control, the variable being controlled that is output is measured and compared with a desired value. This difference between the actual and desired value is called the error. Feedback control manipulates an input to the system to minimize this error. Figure 1.6 shows an overview of a basic feedback control loop. The error in the system is given by

Error= Output - Desired Output.

Here desired output is set point that we need for process.

Feedback control reacts to the system and used to minimize this error. The desired output (set point) is generally entered into the system through a user interface. The output of the system is measured (by respective instrument) and the difference is calculated. Controller will take the action according to error in the system .Feedback is a process in which information about the past or the present influences the same phenomenon in the present or future. As part of a chain of cause-and-effect that forms a circuit or loop, the event is said to *"feedback"* into itself.

Automatic Feedback Control: Output is monitored by using a SENSOR, whose output goes to the *CONTROLLER*, which uses the mathematical model to determine the control input. Usually, the controller is a computer; its output is a low power signal that gets amplified by an ACTUATORto generate the actual control input to the PHYSICAL SYSTE plant (process), the mathematical model is determined together with the process engineers

1.4.4 Advantages of Feedback Control

Not only does the feedback control system require no knowledge of the source or nature of disturbances, but it requires minimal detailed information about how the process itself works.

Feedback control action is entirely empirical, so long as an adjustment is being made in the correct `sense', e.g. more heat means increasing temperature and vice versa, then the control system should remove the effect of an external disturbance.

As we will see, it helps to know more than this, but the minimum information required to make a feedback control system work is whether the adjustment makes the measurement go up or down.

1.4.5 Disadvantages of Feedback Control

The main disadvantage of feedback control is that the disturbance enters into the process and upsets it. It is after the process output is different from the set point that the controller takes some corrective actions. Although most processes allow some fluctuation of controlled variable within a certain range, there are two process conditions which can make the overall effectiveness of feedback control quite unsatisfactory. One of these is the occurrence of disturbances of a large magnitude that is strong enough to seriously affect or even damage the process. The other is the occurrence of a large amount of lag (time delay) within the process. These are discussed further below. The question of importance of either occurrence is defined in economic terms. In either case, the principle concern is the existence of errors that have significant economic consequences in the overall process operation. In these cases, feed forward control can be used to deal with these disadvantages or inadequacies of feedback control. A feedback control system consists of five basic components:

(1) input, (2) process being controlled, (3) output, (4) sensing elements, and (5) controller and actuating devices. A final advantage of feedback control stems from the ability to track the process output and, thus, track the system's overall performance.

1.4.6 Feedback Control

In feedback control, the variable being controlled that is output is measured and compared with a desired value. This difference between the actual and desired value is called the error. Feedback control manipulates an input to the system to minimize this error. Figure 1 shows an overview of a basic feedback control loop. The error in the system is given by

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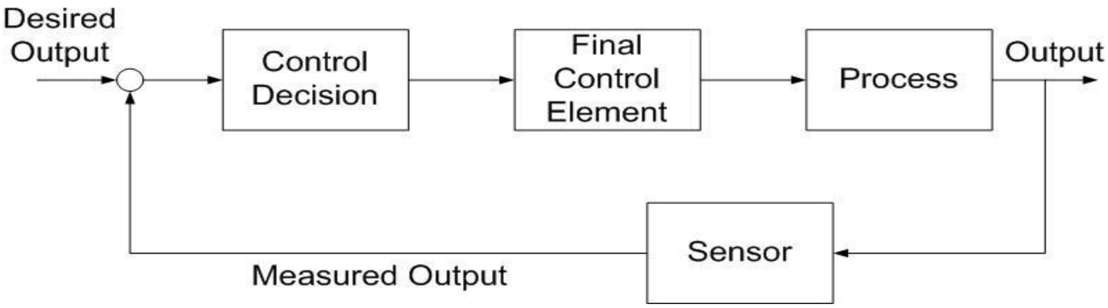


Figure 1.6 Block diagram of close loop system

Automatic Feedback Control: Output is monitored by using a *SENSOR*, whose output goes to the *CONTROLLER*, which uses the mathematical model to determine the control input. Usually, the controller is a computer; its output is a low power signal that gets amplified by an *ACTUATOR* to generate the actual control input to the PHYSICAL SYSTE plant (process), the mathematical model is determined together with the process engineers

1.4.7 Feed forward Control

In this configuration, a sensor or measuring device is used to directly measure the disturbance as it is going to enter the process and the sensor transmits this information to the feed forward controller. The feed forward controller determines the needed change in the manipulated variable, so that, when the effect of the disturbance is combined with the effect of the change in the manipulated variable, there will be no change in the controlled variable at all. The controlled variable is always kept at its set point and hence disturbances have no effect on the process. This perfect compensation is a difficult goal to obtain. It is, however, the objective for which feed forward control is structural. A typical feed forward control loop is shown in the figure below. Another name for feed forward control is open loop control. The reason is that the measured signal goes to the controller parallel to the process. This can be seen in the next figure. This is in contrast to feedback or closed loop control.

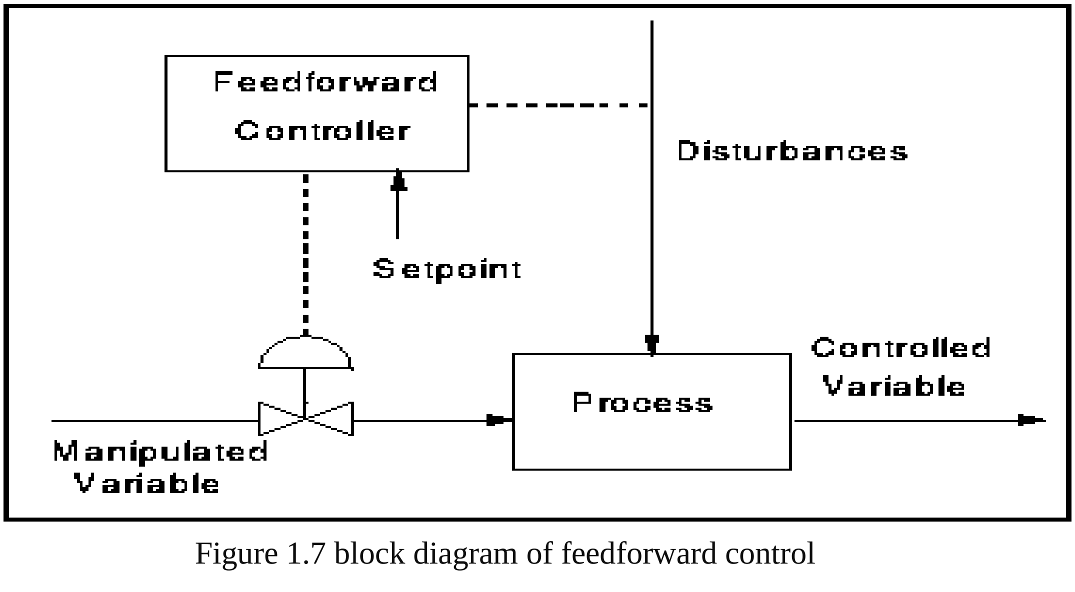


Figure 1.7 block diagram of feedforward control

As mentioned previously the main advantage of feed forward control is that it works to prevent errors from occurring and disturbances have no effect on the process at all. However, there are some significant difficulties.

Complex Computation

The feed forward control computation involves determining exactly how much change in manipulated variable is required for a specific change in disturbance. To be able to make this computation accurately requires significant quantitative understanding of the process and its operation. There is also a tremendous escalation of the theoretical know-how required in the feed forward controller's computation activities.

Knowledge of Process

The structure of feed forward control assumes that :

1. The disturbances are known in advance.
2. The disturbance will have sensors associated with them (measurable).
3. There will not be significant unmeasured disturbances.
4.

- Limitations

  In pure feed forward control, there is no monitoring on the controlled variable. If the controlled variable strays from its set point there is no corrective action to eliminate the error. This makes pure feed forward control somewhat impractical and a rarity in typical process application.

- Specific Controller Required

  The feed forward controller must be specifically and uniquely designed for the one particular control application involved, because of the necessity of accurate and quantitative calculations.

CHAPTER 2

CHEMICAL REACTOR

2.1 Chemical Reactor

A chemical reactor is one of the primary components of a chemical industry used for containing exothermic and endothermic chemical reactions. It is used for the chemical reactions which have heating and cooling of one or more than one chemical**.** In mostof the chemical processes, we use chemical reactors in which chemical reactions takes place. The selection criteria of a chemical reactor deals with multiple aspects of chemical engineering. Chemical engineers design reactors to ensure that the reaction will havegood efficiency and will give desired product at output, producing the highest yield of product.It will require maximum profit and minimum cost. For a chemical reaction we need operating expenses include some form of energy at input like heat, energy change removal, raw material costs, labor, etc. Energy changes can come in the form of heating or cooling, pumping to increase pressure, agitation, etc.Chemical reaction deals with chemical reactors and their design, especially by application of chemical kinetics.

CSTR (Continuous Stirred-Tank Reactor)

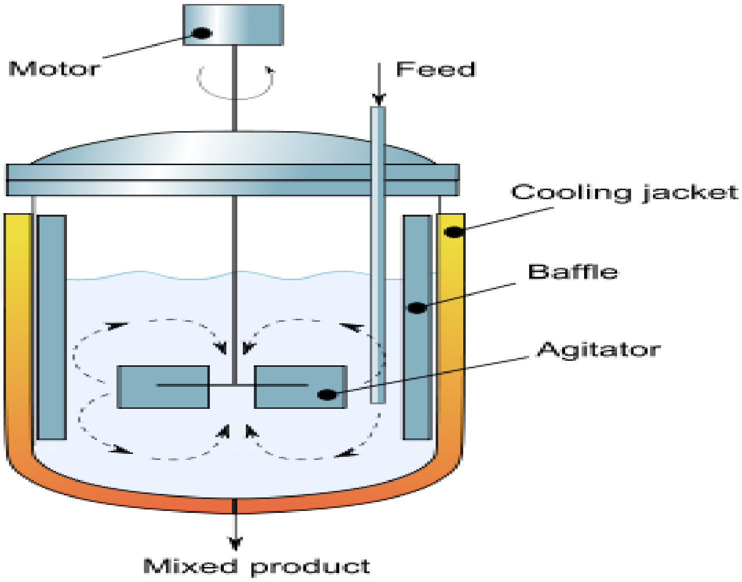


Figure 2.1 Basic diagram of diagram of CSTR

2.2 Types of Chemical Reactor

There are different kinds of reactors such as:

- batch reactor model (batch),
- continuous stirred-tank reactor model (CSTR), and
- Semi batch reactor

Furthermore, catalytic reactors require separate treatment, whether they are batch, CST, or PF reactors, as the many assumptions of the simpler models are not valid.

2.3 Modelling of Chemical Reactor

There are three main basic models used to estimate the most important process variables of different chemical reactors.

Key process variables include:

- Residence time (τ, lower case Greek tau)
- Volume (V)
- Temperature (T)
- Pressure (P)
- Concentrations of chemical species (C_1, C_2, C_3, ... C_n)
- Heat transfer coefficients (h, U)

Continuous reactors (alternatively referred to as flow reactors) carry material as a flowing stream. Reactants are continuously fed into the reactor and emerge as continuous stream of product. Continuous reactors are used for a wide variety of chemical and biological processes within the food, chemical and pharmaceutical industries. A survey of the continuous reactor market will throw up a daunting variety of shapes and types of machine. Beneath this variation however lie a relatively small number of key design features which determine the capabilities of the reactor. When classifying continuous reactors, it can be more helpful to look at these design features rather than the whole system.

As with any type of process equipment, the purpose of classification is to ensure that the best tool is used for the job. It is therefore important to recognize that continuous reactors are part of a larger equipment group which also includes batch reactors. The merits of batch reactors should therefore not be ignored when looking for the optimum solution to a process problem. For this reason, the subject is introduced with a brief summary of the merits of both batch and continuous reactors.Checking condition inside the case of a continuous stirred tank reactor (CSTR).The impeller (or agitator) blades on the shaft for mixingand the baffle at the bottom of the image which also helps in mixing.In a CSTR, one or more fluid reagents are introduced into a tank reactor equipped with an impeller while the reactor effluent is removed. The impeller stirs the reagents to ensure proper mixing. Simply dividing the volume of the tank by the average volumetric flow rate through the tank gives the residence time, or the average amount of time a discrete quantity of reagent spends inside the tank. Using chemical kinetics, the reaction's expected per cent completion can be calculated.In a CSTR, one or more fluid reagents are introduced into a tank reactor equipped with an impeller. The impeller stirs the reagents to ensure proper mixing.Some points of CSTR:

- At steady-state, the flow rate in must equal the mass flow rate out, otherwise the tank will overflow or go empty (transient state).

- The reaction proceeds at the reaction rate associated with the final (output) concentration.
- Often, it is economically beneficial to operate several CSTR in series. This allows, for example, the first CSTR to operate at a higher reagent concentration and therefore a higher reaction rate. In these cases, the sizes of the reactors may be varied in order to minimize the total capital investment required to implement the process.
- It can be seen that an infinite number of infinitely small CSTRs operating in series would be equivalent to a PFR .The behavior of a CSTR is often approximated or modeled by that of a Continuous Ideally Stirred-Tank Reactor (CISTR). All calculations performed with CISTRs assume perfect mixing. If the residence time is 5-10 times the mixing time, this approximation is valid for engineering purposes. The CISTR model is often used to simplify engineering calculations and can be used to describe research reactors. In practice it can only be approached, particularly in industrial size reactors.

2.3.1CSTR with Feedback Control

Several types of feedback control can be used to manipulate the conditions in a CSTR: positive feedback, negative feedback, or a combination of both. Figure 7 illustrates each of these possible situations. As depicted below, each CSTR is equipped with two electrodes that measure the voltage of the solution contained inside the reactor. A computer adjusts the flow rates of the pump(s) in response to any changes in the voltage.

Batch versus continuous

Reactors can be divided into two broad categories, batch reactors and continuous reactors. Batch reactors are stirred tanks sufficiently large to handle the full inventory of a complete batch cycle. In some cases, batch reactors may be operated in semi batch mode where one chemical is charged to the vessel and a second chemical is added slowly. Continuous reactors are generally smaller than batch reactors and handle the product as a flowing stream. Continuous reactors may be designed as pipes with or without baffles or a series of interconnected stages. The advantages of the two options are considered below.

Benefits of batch reactors:

There is a large installed base of batch reactors within industry and their method of use is well established.Batch reactors are excellent at handling difficult materials like slurries or products with a tendency to foul.Batch reactors represent an effective and economic solution for many types of slow reactions.

Benefits of continuous reactors:

The rate of many chemical reactions is dependent on reactant concentration. Continuous reactors are generally able to cope with much higher reactant concentrations due to their superior heat transfer capacities. Plug flow reactors have the additional advantage of greater separation between reactants and products giving a better concentration profile .

Chapter: 3

PID Controller

3.1 On-off or two-position action

It will work in two positions only on and off. When required will be on otherwise off. Depending on the requirement of the water in the tank, the power supply to the heater is either on or off. Advantage of this type of control action is that it is inexpensive and extremely simple. But it is impractical to use on-off control when trying to regulate a variable. It is necessary to have some sort of capacity available .Thus the application of on/off control in industry is severely limited. In most industrial applications continuous control modes, are used. Control Actions.

3.2 Proportional Control

A proportional controller is different from the on off controller in the way it will take action in proportional to the difference between measured and set point. A proportional controller attempts to perform better than the On-off type.Proportional action is the simplest and most commonly encountered of all continuous control modes. In this type of action, the controller produces an output signal which is proportional to the error. Hence, the greater the magnitude of the error, the larger is the corrective action applied. As the gain is increased the system responds faster to changes in set-point but becomes progressively oscillator and more oscillations means unstable. The proportional controller (Kp) reduces the rise time, increases the overshoot, and reduces the steady-state error.Following with transfer function of the system shows how the parameters of proportional controller affect the performance of the system:

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

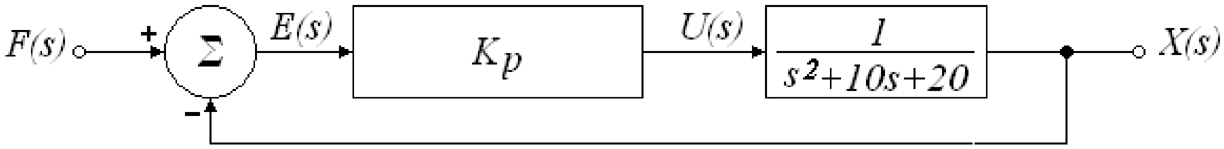


Figure3.1 Block diagram of proportional controller

$$\frac{X(s)}{F(s)} = \frac{\frac{K_p}{s^2+10s+20}}{1+\frac{K_p}{s^2+10s+20}} = \frac{K_p}{s^2+10s+(20+K_p)}$$

- Let Kp=300
- The above plot shows that the proportional controllerreduced both the rise time and the steady-state error, increased the overshoot, and decreased the settling time by small amount.
- Proportional Control - Example
- The proportional controller (K p) reduces the rise time, increases the overshoot, and reduces the steady-state error. For e.g. if transfer function is:
- $$T(s) = \frac{Kp}{s^2 + 10 s + (20 + Kp)}$$
- Kp=300;
- num=[Kp];
- den=[1 10 20+Kp];
- t=0:0.01:2;
- step(num,den,t)

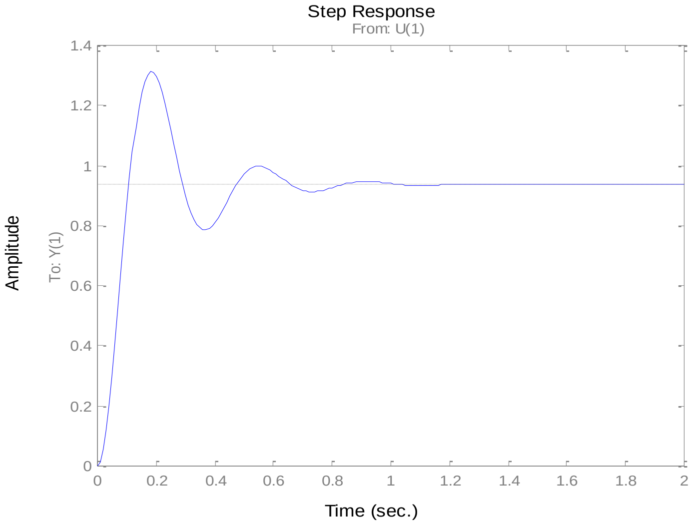


Figure3.2(a) Response with increasing Kp

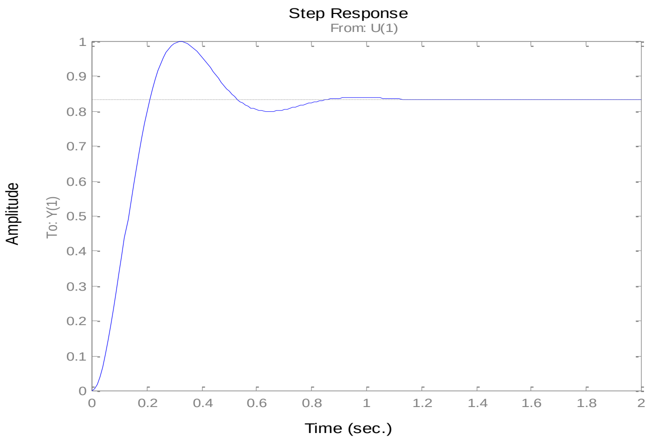


Figure3.2(b) Response with decreasing K_p

3.2.1 P Controller with high gain

- Increasing the proportional feedback gainreduces steady-state errors, but high gains almost always destabilize the system.
- Integral control provides robust reduction in steady-state errors, but often makes the system less stable.
- Derivative control usually increases damping and improves stability, but has almost no effect on the steady state error

Mathematically, proportional control could be expressed as:

$$V = K\epsilon + V_o$$

Where

- V is the adjustment or signal for the adjustment from the controller.
- $\epsilon$is the error.
- $\epsilon = S - L$
- L is the measured value of the controlled variable.
- S is the setpoint.
- K is the proportional constant, named as the gain which shows the sensitivity of the control.
- Vo is the signal output when no error exists.

The gain is often replaced with another parameter, called the proportional band, *PB*. This quantity is defined as the error required moving the final control element over its whole range and is expressed as a percentage of the total range of the measured variableDynamicResponse: Now let's examine the dynamic response of the proportional control. Assume the process is at steady state and the level is at the setpoint. At time = 0, an increase in the inlet flowrate, regarded as a disturbance, enters into the process. If no control action is taken, i.e. the outlet flowrate is not altered; the level (controlled variable) will increase. With proportional control, the level is brought back and maintained in a certain range near the setpoint. The history curve could typically be like that shown below. Different responses are obtained depending on the proportional band, *B*, of the controller. As can be seen the smaller the proportional band the closer to the setpoint the controlled variable becomes but the more oscillatory the response.

The advantages of this type of controller are:

- It is relatively simple and easy to design and tune and It provides good stability
- It responds very rapidly
- Dynamically it is relatively stable

Disadvantages

- Offset: For a sustained change of load, the controlled variable is not returned to the original or desired value, but attains a new equilibrium value termed control point. The difference between the control point and the desired value (set point)is referred to as offset. The reason for this offset with proportional action is that the control action is proportional to the error. Consider the above simple level control system. For the step increase in the flow of liquid into the tank, in order to maintain the level, the valve on the outlet must be opened wider. This will only occur if there is a continuous output from the controller. The output itself can only exist if there is an error signal supplied to the controller. In order to maintain this error, the level will rise above the desired level at the new control point, hence create an offset.

- Overshoot: There is a significant time of oscillation, or in other words, overshoot. Although the period of this oscillation is moderate, this, in some cases, could be highly undesirable.

3.3 Proportional Derivative Control

Derivative control is usually found in combination with proportional control, to form so-called P+D. By adding the derivative action, lead is added in the controller to compensate for lag around the loop, and so P+D can eliminate excessive oscillations. A disadvantage is that it cannot eliminate the offset although somehow it makes it smaller.When gain of the proportional controller is increased then stability and overshoot problems arise .This problem can be solved by adding a term proportional to the time-derivative of the error signal i.e. derivative controller. The value of the damping can be adjusted to achieve a critically damped response. Now, let's take a look at a PD control. The gain of derivative controller (Kd) reduces both the overshoot and the settling time. The closed-loop transfer function of the given system with a PD controller is:

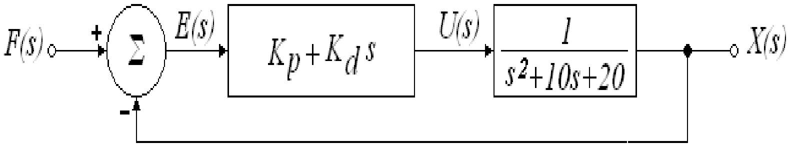


Figure3.3 Block diagram of PD controller

$$\frac{X(s)}{F(s)} = \frac{\dfrac{K_p + K_d s}{s^2 + 10s + 20}}{1 + \dfrac{K_p + K_d s}{s^2 + 10s + 20}} = \frac{K_p + K_d s}{s^2 + (10 + K_d)s + (20 + K_p)}$$

- Let Kp=300,Kd=10

- This plot shows that the proportional derivative controller reduced both the overshoot and the settling time, and had small effect on the rise time and the steady-state error.

- Proportional - Derivative - Example
- The derivative controller (K d) reduces both the overshoot and the settling time.
- $$T(s) = \frac{Kd\cdot s + Kp}{s^2 + (10 + Kd)\cdot s + (20 + Kp)}$$
- K p=300;
- K d=10;
- num=[KdKp];
- den=[1 10+Kd 20+Kp];
- t=0:0.01:2;
- step (num,den,t)

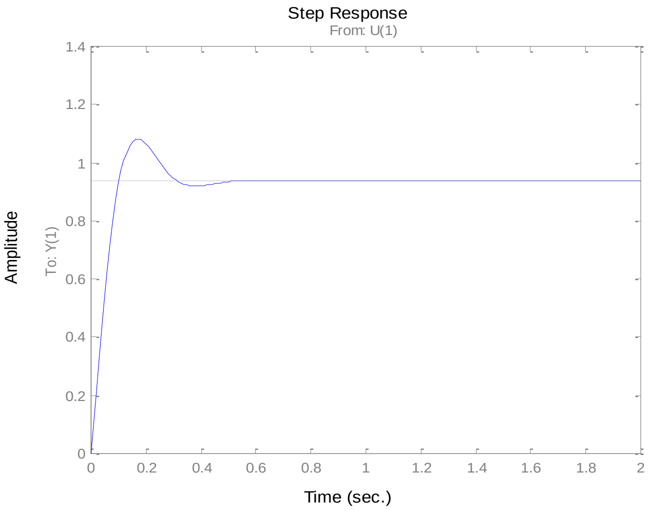


Figure3.4(a)Response of increasing K_d

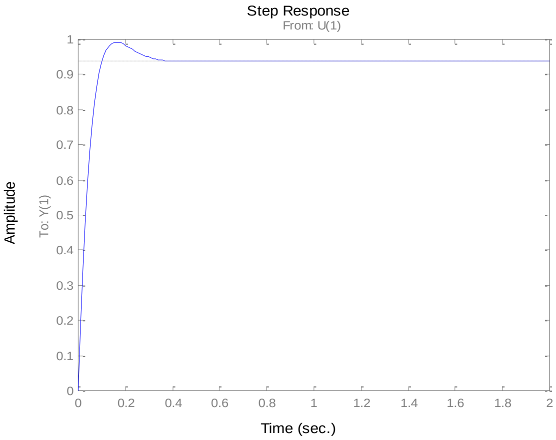


Figure3.4(b) Response of decreasing K_d

3.4 Proportional Integral Controller

The integral controller (Ki) decreases the rise time, increases both the overshoot and the settling time, and eliminates the steady-state error

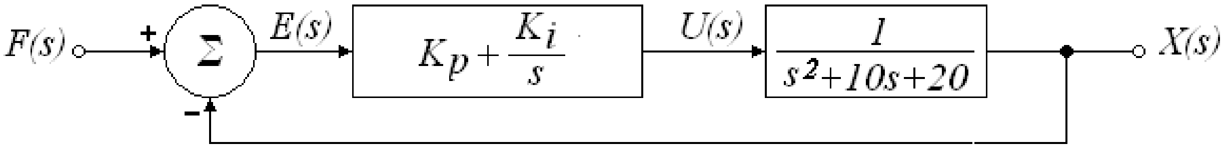


Figure3.5 Block diagram of PI Controller

$$\frac{X(s)}{F(s)}=\frac{\dfrac{K_p+K_i/s}{s^2+10s+20}}{1+\dfrac{K_p+K_i/s}{s^2+10s+20}}=\frac{K_p s+K_i}{s^3+10s^2+(20+K_p)s+K_i}$$

$$T(s)=\frac{Kp\cdot s+Ki}{s^3+10\cdot s^2+(20+Kp)\cdot s+Ki}$$

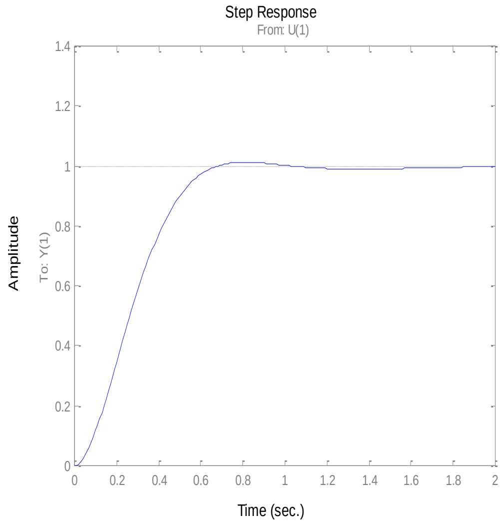
```
Let Kp=30;Ki=70;

num=[Kp Ki];

den=[1 10 20+Kp Ki];

t=0:0.01:2;

step (num,den,t)
```



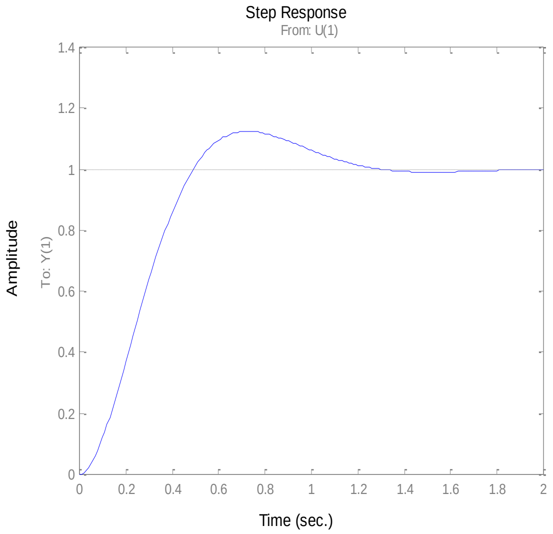


Figure3.6(a)Effect of increasing K_iFigure3.6(b)Effect of decreasing K_i

- We have reduced the proportional gain because the integral controller also *reduces the rise time and increases the overshoot* as the proportional controller does (double effect).
- The above response shows that the *integral controller eliminated the steady-state error*.

3.5 Proportional Integral Derivative Control

Although PD controls overshoot and ringing problems associated with proportional controlbut it does not solve the problem with the steady-state error. Fortunately it is possible to eliminate this while using relatively low gain by adding an integral term to the control function which becomes

$u(t)=K[\ e(t)+ 1/T_i \int e(\tau)\, d\tau + T_d\ de(t)/dt]$

By taking Laplace of the above equation:

$$G_{PID}(s)=\frac{U(s)}{E(s)}=K_p\left(1+\frac{1}{T_i s}+T_d s\right)$$

$$U(s)=K_pE(s)+K_i\frac{1}{s}E(s)+K_dsE(s)$$

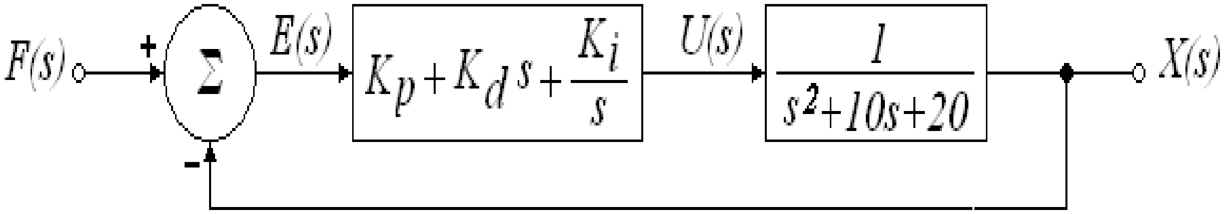


Figure3.7 Block diagram of PID controller

$$\frac{X(s)}{F(s)}=\frac{\dfrac{K_p+K_ds+K_i/s}{s^2+10s+20}}{1+\dfrac{K_p+K_ds+K_i/s}{s^2+10s+20}}=\frac{K_ds^2+K_ps+K_i}{s^3+(10+K_d)s^2+(20+K_p)s+K_i}$$

- Let Kp=350, Ki=300, Kd=5500

- >>num=[5500 350 300];
- >> den=[1 5600 370 300];
- >> step(num,den)

From above result characteristics of P, I, and D controllers are explained in figure 3.8

A proportional controller (Kp) will reduce the rise time, but never eliminate, the steady-state error. An integral control (Ki) will have the effect of eliminating the steady-state error, but it may make the transient response worsethe response becomes more oscillatory and needs longer to settle, the error disappears.

A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Adjustment based on rate of change of errors. 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. Effects of each of controllers Kp, Kd, and Ki on a closed-loop system are summarized in the table shown below.

CL RESPON	**RISE TIME**	**OVERSHOOT**	**SETTLING TIME**	**S-S ERROR**
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small Change	Decrease	Decrease	Small Change

Figure3.8 Effect of various gainson output

Note that these correlations may not be exactly accurate, because Kp, Ki, and Kd are dependent of each other. In fact, changing one of these variables can change the effect of the other two. For this reason, the table should only be used as a reference when you are determining the values for Ki,Kp and Kd.In applications, sometimes the above three action are combined together to set up the proportional plus integral plus derivative action, i.e, P+I+D.

This combined action is able to:

- eliminate the offset due to the existence of integral action
- reduce the maximum deviation and time of oscillation, which is a compromise between the advantage and disadvantage of P+I and P+D
- In applications, sometimes the above three action are combined together to set up the proportional plus integral plus derivative action, i.e. P+I+D.

- A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems – a PID is the most commonly used feedback controller. A PID controller calculates an "error" value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error by adjusting the process control inputs.

- The PID controller calculation (algorithm) involves three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. Heuristically, these values can be interpreted in terms of time's depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change.[1]The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, or the power supplied to a heating element.
- In the absence of knowledge of the underlying process, a PID controller has historically been considered to be the best controller. By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability.
- Some applications may require using only one or two actions to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value due to the control action.
- The mnemonic PID refers to the first letters of the names of the individual terms that make up the standard three-term controller. These are P for the proportional term, I for the integral term and D for the derivative term in the controller. Three-term or PID controllers are probably the most widely used industrial controller. Even complex industrial control systems may comprise a control network whose main control building block is a PID control module. The three-term PID controller has had a long history of use and has survived the changes of technology from the analogue era into the digital computer control system age quite satisfactorily. It was the first (only) controller to be mass produced for the high-volume market that existed in the process industries. Eq(1) shows the time domain equation of ideal PID controller.
- The general form of PID controller is
- $$u(t) = K_c\left(e(t) + \frac{1}{\tau_i}\int_0^t e(t)dt + \tau_d \frac{de(t)}{dt}\right) \quad (1)$$
- $$u(s) = K_c\left(1 + \frac{1}{\tau_i s} + \tau_d s\right)e(s) \qquad (2)$$
- $$u(s) = K_c\left(\frac{1+\tau_i s+\tau_i\tau_d s^2}{\tau_i s}\right)e(s) \qquad (3)$$
- The real PID controller is

$$u(s) = K_c\left(\frac{1+\tau_i s}{\tau_i s}\right)\left(\frac{1+\tau_d s}{1+\alpha\tau_d s}\right)e(s)$$

Usually, initial design values of PID controller obtained by all means needs to be adjusted repeatedly through computer simulations until the closed loop system performs or compromises as desired. This stimulates the development of "intelligent" tools that can assist the engineers to achieve the best overall PID control for entire operating envelops.

The following diagram shows the selection of different terms for the PID controller.

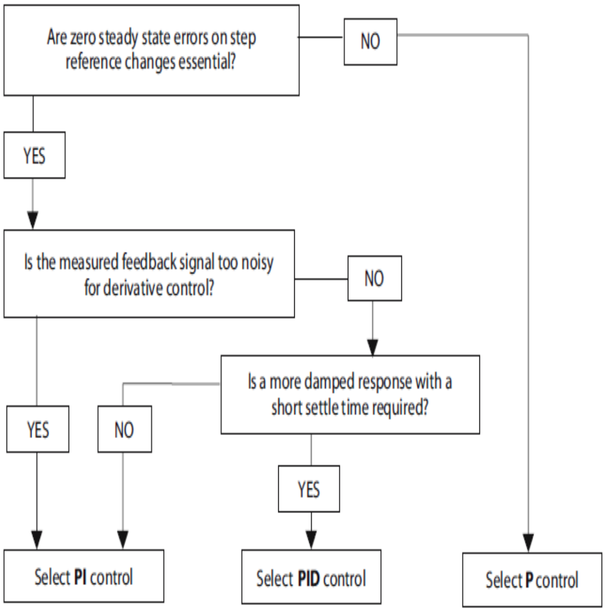


Figure3.9: Selection of different terms in PID controller

To use PID Controller

1. Obtain an open-loop response and determine what needs to be improved
2. Add a proportional control to improve the rise time
3. Add a derivative control to improve the overshoot
4. Add an integral control to eliminate the steady-state error
5. Adjust each of Kp, Ki, and Kd until you obtain a desired overall response.

It is not always necessary to implement all three controllers (proportional, derivative, and integral) into a single system. For example, if a PI controller gives a good enough response (like the above example), then no need to implement derivative controller to the system. Keep the controller as simple as possible.

3.7 The Proportional-Integral-Derivative (PID) algorithm

As the name suggests, the PID algorithm consists of three basic modes, theProportional mode, the Integral and the Derivative modes. When utilizing thisalgorithm it is necessary to decide which modes are to be used (P, I or D)and then specify the parameters (or settings) for each mode used. Generally,three basic algorithms are used P, PI or PID.

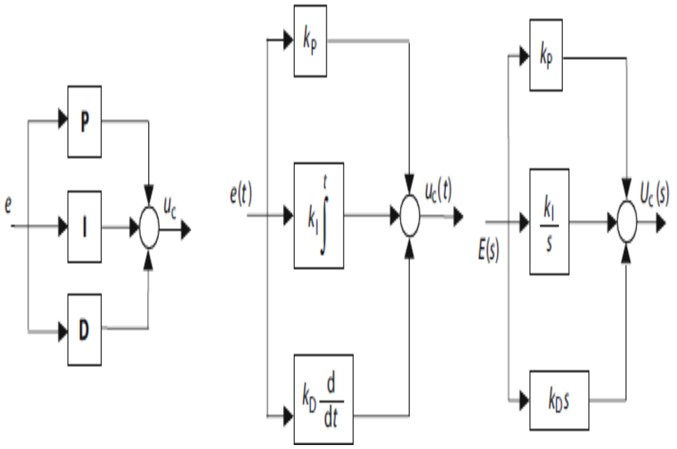


Figure3.10 PID algorithm

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3.7 Controller tuning

Controller tuning involves the selection of the best values of kc, Ti and TD (if aPID algorithm is being used). This is often a subjective procedure and iscertainly process dependent. A number of methods have been proposed inthe literature over the last 50 years. However, recent surveys indicate,30 % of installed controllers operate in manual.30 % of loops increase variability.25 % of loops use default settings.30 % of loops have equipment problems.A possible explanation for this is lack of understanding of process dynamics,lack of understanding of the PID algorithm or lack of knowledge regardingeffective tuning procedures. This section of the notes concentrates on PIDtuning procedures. The suggestion being that if a PID can be properly tunedthere is much scope to improve the operational performance of chemicalprocess plant .When tuning a PID algorithm, generally the aim is to match some preconceived 'ideal' response profile for the closed loop system. All general methods for control design can be applied to PID control. A number of special methods that are tailor made for PID control have also been developed, these methods are often called tuning methods. Irrespective of the method used it is essential to always consider the key elements of control, load disturbances, sensor noise, process uncertainty and reference signals. The most well known tuning methods are those developed by Ziegler and Nichols. They have had a major influence on the practice of PID control for more than half a century. The methods are based on characterization of process dynamics by a few parameters and simple equations for the controller parameters. It is surprising that the methods are so widely referenced because they give moderately good tuning only in restricted situations. Plausible explanations may be the simplicity of the methods and the fact that they can be used for simple student exercises in basic control courses.

3.8.1Ziegler Nichols closed loop method

A recent opinion piece published in the trade magazine Control Engineering proposed that the Ziegler-Nichols tuning rule would serve as the basis for a coming new generation of PID technology: "Improved performance, ease of use, low cost but it seems to us that Ziegler-Nichols tuning is a very limited technology that is unlikely to be successful in that role. The rest of this article will explain why, exploring how to use the rule and where things can go wrong.

3.8.2 Ziegler-Nichols Rule

The Ziegler-Nichols rule is a heuristic PID tuning rule that attempts to produce good values for the three PID gain parameters:

1. Kp - the controller path gain
2. Ti - the controller's integrator time constant
3. Td - the controller's derivative time constant

Given two measured feedback loop parameters derived from measurements:

1. the period Tu of the oscillation frequency at the stability limit
2. the gain margin Ku for loop stability

3.8.3 When to use Ziegler-Nichols

Tuning rules work quite well when you have an analog controller, a system that is linear, monotonic, and sluggish, and a response that is dominated by a single-pole exponential "lag" or something that acts a lot like one.Actual plants are unlikely to have a perfect first-order lag characteristic, but this approximation is reasonable to describe the frequency response rolloff in a majority of cases. Higher-order poles will introduce an extra phase shift, however. Even if they don't affect the shape of the gain rolloff much, the phase shift matters a lot to loop stability. You can't depend upon a single "lag" pole to match both the amplitude rolloff and the phase shift accurately.

So the Ziegler-Nichols model presumes an additional fictional phase adjustment that does not distort the assumed magnitude rolloff. At the stability margin, there is a 180 degree phase shift around the feedback loop (Nyquist's stability criterion). A first order lag can contribute no more than 90 degrees of that phase shift. The rest of the observed phase shift must be covered by the artificial phase adjustment. The phase adjustment is presumed to be a straight line between zero and the critical frequency where 180 degrees of phase shift occurs. A "straight line" phase shift corresponds to a pure time delay. Is this consistent with the actual phase shifts? Well, probably not, so hope for the best.

The model matches the system response at frequencies 0 and at the stability limit, and everything else is more or less made up in between. If the actual system is linear, monotonic, and sluggish, it doesn't make much difference that the model is fake, and results are good enough. If the actual system does not match the assumed model adequately, then sorry, you're on your own.

3.8.5 When to use Ziegler-Nichols

You don't need to determine all of the model parameters to apply Z-N tuning, but if you wanted to do so, here is how you could measure them.Perform a frequency response test on the system, to determine the gain magnitude and the phase shift as a function of frequency. You can take your system offline, attach a signal source, and attach a data acquisition system to measure input and output data sets. Or, if you are smarter about it, you can measure your system response online while the PID loop is operating.

Given the magnitude and phase open-loop response curves of the plant, you can fit the assumed model in the following manner.

1. The ratio of output level to input level at low frequencies determines the gain parameter `K` of the model.
2. Observe the frequency F_u at which the phase passes through -pi radians (-180 degrees). The inverse of this frequency is the period of the oscillation, T_u.
3. Observe the plant gain K_c that occurs at the critical oscillation frequency F_u. The inverse of this is the gain margin K_u.
4. Apply the frequency F_u to the plant first order lag terms to solve for the model's `a` term.

$$a \quad = \quad \sqrt{K^2 \cdot K_u{}^2 - 4\,\pi \cdot F_u{}^2}$$

5. Evaluate the phase shift of the lag stage by substituting F_u into the first-order lag model.

$$\phi \quad = \quad -\tan^{-1}\left(2\,\pi \cdot \frac{F_u}{a}\right)$$

6. The rest of the 180 degrees of phase shift are assigned to the pure time delay term.

$$T = \frac{(-\pi - \phi)}{2\pi \cdot F_u}$$

3.8.5 Applying the Tuning Rule

Use the values of K_u and T_u to determine values of PID gain setting according to the following tuning rule table.

Rule Name	Tuning Parameters
Classic Ziegler-Nichols	Kp = 0.6 Ku Ti = 0.5 Tu Td = 0.125 Tu
Pessen Integral Rule	Kp = 0.7 Ku Ti = 0.4 Tu Td = 0.15 Tu
Some Overshoot	Kp = 0.33 Ku Ti = 0.5 Tu Td = 0.33 Tu
No Overshoot	Kp = 0.2 Ku Ti = 0.5 Tu Td = 0.33 Tu

Figure 2.19

The formula to calculate proportional value and integral and derivative value is :

$$P = \frac{1.5 \cdot T}{K \cdot d} \qquad T_I = 2.5 \cdot d \qquad T_D = 0.4 \cdot d$$

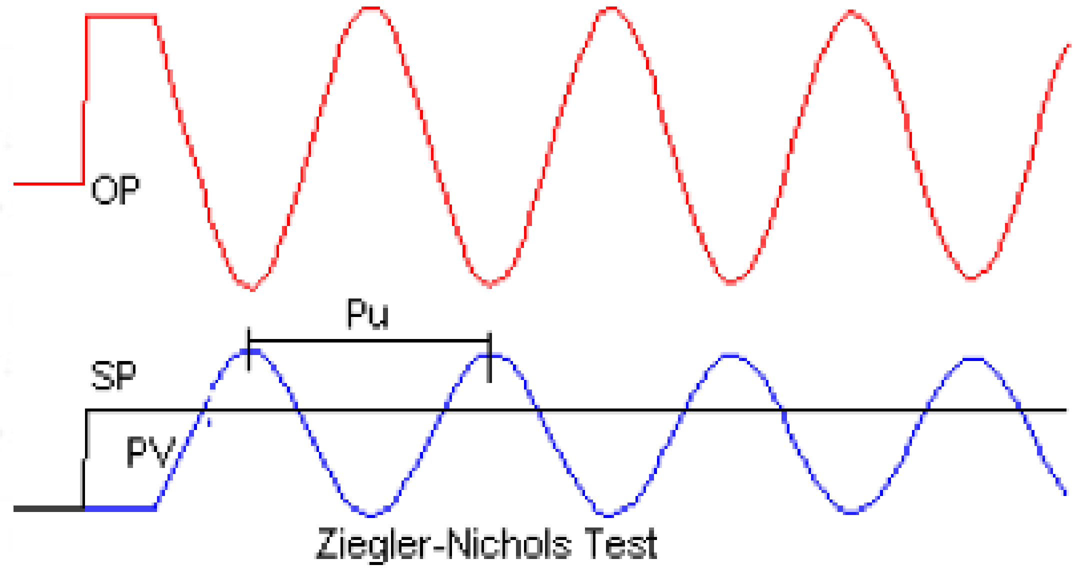

Figure 3.12 Ku and Tu calculations

1. Disable D and I action (pure P control).
2. Make a step change to the setpoint.
3. Repeat, adjusting controller gain until achieving a stable oscillation.

The method is straightforward. First, set the controller to P mode only. Next, set the gain of the controller (kc) to a small value. Make a small setpoint (orload) change and observe the response of the controlled variable. If kc is lowthe response should be sluggish. Increase kc by a factor of two and makeanother small change in the setpoint or the load. Keep increasing kc (by afactor of two) until the response becomes oscillatory. Finally, adjust kc until aresponse is obtained that produces continuous oscillations. This is known asthe ultimate gain (ku). Note the period of the oscillations (Pu). The control lawsettings are then obtained from the following tablePractical use of the techniqueIt is unwise to force the system into a situation where there are continuous Oscillations as this represents the limit at which the feedback system is stableGenerally, it is a good idea to stop at the point where some oscillation hasbeen obtained.

Chapter 4

Fuzzy Logic

Fuzzy logic is widely used in machine control. Fuzzy logic is a form of logic that is the extension of boolean logic, which incorporates partial values of truth. Instead of sentences being "completely true" or "completely false," they are assigned a value that represents their degree of truth. In fuzzy systems, values are indicated by a number (called a truth value) in the range from 0 to 1, where 0.0 represents absolute false and 1.0 represents absolute truth. Fuzzification is the generalization of any theory from discrete to continuous. Fuzzy logic is important to artificial intelligence because they allow computers to answer ‘to a certain degree’ as opposed to in one extreme or the other. In this sense, computers are allowed to think more 'human-like' since almost nothing in our perception is extreme, but is true only to a certain degree. Through fuzzy logic, machines can think in degrees, solve problems when there is no simple mathematical model. It solves problems for highly nonlinear processes and uses expert knowledge to make decisions. Fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller. This makes it easier to mechanize tasks that are already successfully performed by humans.

4.1 History and applications

Fuzzy logic was first proposed by Lotfi A. Zadeh of the University of California at Berkeley in a 1965 paper. He elaborated on his ideas in a 1973 paper that introduced the concept of "linguistic variables", which in this article equates to a variable defined as a fuzzy set. Other research followed, with the first industrial application, a cement kiln built in Denmark, coming on line in 1975.Following such demonstrations, Japanese engineers developed a wide range of fuzzy systems for both industrial and consumer applications. In 1988 Japan established the Laboratory for International Fuzzy Engineering (LIFE), a cooperative arrangement between 48 companies to pursue fuzzy research.

Fuzzylogic is a form of many-valued logic or probabilistic logic; it deals with reasoning that is approximate rather than fixed and exact. In contrast with traditional logic theory, where binary sets have two-valued logic: true or false, fuzzy logic variables is not having only these two values but have many values ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, in fuzzy logics we use some variables to specify a quantity that are called linguistic variables. When linguistic variables are used, these degrees may be managed by specific functions. Table is given below for this.

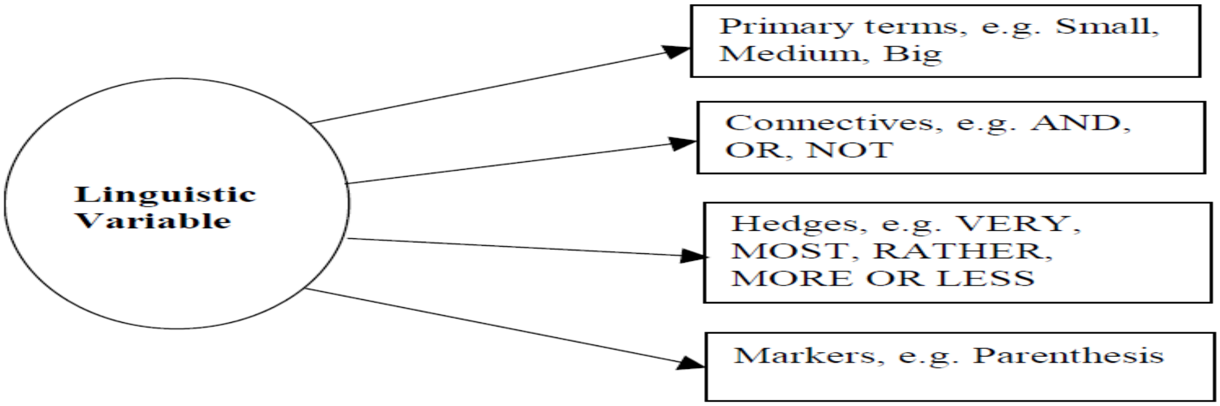

Figure4.1 Linguistic variables

The input variables in a fuzzy control system are in general mapped into by sets of membership functions similar to this, known as "fuzzy sets". The process of converting a crisp input value to a fuzzy value is called "fuzzification".Some parameters related to the fuzzy logic are given below:

- Degree of membership: degree to which a crisp value is compatible to a membership function, value from 0 to 1, also known as truth value or fuzzy input.
- Membership function, MF: defines a fuzzy set by mapping crisp values from its domain to the sets associated degree of membership.
- Crisp inputs: It is like to only represent two vales mostly 1 or 0.Distinct or exact inputs to a certain system variable, usually measured parameters external from the control system, e.g. 6 Volts.
- Label: descriptive name used to identify a membership function.

- Scope: Domain, the width of the membership function, the range of concepts, usually numbers, over which a membership function is mapped.
- Universe of discourse: range of all possible values, or concepts, applicable to a system variable.
- Given "mappings" of input variables into membership functions and truth valuesthe fuzzy logic controller then makes decisions for what action to take based on a set of "rules", each of the form:

Fuzzy Linguistic Variables are used to represent qualities spanning a particular spectrum. Fore.g. If variable cold is used then there it is not clear how much cold is this then linguistic variables are used to represent this.

- Temp: {Freezing, Cool, Warm, Hot} we can represent freezing as very cold.

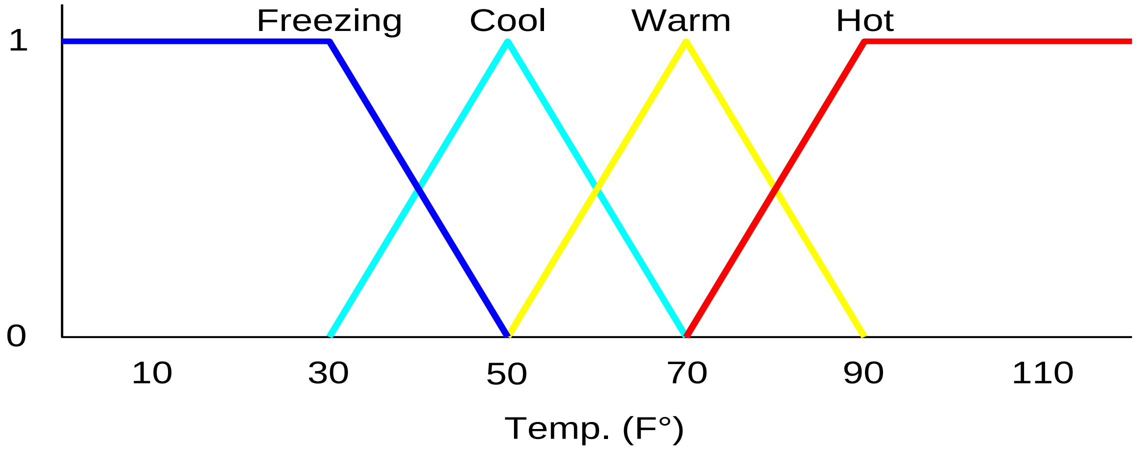

Figure4.2Use of linguistic variables

A fuzzy set is defined for the input error variable "e", and the derived change in error, "delta", as well as the "output", as follows: These rules are typical for control applications in that the antecedents consist of the logical combination of the error and error-delta (change in error) signals, while the consequent is a control command output. The rule outputs can be defuzzified using various defuzzification:

Traditional control systems are based on mathematical models in which the control system is described using one or more differential equations that define the system response to its inputs. Such systems are often implemented as "PID controllers" (proportional-integral-derivative controllers). They are the products of decades of development and theoretical analysis, and are highly effective.If PID and other traditional control systems are so well-developed, why bother with fuzzy control? It has some advantages. In many cases, the mathematical model of the control process may not exist, or may be too "expensive" in terms of computer processing power and memory, and a system based on empirical rules may be more effective.

Furthermore, fuzzy logic is well suited to low-cost implementations based on cheap sensors, low-resolution analog-to-digital converters, and 4-bit or 8-bit one-chip microcontroller chips. Such systems can be easily upgraded by adding new rules to improve performance or add new features. In many cases, fuzzy control can be used to improve existing traditional controller systems by adding an extra layer of intelligence to the current control method. By adding rules we can change the system.

4.2 Fuzzy control in detail

Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs, such as switches, thumbwheels, and so on, to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value.

The most common shape of membership functions is triangular, although trapezoidal and bell curves are also used, but the shape is generally less important than the number of curves and their placement. From three to seven curves are generally appropriate to cover the required range of an input value, or the "universe of discourse" in fuzzy jargon. As discussed earlier, the processing stage is based on a collection of logic rules in the form of IF-THEN statements, where the IF part is called the "antecedent" and the THEN part is called the "consequent". Typical fuzzy control systems have dozens of rules.

In practice, the controller accepts the inputs and maps them into their membership functions and truth values. These mappings are then fed into the rules. If the rule specifies an AND relationship between the mappings of the two input variables, as the examples above do, the minimum of the two is used as the combined truth value; if an OR is specified, the maximum is used. The appropriate output state is selected and assigned a membership value at the truth level of the premise. The truth values are then defuzzified. For an example, assume the temperature is in the "cool" state, and the pressure is in the "low" and "ok" states. The pressure values ensure that only rules 2 and 3 fire:

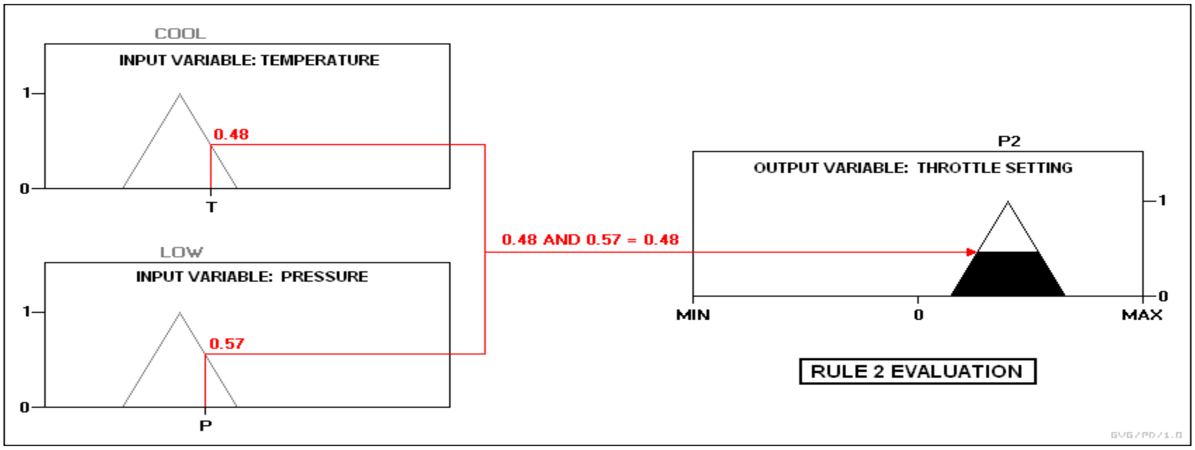

Figure4.3 Decision based on rulesin fuzzy

With this scheme, the input variable's state no longer jumps abruptly from one state to the next. Instead, as the temperature changes, it loses value in one membership function while gaining value in the next. In other words, its ranking in the category of cold decreases as it becomes more highly ranked in the warmer category.At any sampled timeframe, the "truth value" of the brake temperature will almost always be in some degree part of two membership functions: i.e.: '0.6 nominal and 0.4 warm', or '0.7 nominal and 0.3 cool', and so on. The above example demonstrates a simple application, using the abstraction of values from multiple values. This only represents one kind of data, however, in this case, temperature. Adding additional sophistication to this braking system could be done by additional factors such as traction, speed, inertia, set up in dynamic functions, according to the designed fuzzy system.

4.3 Logical interpretation of fuzzy control

Where:

Errore(t)
Change in error Δe(t)
Controller output u(t)
NB is negative big
NS is negative small
NM is negative medium
ZO is zero
PS positive small
PB positive big
PM is positive medium

U(t)		Error						
Change in error		NB	NM	NS	ZO	PS	PM	PB
	NB	NB	NB	NB	NB	NM	NS	ZO
	NM	NB	NB	NB	NM	NS	ZO	PS
	NS	NB	NB	NM	NS	NS	PS	PS
	ZO	NB	NM	NS	ZO	ZO	PM	PM
	PS	NM	NS	ZO	PS	PS	PB	PB
	PM	NS	ZO	PS	PM	PM	PB	PB
	PB	ZO	PS	PM	PB	PB	PB	PB

Figure 4.4 Fuzzy Rules matrix

Chapter 5

Case Study

Performances indices on which we can analyse system are givenbelow. These always exist in dynamic type systems .Most of the systems to that we deals are dynamic in nature. In the following diagram all these parameters are explained. In this case study 5 parameters are taken to evaluate the best controller.

5.1 Parameters to analyse the dynamic response of a system

Some parameters that were needed to analyse the best controller are explained in this case study are given below. These are the performance indices to evaluate the performance of the controller.

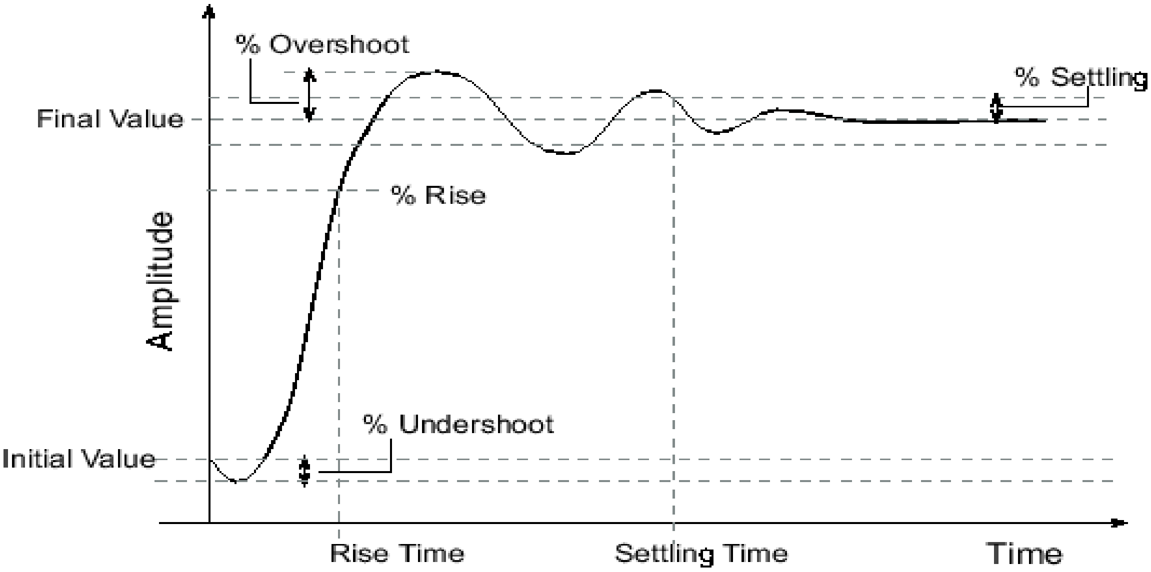

Figure 5.11 various parameters of system stability

Decay ratio: this is the ratio of the maximum amplitude of successive oscillations.

Overshoot: It is measure of deviation of response from its ultimate value .When step input is given to check the behaviour of the system. It is not same as given at input deviating from input is overshoot .Basically first overshoot is measured because after first overshoot the system will tend to stable. . 5/10% overshoot is normally acceptable for most loops. First overshoot will always be of highest magnitude. Its formula is given as:

Peak Overshoot: $\% M_p = \frac{c(t_p) - c(\infty)}{c(\infty)} * 100\%$

$$overshoot = \exp(\frac{\Pi\xi}{\sqrt{1-\xi^2}})$$

Where ξ is damping factor whose value will decide the type of system.

Peak Time: Peak time is defined as the time required reaching the peak of the unit step response.
Rise time (t_r): It is the time taken by the system to reach its first required value. Its value depends on the value of damping factor if its value is increased system will be slow and rise time will increased.
Settling Time: It is the time required for the response to reach and stay within a specified tolerance band of its final value. The tolerance band is taken randomly as 5%.As the value of damping decreased settling time will also increased because the system will be oscillatory will not be settled easily as oscillation will decreased and system will settle after delay of time. Table 1 shows the comparative overview of different transient domain parameters like peak overshoot, peak time and settling time of feedback and feedback plus feed forward controller.
Criteria to choose good controller: Some concepts are clear when the system is system for e.g. When decay ratio is ¼.System is often considered as satisfactory response. Similarly there are some other criteria's of errors given below:

5.1.1 Error Weighting for Performance Assessment

The tuning of different parameters in a controller is not exact and is usually a compromise that is largely dependent on the process being controlled. There are a few methods used to evaluate and compare the control performance for different parameters. One method is using quantitative performance statistics for dynamic process simulations. This type of performance assessment is usually used in an academic research environment and uses different criteria to minimize the value of error from the set point.

Where:

Integral Absolute Error (IAE) – Use for systems that need to suppress all errors equally

$$IAE = \int_{0}^{\infty} \left| e(t) \right| dt$$

Integral Square Error (ISE) – Use for systems where large errors are problematic

$$ISE = \int_{0}^{\infty} e^{2}(t) dt$$

By taking the square of the error, this method will favor parameters that prevent large deviations from the set point.

Integral Time Absolute Error (ITAE) – Use for systems where persistent errors are problematic

By multiplying the deviations by the time at which they occur, this method will favor parameters that quickly force the response to the set point.

Integral Time Square Error (ITSE) – Use for systems where persistent large errors are problematic

A second method, commonly used in industry, uses the deviation from the set point to assess the variability of the final product. The less variability there is, the better the control performance.

From the above discussions, it is clear that feed forward plus feedback controller is a better controller, rather than feedback controller, when temperature control of reactor system is concerned.

5.2 Case Study

The chemical processes are usually require precise control .Each parameter require accuracy to prepare chemical .In this thesis various parameters are controlled with controller when chemical is prepared. In this case study three main steps are highlighted when chemical is prepared. Various chemicals are mixed in a proper concentration .It means first step is to take care of concentration. When required concentration of chemicals is met it is mixed properly in CSTR (The stir is rotated with the some type of actuator) or heated at a specified temperature. In this work temperature and concentration and temperature are controlled by using various controllers PID and FLC .At the end results are compared FLC gives better results. The mathematical model is prepared by converting each part of the process into its transfer function.

5.2.1 Temperature control

Temperature control is one of key functions of a chemical reactor. If temperature is not controlled properlythen it can severely affect both yield and product quality .Too much or too less temperature cannotproduce the required yield and too much high temperature can be dangerous for the system. In a batch reactor, good temperature control is achieved when the heat added or removed by the heat exchange surface equals the heat generated or absorbed by the process material. Controlling the outlet temperature does not prevent hot/cold spots within the reactor. Overheating/overcooling is prevented by the limited temperature difference between the product and heat transfer fluid. The feedback signal for controlling the process temperature can be the product temperature or the heat transfer fluid temperature. It is often more practical to control the temperature of the heat transfer fluid.

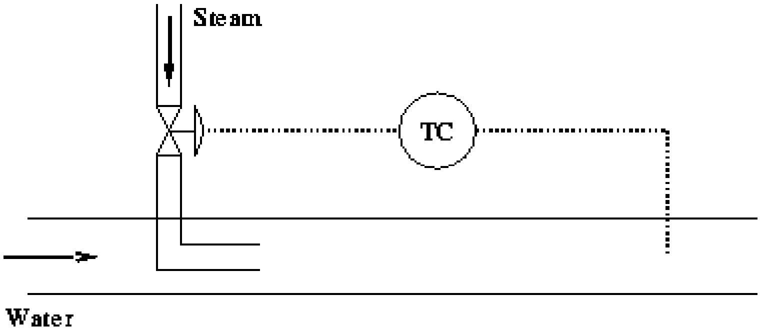

Figure 5.1 Temperature control strategy

Flow Control

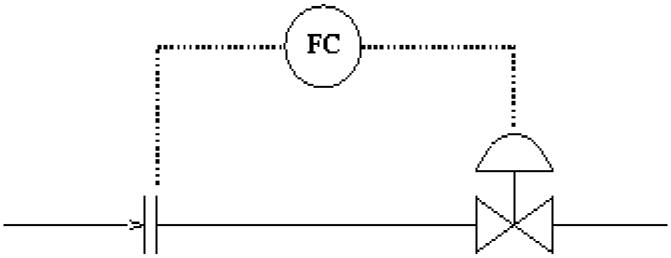

Figure5.2 Flow control strategy

5.3 Mixing with agitator

Mixing is another important classifying feature for continuous reactors. Good mixing improves the efficiency of heat and mass transfer. In terms of trajectory through the reactor, the ideal flow condition for a continuous reactor is plug flow (since this delivers uniform residence time within the reactor). There is however a measure of conflict between good mixing and plug flow since mixing generates axial as well as radial movement of the fluid. In tube type reactors (with or without static mixing), adequate mixing can be achieved without seriously compromising plug flow. For this reason, these types of reactor are sometimes referred to as plug flow reactors.

Mechanical agitator in CSTR

Some continuous reactors use mechanical agitation for mixing (rather than the product transfer pump). Whilst this adds complexity to the reactor design, it offers significant advantages in terms of versatility and performance. With independent agitation, efficient mixing can be maintained irrespective of product throughput or viscosity. It also eliminates the need for long flow channels and high pressure drops. One less desirable feature associated with mechanical agitators is the strong axial mixing they generate. This problem can be managed by breaking up the reactor into a series of mixed stages separated by small plug flow channels. So most familiar form of continuous reactor of this type is the continuously stirred tank reactor (CSTR). The disadvantage with a single stage CSTR is that it can be relatively wasteful on product during start up and shutdown. The reactants are also added to a mixture which is rich in product. For some types of process, this can have an impact on quality and yield. These problems are managed by using multi stage CSTRs. At the large scale, conventional batch reactors can be used for the CSTR stages.

Chemical plants are intended to be operated under known and specified conditions to obtain the required specifications. There are several reasons why this is so: A chemical plant might be thought of as a collection of tanks in which materials are heated, cooled and reacted, and of pipes through which they flow. Such a system will not, in general, naturally maintain itself in a state such that precisely the temperature required by a reaction is achieved, a pressure in excess of the safe limits of all vessels be avoided, or a flow rate just sufficient to achieve the economically optimum product composition arise.

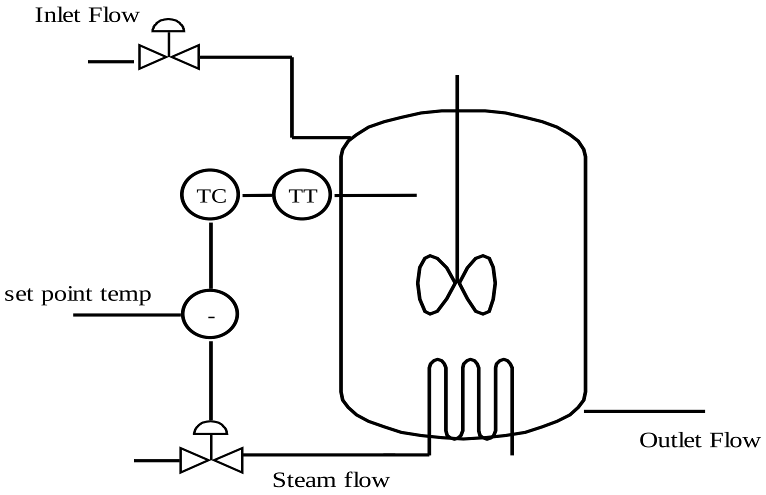

Figure 5.4: Schematic diagram of reactor system

The control objective can be achieved by implementing different control loops. The control loops which can be implemented in this process are feedback control loop, feed forward control loop, combination of feedback and feed forward control loop and cascade control loop. In this feedback control loop the controller is reverse acting, the valve used is of air to open (fail close) type. A thermocouple is used as the sensing element which is implemented in the feedback path of the control architecture. The temperature of the outgoing fluid is measured by the thermocouple and the output of the thermocouple (voltage) is sent to the transmitter unit, which eventually converts the temperature output to a standardized signal in the range of 4-20 m A. This output of the transmitter unit is given to the controller unit.

5.4 Problem Formulation

Mathematical model of CSTR: A CSTR is having area A and height h .A valve isthere at the output of the tank which restricts the flow at output and will provide resistance R.

$$q=\frac{h}{R}$$

Differential equations can be evaluated by using mass balance equation as following:

Mass flow in-mass flow out=rate of accumulation of mass of liquid in tank ……………..eqn. 1

Now density=mass/volume

$\rho=M/V$ and $M=V\rho$

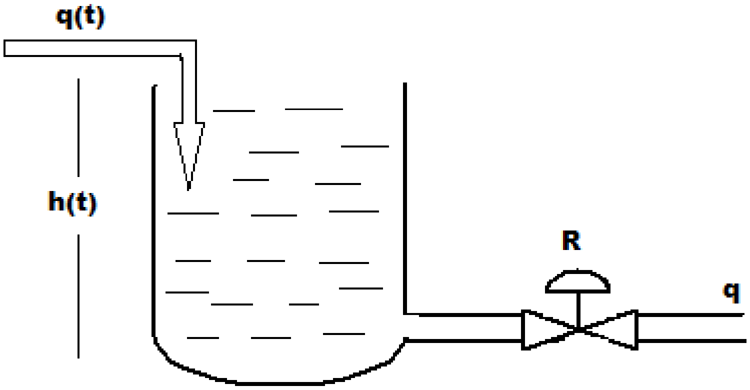

Figure5.5 Mathematical model of CSTR

Using equation 1

q(t)ρ-q$_0$(t)ρ=$\frac{d(A\rho h)}{dt}$

q(t)ρ-q $_0$ (t)ρ = A ρ $\frac{dh}{dt}$

q(t)-q $_0$ (t) =A $\frac{dh}{dt}$

q(t)-q $_0$ (t) =A $\frac{dh}{dt}$

q(t)- $\frac{h}{R}$ = A $\frac{dh}{dt}$

Taking Laplace transform on both sides:

Q(s)=$\frac{H(s)}{R}$ +As H(s)

Q(s)=H(s) [$\frac{1}{R}$ +As]

$\frac{Q(s)}{H(s)}=\frac{1}{R}$ +As

$$\frac{Q(s)}{H(s)}=\frac{ARs+1}{R}$$

Now time constant of the system is τ=RC

$\frac{H(s)}{Q(s)}=\frac{R}{ARs+1}$ is transfer function of the CSTR.This is how mathematical modelling of a system is done

System dynamics and mathematical model of each and every part of the system is obtained by experimental data. Transfer functions of CSTR, sensor, disturbances are shown below.

Q(s) is input it may be step, impulse or ramp for e.g. Impulse means high magnitude and short time. i.ehigh volume of liquid may be pouring quickly(in very short time) a volume of liquid in to tank.

Transfer function of flow sensor: $\frac{0.1}{5s+1}$

Transfer function for pressure disturbance: $\frac{1}{20s+1}$

Transfer function for flow disturbance: $\frac{2}{20s+1}$

Transfer function of I/P convertor: 0.75

Feedback Control

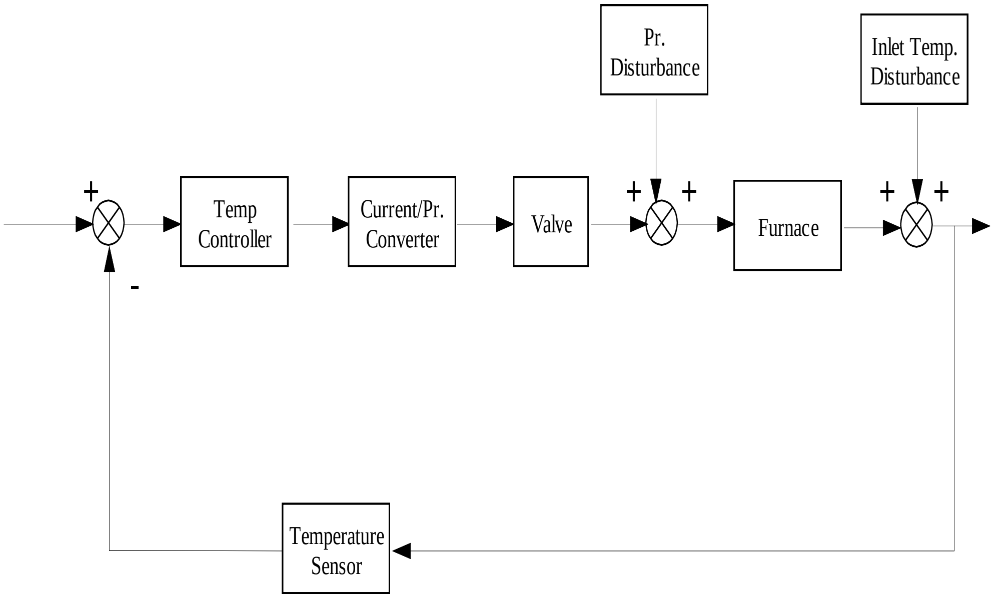

Figure 5.6: Block Diagram Approach of Feedback Control

To control the temperature feedback control is employed and PID controller is used as the controlling element. The general block diagram approach of feedback controller is shown below.

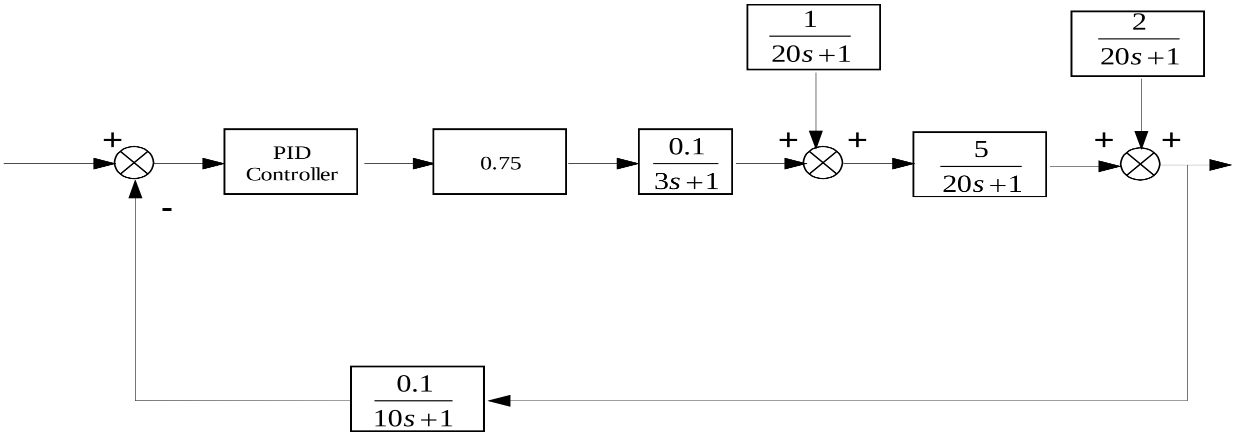

Figure 5.6(a): Transfer Function Approach of Feedback Control

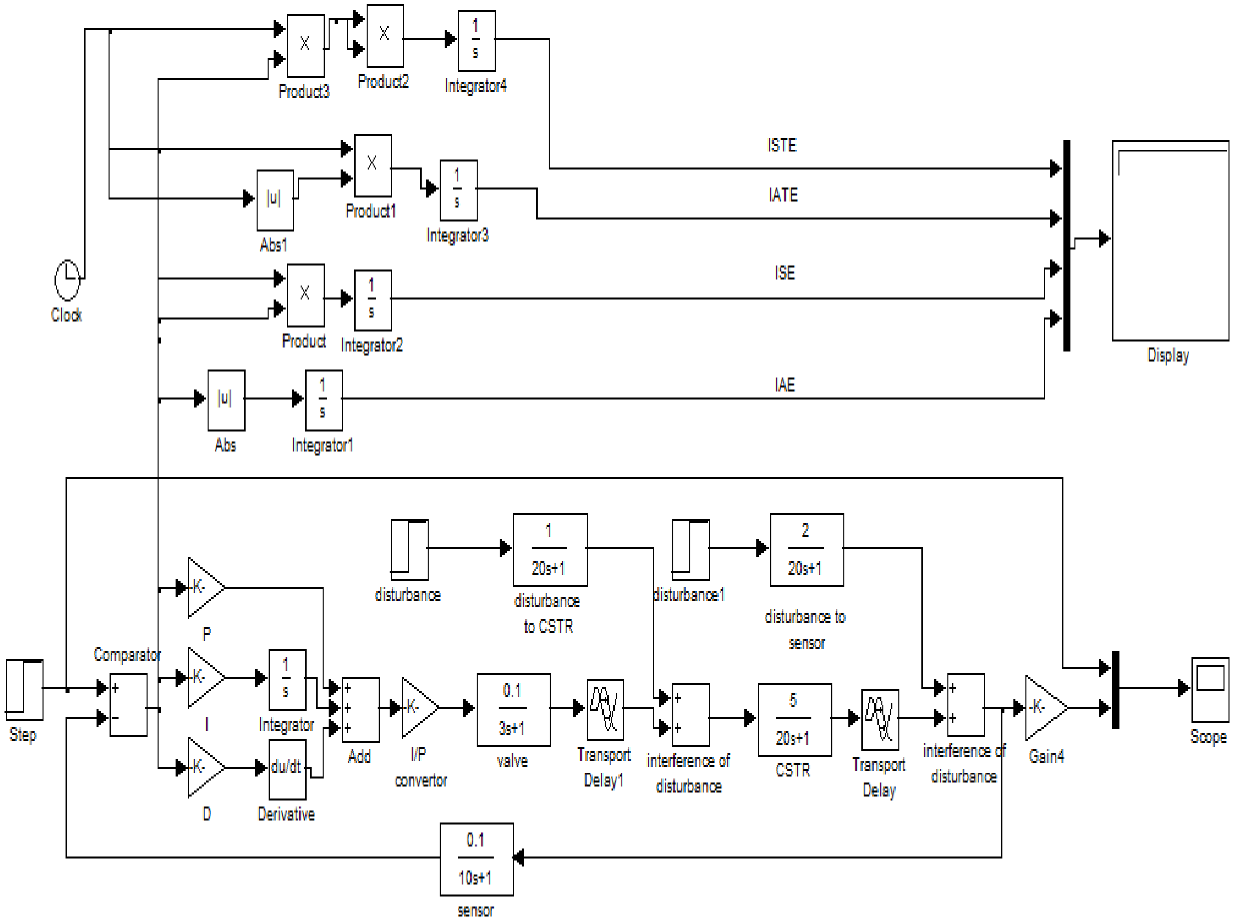

Figure5.6(b) Simulation of CSTR in feedback control using PID

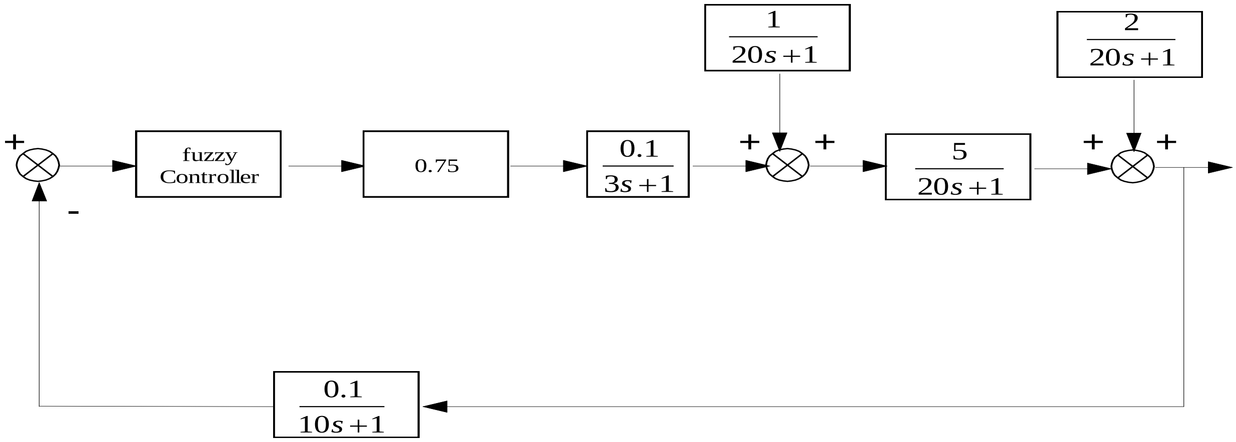

Figure5.7 block diagram of CSTR parametercontrol using fuzzy logic controller

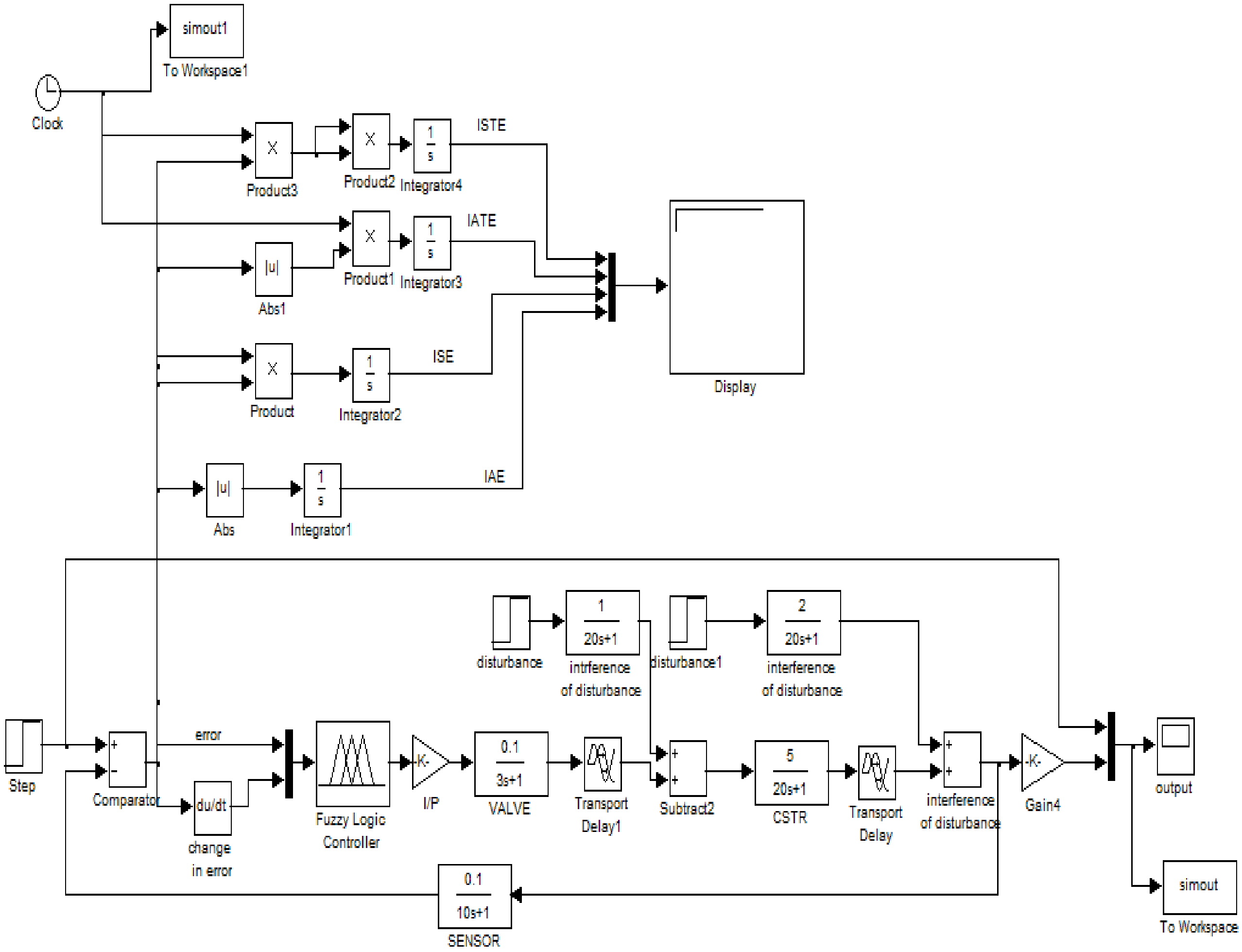

Figure 5.7(a) Simulation of CSTR parameters control using fuzzy logic

5.5 Feedback and Feed forward Controller

If we use both feed forward and feedback control, it can significantly improve performance over simple feedback control whenever there is a major disturbance that can be measured before it affects the process output. In the most ideal situation, feed forward control can entirely eliminate the effect of the measured disturbance on the process output. Even when there are modelling errors, feed forward control can often reduce the effect of the measureddisturbance on the output better than that achievable by feedback control alone. However, to decide whether to use feed forward control or not depends on whether the degree of improvement in the response to the measured disturbance. Feed forward control is always used along with feedback control because a feedback control system is required to track set point changes and to suppress unmeasured disturbances that are always present in any real process. The feed forward part of the control system does not affect the stability of the feedback system and that each system can be designed independently. The continuously stirred tank reactor is under feedback temperature control. Feed forward control is used to rapidly suppress feed flow rate disturbances.

Due to inherent disadvantages of feedback controller, feed forward controller is used. Feed forward controller, estimates the probable error criteria and tries to remove the error, before it occurs.

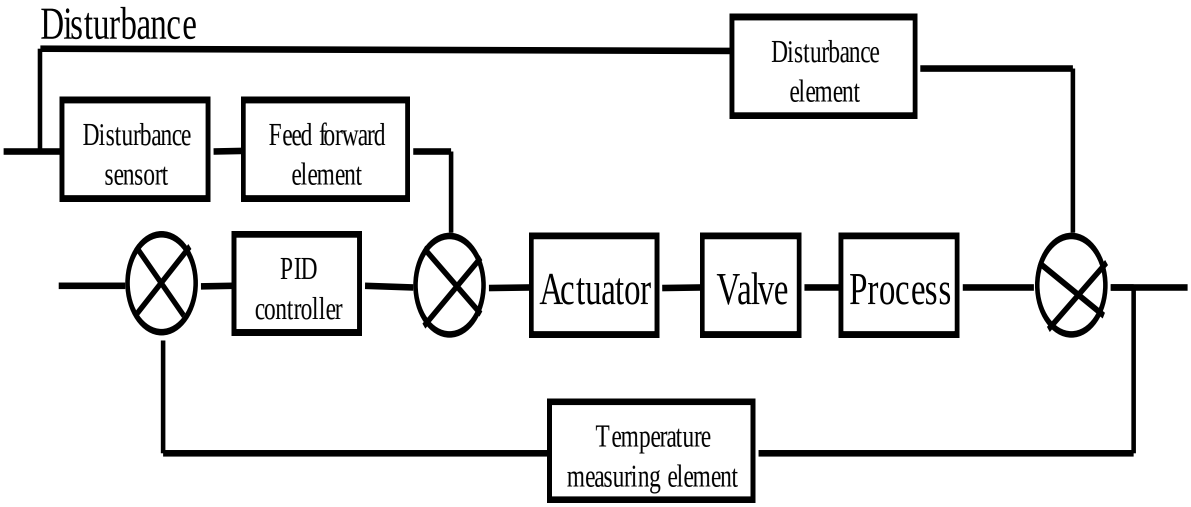

Figure 5.8(a): Architecture of feedback plus feed forward control

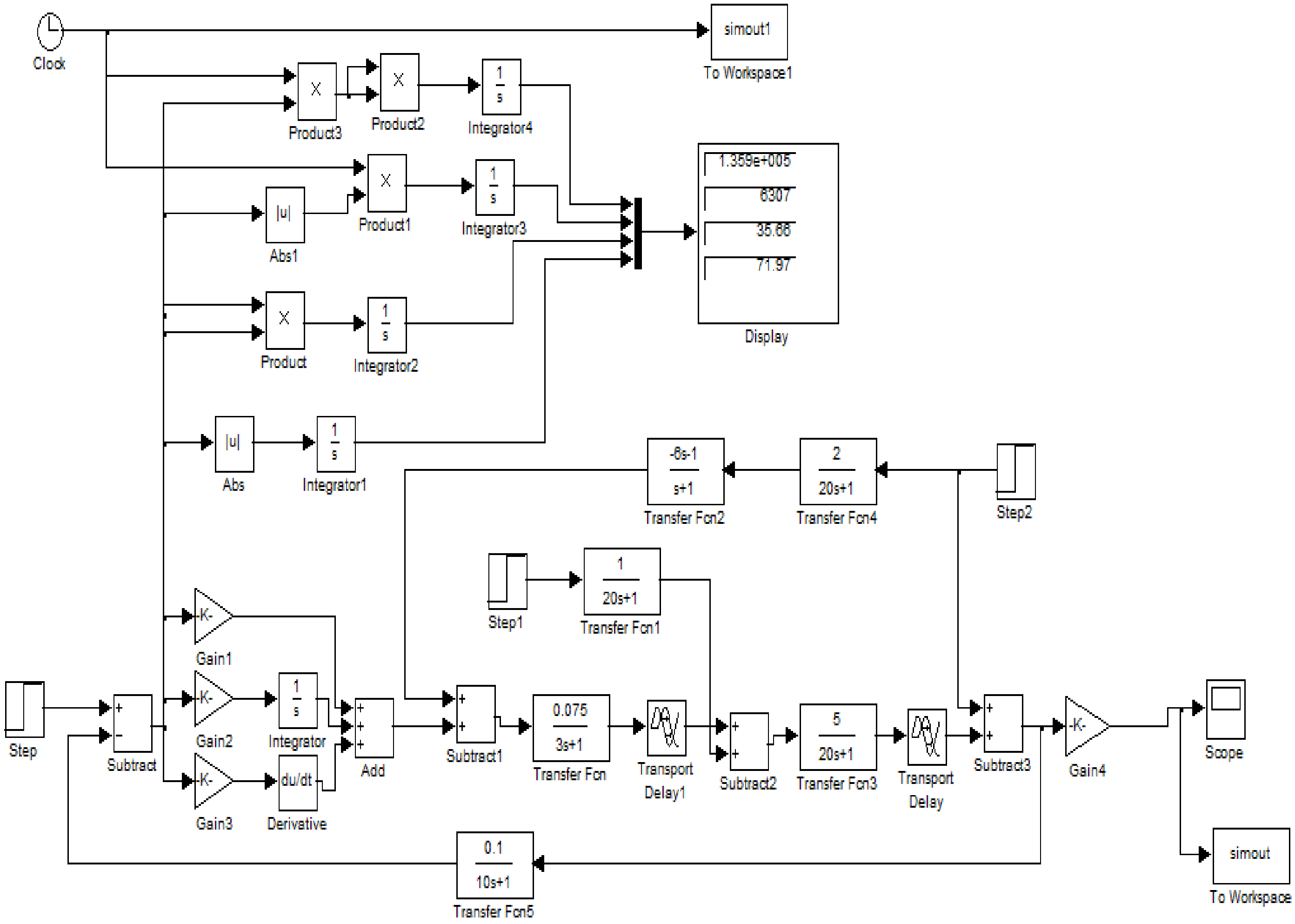

Figure5.8(b) Simulation of feedback and feed forward control using PID controller in CSTR

5.6 RESULTS&DISCUSSIONS

Assumption: Input used is step input.

Some parameters that are used in analysis of better controller are explained below graph.

Figure 4.11 shows the unit step response of reactor system with PID controller, which controls the outgoing temperature of the reactor.

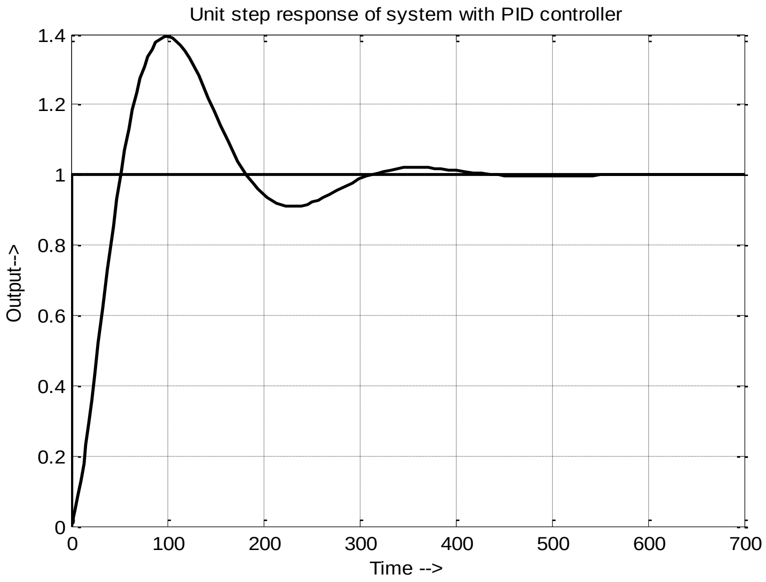

Figure 5.9: Unit step response of system with PID controller with feed back

Figure 5.10 shows the unit step response of the reactor system with feedback plus feed forward controller. The feed forward controller is used in conjunction with the feedback controller.

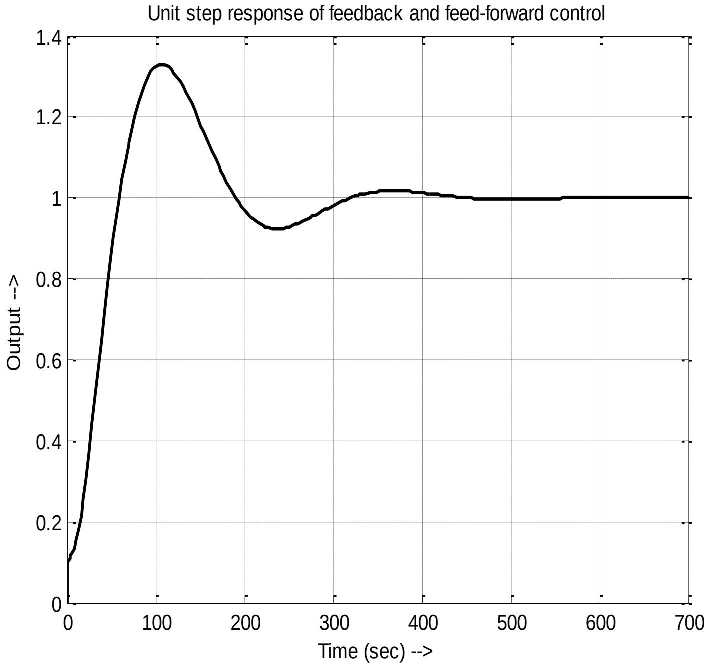

Figure 5.10: Unit step response of feedback plus feed forward PID controller

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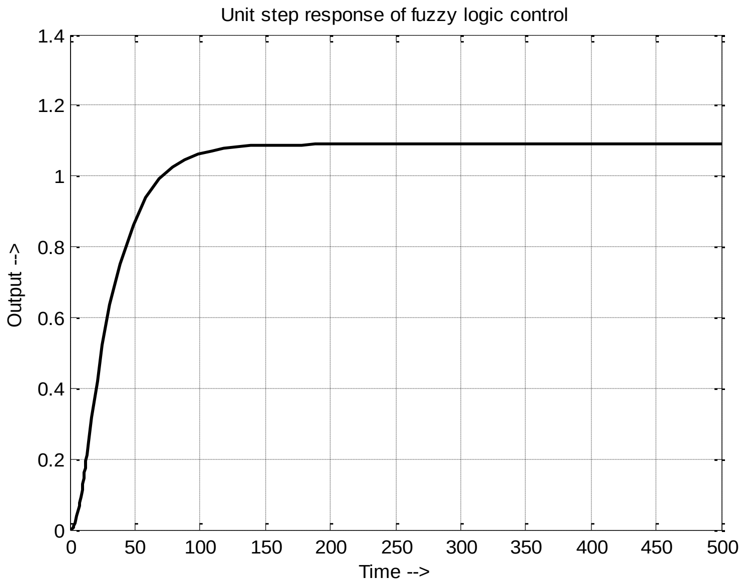
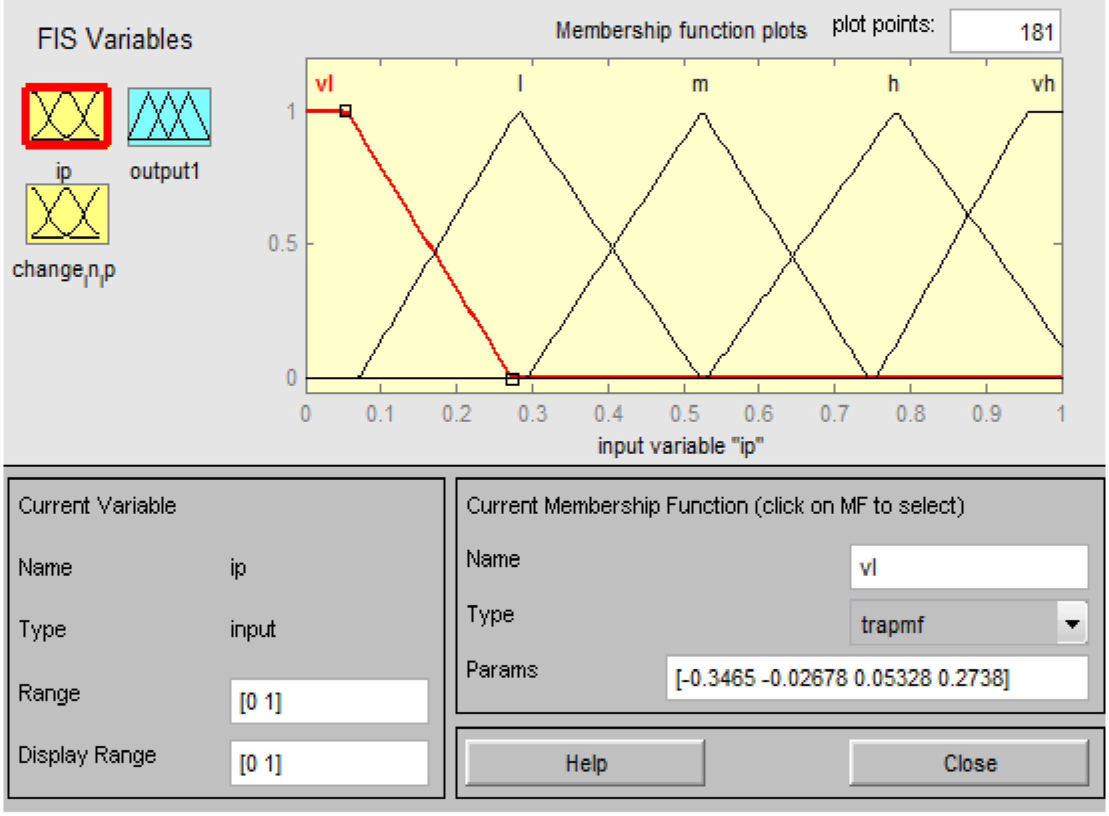


Figure 5.13: Unit step response of fuzzy logic controller



plot points: 181

Current Variable

Name ip

Type input

Range [0 1]

Display Range [0 1]

Current Membership Function (click on MF to select)

Name vl

Type trapmf

Params [-0.3465 -0.02678 0.05328 0.2738]

Figure5.14(a) View of fuzzy logicmembership functions

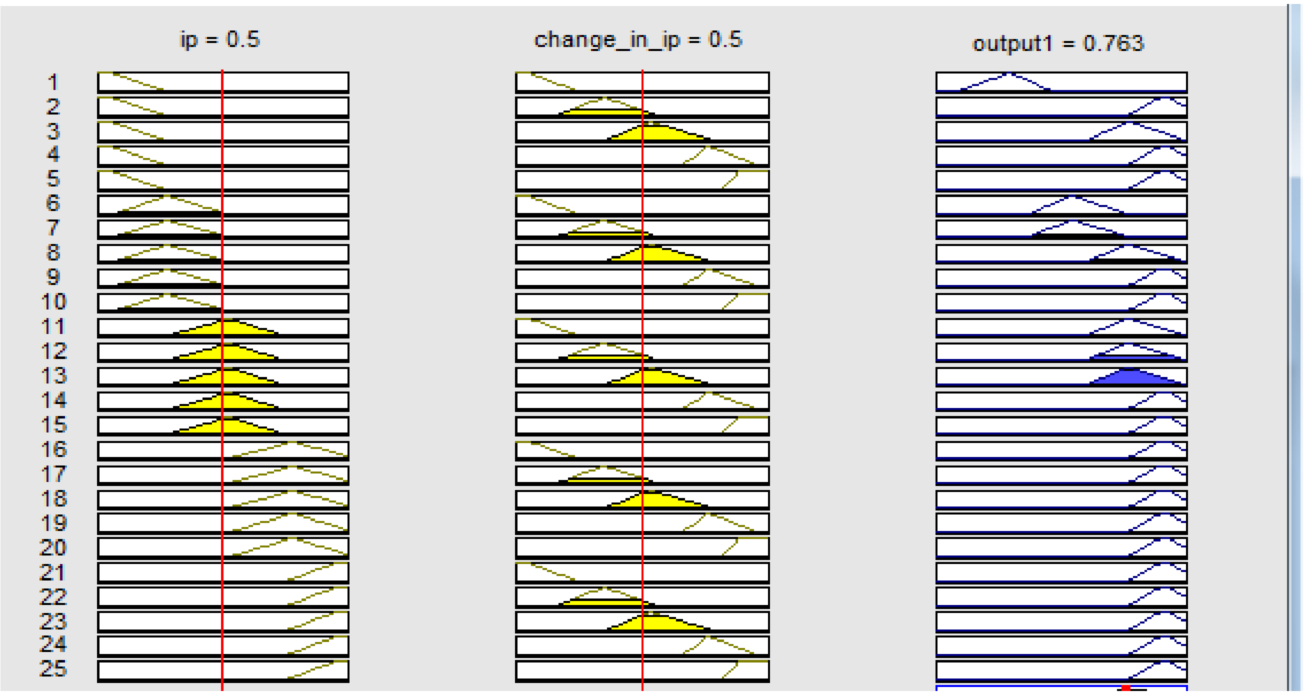


Figure5.14(b) View of the fuzzy optimization using centroid method

Table 1: Transient domain and Fuzzy parameters analysis of PID

	M_p	t_p	t_s
Feedback with PID	39.4%	100.27 sec	364.01 sec
Feedback plus feed forward with PID	35.83%	95.68 sec	345.3 sec
Fuzzy system	11.2%	65.8 sec	300 sec

Table 2: Error criteria of different controllers

	IAE	ISE
Feedback with PID	74.97	36.9
Feedback plus feed forward with PID	71.58	34.89
Fuzzy logic	32.5	25.8

From the above discussions, it is clear that feed forward plus feedback controller is a better controller, rather than feedback controller, when temperature control of reactor system is concerned.

5.7 CONCLUSIONS

In this thesis, comparative studies of different controllers are studied and performance is evaluated according to the time domain and frequency domain functions. It is observed that the feedback plus feed forward controller is more efficient than feedback controller. In future scope of this work, a fuzzy based controller can be developed.

5.8 FutureScopes

Fuzzy logics Kits are available in the industries .This is like other electronic kits that we can use to implement hardware part .In future theses will available in the market and we can control process with the help of this hardware.

Literature Review

Jong-Hwan Kimet.et al. this paper describes the in industrial applications proportional integral derivative (PID) controllers are widely use. They exhibit poor performance when apply to systems containing unknown nonlinearities, such as dead zones, saturation, and hysteresis. the performance of our scheme via experiments performed on a dc servomotor position control tested under varying load conditions. They propose a fuzzy logic-based pre compensation approach for PID controllers. in this results show that the fuzzy pre compensated PID controllers have superior performance compared to conventional PID controllers. In his experimental test bed, the variations in loading conditions correspond to variations in the level of nonlinearities in the plant. In past, the proposed scheme is robust to variations in load. his scheme is easily implement in practice simply by add a fuzzy pre compensator to an existing PID controller .the advantage of our present approach is that an existing PID control system can be easily modified into our control structure simply by adding the fuzzy pre compensator. The propose control scheme has very good performance compared to a conventional PID controller. His experimental results on a DC-motor position control test bed demonstrate the robustness of our scheme to variations in loading conditions.[3]

Vinod Kumaret.al. This paper presents a hybrid system controller, incorporating fuzzy controller with vector-control method for induction motors. The vector-control method has been optimized by using fuzzy controller instead of a simple P-I controller. The presented hybrid controller combines the benefits of fuzzy logic controller and vector-control in a single system controller. High quality of the regulation process is achieved through utilization of the fuzzy logic controller, while stability of the system during transient processes and a wide range of operation are assured through h application of the vector-control. The hybrid controller has been validated by applying it to a simulation model

Jing-Chung Shenet. al. this paper describes This paper presents PID tuning rules for second systems. These tuning rules are derived by optimizing the integrated absolute errors of set point and load disturbance responses under robustness and bandwidth constrains. For deriving the tuning formulas, PID controllers for normalized systems were designed. The relationship between the controller parameters, the parameters that characterize the system dynamics and the normalized gain crossover frequency are determined and the tuning formulas are then derived. Simulation examples and experimental results are provided to demonstrate the effectiveness of these tuning rules

MohdFua'adRahmat et.al in this paper through introducing Continues Stirred Tank Reactor (CSTR) is an important subject in chemical process and offering a diverse range of researches in the area of the chemical and control engineering. Various control approaches have been applied on CSTR to control its parameters. This paper presents two different control strategies based on the combination of a novel socio-political optimization algorithm, called Imperialist Competitive Algorithm (ICA), and concept of the gain scheduling performed by means of the least square and fuzzy logic approaches. The goal is to control the temperature of CSTR in presence of the set point changes. The works followed with designing those controllers and simulating in MATLAB software. The performance of the proposed controllers has been considered based on the Sum of the Square Error (SSE) and Integral Absolute Error (IAE) Criteria. The results clearly indicate that both suggested control strategies offer an acceptable performance with respect to the functional changes of the process. In other word, robustness of the proposed methods in dealing uncertainties throughout the tracking of the reference signal take the highlighted point into account. Furthermore, fuzzy based structure strategy gives the more flexibility and precise behaviour in control action in comparison to the least square based approach.

Aidan O'Dwyer et.al This paper focuses on the ability of proportional integral (PI) and proportional integral derivative (PID) controllers to compensate many practical industrial processes has led to their wide acceptance in industrial applications. The requirement to choose either two or three controller parameters is perhaps most easily done using tuning rules. A summary of tuning rules for the PI control of single input, single output (SISO) processes with time delay is provided in this paper This paper discusses PI-PD tuning of open-loop unstable sampled-data control systems. The examples used in this paper include typical first and second order plants taken from the processes industry. We propose a class of tuning formulae based on minimization of integral square error and time-domain quality of fit indices to measure performance, that are used to obtain polynomial representation of the controller parameters. The results for the process control examples are indicative of vastly improved time-domain performance and reduction in controller variance in the case of PI-PD controller, when compared to the more traditional PID controller. The empirical formulae derived in this paper are shown to be valid for a wide range of process parameters.

D.M. Gorinevsky et.al this paper presents a method for tuning the feedback controller of paper machine cross-directional control systems. The tuning method is based on identification of the process model, identification of the disturbance model and tuning the feedback controller by minimizing the paper property variations. To obtain a longer disturbance realization sequence and increase data available for identification of the process disturbance, 2-dimensional process identification residuals are used for identifying an integrated moving average disturbance model. The identification method is based on the Recursive Extended Least Squares. Based on the identified process and disturbance models, the Dahlin controller and control filter are tuned to minimize a quadratic performance index which includes the process output variance and the incremental control move variance. A penalty for excessive actuator move can be used to minimize the process variation while keeping the control action within acceptable bounds. The proposed method has been implemented in an industrial tuning tool. It has been validated using many sets of paper mill data. The tool predicts the closed-loop process variance and control variance with a satisfactory degree of accuracy.

Kiyong Kim et.al shows voltage regulator systems are utilizing the proportional, integral, and derivative (PID) control for stabilization. Two PID tuning approaches, pole placement and pole–zero cancellation, are commonly utilized for commissioning a digital excitation system. Each approach is discussed including its performance with three excitation parameter variations. The parameters considered include system loop gain, uncertain exciter time constants, and forcing limits. This paper is intended for various engineers and technicians to provide a better understanding of how the digital controller is tuned with pros and cons for each method.

G. K. I Mann et al [3], designs a fuzzy PID controller which is still a complex task due to the involvement of a large number of parameters in defining the fuzzy rule base. This paper investigates different fuzzy PID controller structures, including the Mandeni-type controller. By expressing the fuzzy rules in different forms, each PID structure is distinctly identified. For purpose of analysis, a linear-like fuzzy controller is defined. A simple analytical procedure is developed to deduce the closed form solution for a three-input fuzzy inference. This solution is used to identify the fuzzy PID action of each structure type in the dissociated form. The solution for single-input–single-output nonlinear fuzzy inferences illustrates the effect of nonlinearity tuning. The design of a fuzzy PID controller is then treated as a two-level tuning problem. The first level tunes the nonlinear PID gains and the second level tunes the linear gains, including scale factors of fuzzy variables. By assigning a minimum number of rules to each type, the linear and nonlinear gains are deduced and explicitly presented. The tuning characteristics of different fuzzy PID structures are evaluated with respect to their functional behaviors. The rule decoupled and one-input rule structures proposed in this paper provide greater flexibility and better functional properties than the conventional fuzzy PID structures**.**

Manish Kumar et al. [13] develops methodologies to learn and optimize fuzzy logic controller parameters based on neural network and genetic algorithm. The strategies developed have been applied to control an inverted pendulum and results have been compared for three different fuzzy logic controllers developed with the help of iterative learning from operator experience, genetic algorithm and neural network. The results show that Genetic- Fuzzy and Neuro -Fuzzy approaches were able to learn rule base and identify membership function parameters accurately.

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