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Temperature Control of CSTR using PID and PID (Two Degree of Freedom) Controller

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Abstract- **Continuous Stirred Tank Reactor (CSTR) is an important topic in process control and offering a diverse range of researches in the area of the chemical and control engineering. This paper present two different control strategies based on PID control and Two degree of freedom PID control. The objective is to control the temperature of CSTR in presence of the set point. Model design and simulation are done in MATLAB SIMULINK software. The temperature control is found better with addition of two degree of freedom PID controller than PID controller.**

Keywords- PID controller (2 DOF), PID Controller, Chemical Temperature, CSTR, Coolant Temperature

1. Introduction

Continuously stirred tank reactors (CSTR) with a recirculating jacket heat transfer system may have more interesting dynamic behaviour than the classical representation of a & "once through" jacket. A particular CSTR with a single steady-state as a function of jacket temperature may have multiple steady-state behaviour if the jacket inlet temperature is considered the manipulated.

The PID controller is the most common form of feedback. It was an essential element of early governors and it became the standard tool when process control emerged in the 1940s. In process control today, more than95% of the control loops are of PID type, most loops are actually PI control.PID controllers are today found in all areas where control is used. The controllers come in many different forms.

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

$$U(t) = MV(t)=Kpe(t)+Ki\int e(t)dt+Kd\ \frac{de(t)}{dt}$$

2DOF PID controller, also known as ISA-PID controller, we can achieve good performance for both reference tracking and disturbance rejection. It contains a standard PID controller in the feedback loop and adds a pre-filter to the reference signal. The pre-filter helps produce a smoother transient response to set-point changes. In this case, we are using a Simulink PID Controller (2DOF) block to control a continuous stirred tank reactor (CSTR) and you design this 2DOF PID controller in the PID Tuner. In this paper, CSTR has been use for the production of Propylene Glycol by hydrolysis of propylene oxide with sulphuric acid as Catalysist. Water is supplied in access, so reaction is of first order.

2. CASE STUDY

The examined reactor has real background and graphical diagram of the CSTR reactor is shown in Figure 1. The mathematical model of this reactor comes from mass balance and energy balance inside the reactor. Notice that: a jacket surrounding the reactor also has feed stream and exit streams. The jacket is assumed to be perfectly mixed and at lower temperature than the reactor. Energy passes from the reactor walls into jacket removing the heat generated by reaction. The control objective is to keep the temperature of the reacting mixture T, constant at desired value. The only manipulated variable is the coolant temperature (T_J).

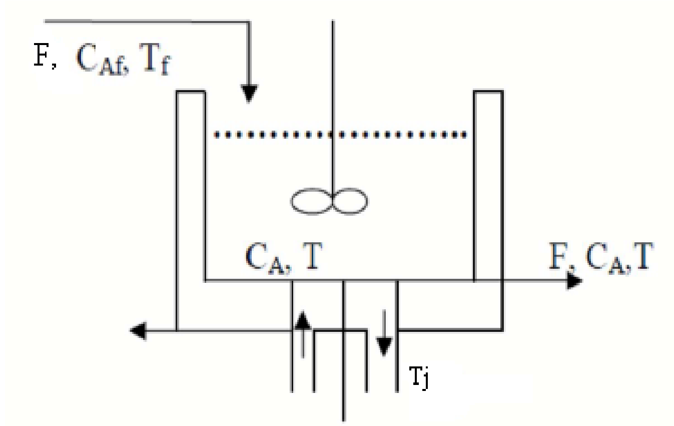

Figure1.Continues stirred tank reactor with cooling jacket

3. Steady State Solution

The steady state solution is obtained when dCA/dt= 0 ,dT/dt=0,dTj/dt=0 that is

f1(CA,T,Tj)=dCA/dt=0=F/V(CAf –CA)–Koexp(-E/RT)CA….(1.1)

f2(CA,T,Tj)=dT/dt=0=F/V(Tf–T)+(-ΔH/ρCP)K0exp (-Ea/RT)C_A-UA(T-Tj)/VρC_P

Table for Reactor Parameter's value

Parameter	*Values*	*Unit*
Ea	32.400	Btu/lbmol
k_o	$16.96*10^{12}$	Hr^{-1}
U	75	Btu/hrft^2 ^{o}F
ρc_p	53.25	Btu/ft^3 ^{o}F
R	1.987	Btu/lbmol^{o}F
F	340	Ft^3/hr
V	85	Ft^3
Ca_f	0.132	Lbmol/ft^3
T_f	60	^{o}F

4. PROBLEM FORMULATION

The goal of the linearization procedure is to find a model with the form

X' = Ax + Bu ……………………(1.3)

y = Cx + Du ……………………(1.4)

Where the states, inputs and output are in deviation variable.

$$A = \begin{bmatrix} \partial f_1/\partial x_1 & \partial f_1/\partial x_2 \\ \partial f_2/\partial x_1 & \partial f_2/\partial x_2 \end{bmatrix}$$

$$B = \begin{bmatrix} \partial f_1/\partial u_1 \\ \partial f_2/\partial u_1 \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 1 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

Using all reactor parameter's value we can find the following

State space model system –

-

$$A = \begin{bmatrix} -7.9909 & -0.013674 \\ 2922.9 & 4.5564 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 1.4582 \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 1 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

By MATLAB command we can find out reactor process transfer function (G_p)

$$G_P = \frac{1.4582s+11.65}{S^2+3.434s+3.557} \qquad \text{…………..(1.5)}$$

Plant output for step change

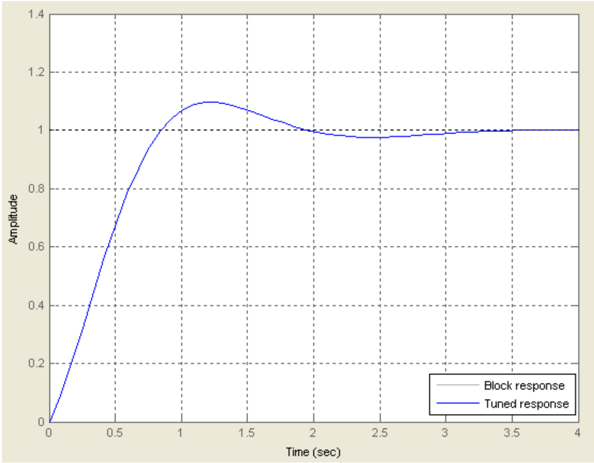

Figure2.

The feed stream concentration is 0.132 lbmol/ft and an 50% conversion of propylene oxide has been to be determined reasonable. Since 50% of propylene oxide is converted to propylene glycol, the propylene glycol concentration is 0.066 lbmol/ft^3. In this process. it is seen that the process has inverse response with delay time as well as overshoot. To overcome this problem and to obtain the desired response, we are using of PID controller and PID (two degree of freedom). For that, the controller parameters are calculated. The desired parameters for the PID controller are the proportional gain (K_P) integral gain (K_I) and the differential gain (K_D) can be calculated by the Automatic PID tuning method in MATLAB software or Ziegler Nichols tuning method

Stability Analysis

The stability of particular operating point is determined by finding the A-matrix for that particular operating point and finding the Eigen values of the A-matrix.

$$A = \begin{bmatrix} -7.9909 & -0.013674 \\ 2922.9 & 4.5564 \end{bmatrix}$$

A= [-7.9909, -0.013674; 2922.9, -4.5564];

Y = eig(A);

Y = -6.2737
-6.2737

Both of the eigen values are negative, indicating that the point is stable.

SIMULATION TESTING AND RESULT

The operation of the CSTR is disturbed by external factors such as changes in the feed flow rate and temperature .we need to form of control action to alleviate the impact of the changing disturbances and to keep T at desired set point (SP). In this system the manipulated temperature Tj is responsible to maintain the temperature Tat the desired SP. The CSTR with PID controller is shown in below. The reaction is exothermic and the heat generated is removed by the coolant, which flows in the jacket around the tank.

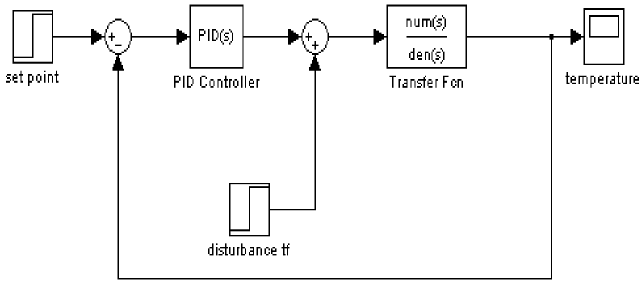

Figure3. Single loop CSTR with PID controller

Temperature output response

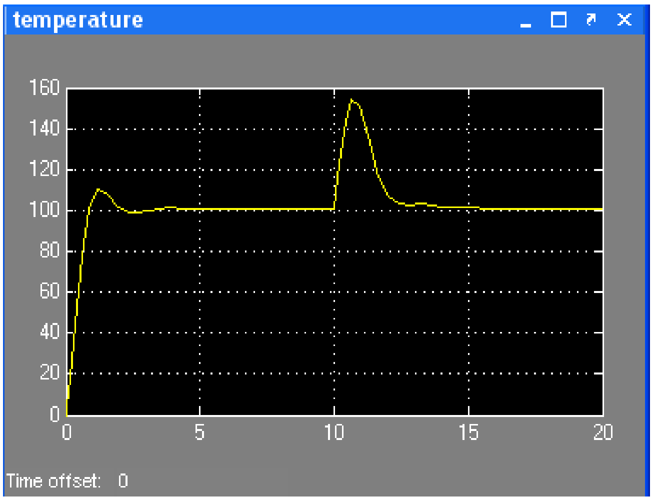

Figure4

The disturbance rejection performance satisfies the requirements. However, because the controller is very aggressive, the overshoot of reference tracking exceeds the limit. You need to adjust the pre-filter in the 2DOF PID block to improve the reference tracking performance

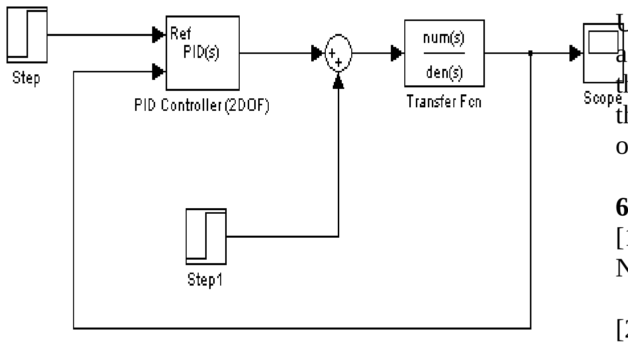

Figure5.CSTR with PID (2DOF)

The parameter b in an ISA PID controller is the set-point weight on the reference signal feeding into the proportional gain of the controller. It has a range between 0 and 1, and its default value is 1. By reducing its value, the reference tracking performance becomes smoother. Because b and P are changed, we need to adjust the initial condition of the integrator I0 in the PID controller block to make sure the initial operating point is still at equilibrium. The relationship is

$$I0 = u0 - ((b-1)*y0*P) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1.6)$$

Temperature output response

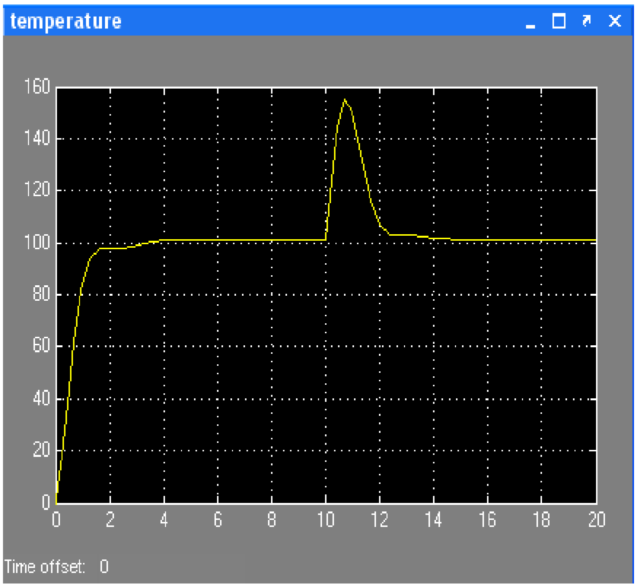

Figure6.

The above figure shows that there is no overshoot in reference tracking with the updated design.

5. CONCLUSION

When there is PID control with the system it generates a high value of overshoots with reference tracking response.

When there is PID controller (two degree of freedom) with the system it generates low value overshoots with reference tracking response.

Use the PID Tuner to achieve good disturbance rejection and then manually adjust set-point weights **b** and/or **c** in the block dialog to achieve good reference tracking. Notice that changing **b** and **c** does not affect closed-loop stability or disturbance rejection performance.

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