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IMPLEMENTATION OF MODEL PREDICTIVE CONTROL AND AUTO TUNING BASED PID FOR EFFECTIVE TEMPERATURE CONTROL IN CSTR

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Abstract- Continuous Stirrer Tank Reactor (CSTR) is an important topic in process control and offering a diverse range of researches in the area of chemical and control engineering. A simulation on mathematical model has several advantages over the experiment on a real model or system, which is used for steady state analysis and dynamic state analysis. The main objective is to control the temperature of CSTR in the presence of disturbance. Various control approaches have been applied on CSTR to control its parameters through PID control and MODEL PREDICTIVE CONTROL (MPC). Model design and simulation are done in MATLAB SIMULINK.

Keywords- *CSTR, Model response, Relay feedback, PID control, Model predictive control (MPC)*

I. INTRODUCTION

The problem of controlling the temperature of CSTR is considered as a challenging issue especially for a control engineer corresponding to its non linear dynamics. Most of the traditional controllers are restricted just for linear time invariant system application. But in real world, the non linear characteristics of system and their function parameter changes due to wear and tear, that's why these changes can't be neglected. One of the most important controllers both in academic and industrial application is PID. PID controller has been applied in feedback loop mechanism and extensively used in industrial process control since 1950's. Easy implementation of PID controller made it more popular in Control System application. Basically PID tries to correct the error between measured outputs and desired outputs of the process in order to improve the transient and steady state response as much as possible.

Model Predictive Control is the only advanced control technique, which has been very successful in particular applications. MPC refers to a class of computer controlled algorithms that utilize and explicit process model to predict the future response of the plant. At each control interval, an MPC algorithm attempts to optimize future plant behavior by computing a sequence of future manipulated ariable adjustments. The first input in the optimal sequence is then sent into the plant and entire calculation is repeated at subsequent control intervals.

The most important advantage of MPC algorithms is the fact that they have the unique ability to take into account constraints imposed on process inputs (manipulated variables) and outputs (controlled variables) or state variables which usually determine the quality, economic efficiency and safety of production. MPC techniques have been recognized as efficient approaches to improve operating efficiency and profitability. It has become the accepted standard for complex controlled problems in the process control. This paper, CSTR has been used for the production of Propylene Glycol by Hydrolysis of Propylene Oxide with Sulphuric acid as catalyst. Water is supplied in access, so reaction is of first order.

A proportional-integral-derivative controller (PID) Controller) [4] is a common feedback loop component used for control system. In this paper a PID controller is implemented to track the set point and also to reject the disturbance occurs in the process. Relay feedback test is conducted to carry out the tuning parameters of PID controller to satisfy the servo and regulatory responses.

II. MODELLING OF CSTR

The examined reactor has real background and graphical diagram of the CSTR reactor as shown in fig I. The mathematical model of this reactor comes from balances inside the reactor. Notice that a jacket surrounding the reactor also has feed and exit streams. The jacket is assumed to be perfectly mixed at lower temperature than the rector. Energy passes through 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 flow rate.

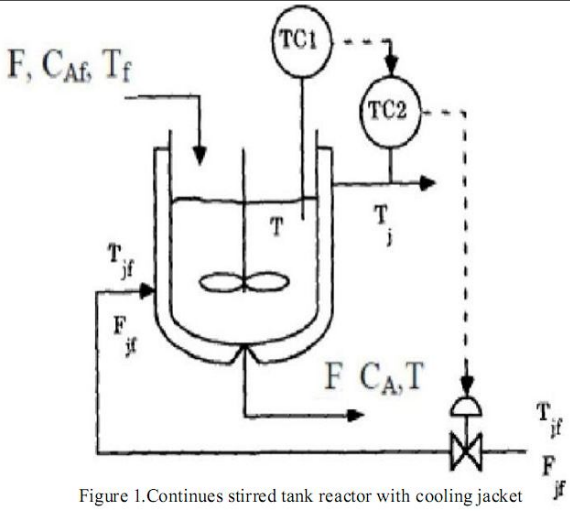


Figure 1.Continues stirred tank reactor with cooling jacket

TABLE I. VALUES FOR REACTOR PARAMETERS

Parameter	Values	Unit
Ea	32.400	Btu/lbmol
K_O	$16.96*10^{12}$	Hr^{-1}
U	75	Btu/hrft^2 ^{0}F
Pc_p	53.25	Btu/ft^3 ^{0}F
R	1.987	Btu/lbmol ^{0}F
F	340	Ft^3/hr
V	8.5	Ft^3
V_j/V	0.25	-
T_{jf}	0	^{0}F
P_jc_{pj}	55.6	Btu/ft^3 ^{0}F
Ca_f	0.132	Lbmol/ft^3
T_f	60	^{0}F

1. *Steady State Solution*

The steady state solution is obtained when

$$\frac{dCA}{dt} = 0, \frac{dT}{dt} = 0, \frac{dT_j}{dt} = 0$$

That is

$$f_1(C_A,T,T_j) = \frac{dC_A}{dt} = 0$$
$$= F/V(C_{Af} - C_A) - K_0 exp(-E/RT)C_A$$

$$f_2(C_A,T,T_j) = \frac{dT}{dt} = 0$$
$$= F/V(T_f - T) + (-\Delta H/\rho C_p)K_0 exp(-E/RT)C_A$$
$$- UA/V_\rho C_p(T - T_j)$$

$$f_3(C_A,T,T_j) = \frac{dT_j}{dt} = 0$$
$$= F_j/V_j(T_{jf} - T_j) + UA(T - T_j)/(V_j \rho_j c_{pj}) \quad (1)$$

2. *Linearization*

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

$$\dot{X} = Ax + Bu \quad (2)$$
$$y = Cx + Du \quad (3)$$

Where the states, inputs and output are in deviation variable. Using the parameters given in above table we can find the State space model for PID controller design

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

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

$$C = [0 \quad 1]$$

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

Hence transfer function for PID control will be (T/Tj)

$$G_p = \frac{1.458s + 11.65}{s^2 + 3.434s + 3.557} \quad (4)$$

III. CONTROLLER METHODS

A. PID Controllers

When the characteristics of a plant are not suitable, they can be changed by adding a compensator in the control system. One of the simple and useful compensators feedback control design is described in this section. In this paper, the control method is designed based on the time-dimension performance specifications of the system, such as settling time, rise time, peak overshot, and steady state error and so on.

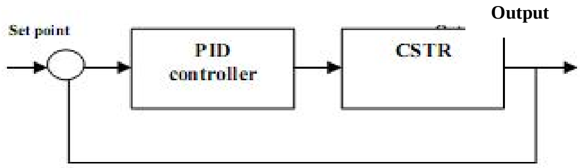


Figure. 2 : Block diagram of a closed loop system

A PID controller calculates an “error” value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs.

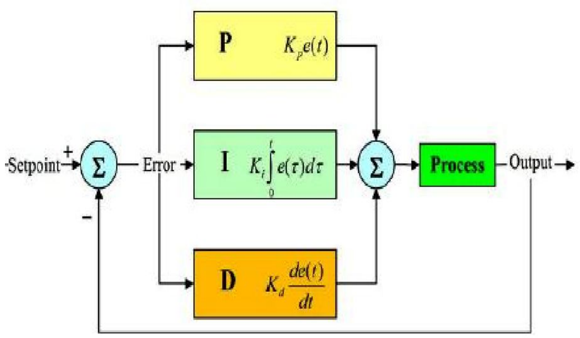


Figure. 3 Block diagram of PID controller

Three parameters K_d, K_p and K_i must be adjusted in the PID controller. In guaranteeing stability, performance and shaping the closed-loop response, it is important to select a suitable compensator.

I. *PROPORTIONAL GAIN Kp:*

Large proportional control can increase response, speed and reduce the steady state error, but will lead to oscillation of the system.

II. *INTEGRAL GAIN K_I:*

Integral control is favourable for diminishing the steady state error but it will lengthen the transient response. This paper attempts to design optimal values for controller parameters. Then it obtain the value of PID gains by Ziegler and Nichols Method. Ziegler and Nichols provided a technique for selecting the PID gains that works for a large class of industrial systems.

III. *RELAY FEEDBACK TEST:*

The Astrom and Hagglund relay feedback test is based on the Observation that, when the output lacks behind the input by π radians, the closed loop system can oscillate with a period of *P*u. The block diagram of Relay feedback test is shown in Fig.4. The output response of relay feedback test is shown in Fig.5. From the response we can find the parameters are ultimate gain and ultimate period by using equations 4 & 5.

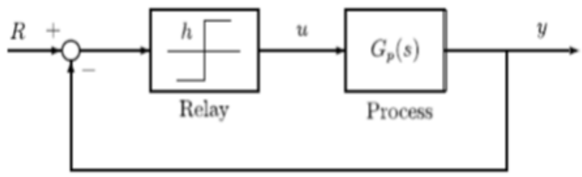


Figure. 4 Block diagram of Relay feedback test.

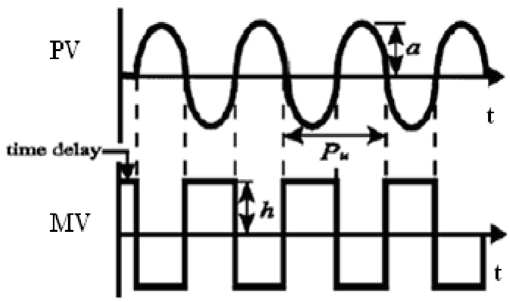


Figure. 5: Output response of relay feedback test.

A Relay of magnitude *h* is inserted in the feedback loop. Initially, the input *u(t)* is increased by *h*. Once the output *y(t)* starts increasing after a time delay (*D*), the relay switches to the opposite direction, *u(t)-h*. Because there is a phase lag of –π, a limit cycle of amplitude *a* is generated, as shown in fig 5. The period of the limit cycle is the ultimate period, *P*u . The approximate ultimate gain, *K*u, and the ultimate frequency, w_u are

$$K_u = \frac{4h}{\pi a} \quad (5)$$

$$W_u = \frac{2\pi}{P_u} \quad (6)$$

IV. *MODEL PREDICTIVE CONTROLLER*

The Model Predictive Control problem is formulated as solving on-line a finite horizon open loop optimal control problem subject to system dynamics and constraints involving states and controls. Fig (6) shows the basic principle of model predictive control. Based on measurements obtained at time *t*, the controller predicts the future dynamic behavior of the system over a prediction horizon T_P and determines (over a control horizon) the input such that a predetermined open-loop performance object function is optimized.

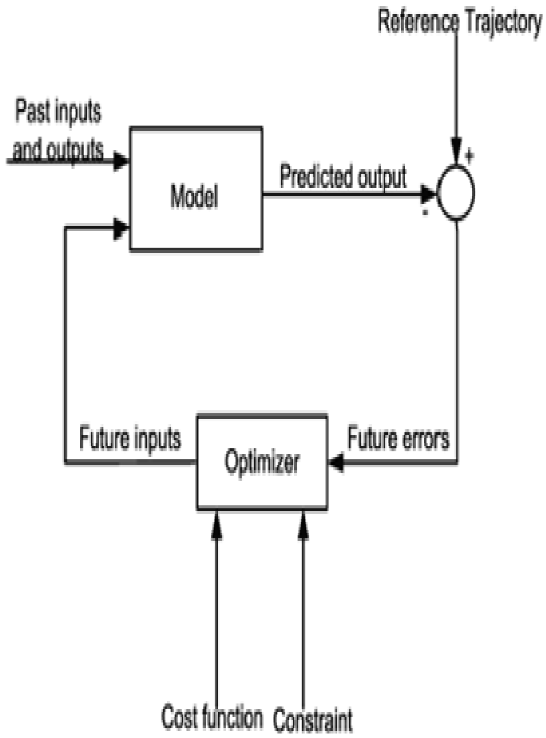


Figure6: Block diagram of MPC controller.

IV. OPTIMIZATION FUNCTION:

A mathematical description of the cost function used by the controller to optimize control moves over the control horizon is given, values of set points, measured disturbances, and constraints are specified over a finite horizon of future sampling instants, k+1, k+2, ...k+P ,Where P is the prediction horizon and the controller computes M moves uk, uk+1, ...uk+M-1, where M is the control horizon as shown in Fig.7. For conical tank system, consider the predictive horizon P=20 and control horizon M=3, to track the servo and regulatory response under multi set point tracking system. The cost function / optimization equation to reduce the error is shown below.

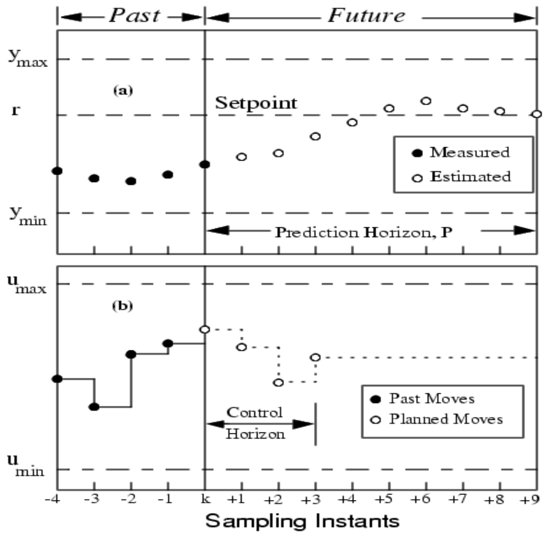
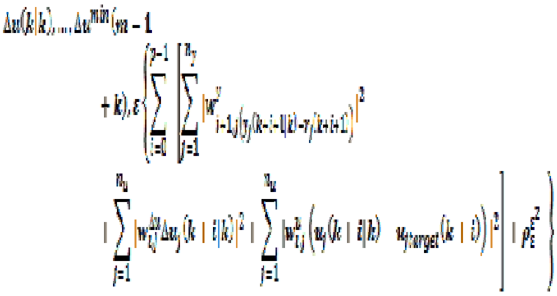


FIGURE 7: Performance of MPC controller



V. SIMULATION RESULTS

A. SIMULATION METHOD:

The mathematical model of the temperature control of CSTR is obtained using first principle differential equation and is implemented by using MATLAB/ Simulink. The Simulink model of open loop response of CSTR process is shown in fig.8. The system behavior is analyzed by using the step response model of CSTR process.

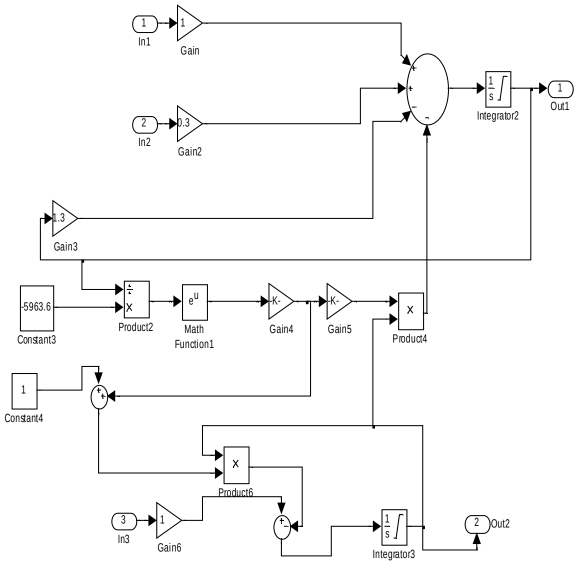


Figure. 8 Open loop response of Continuous stirred tank reactor process.

A. TUNING RULES:

The tuning rules are obtained from the [9] Handbook of PI and PID controller tuning rules by Aidan O'Dwyer are listed in Table (2). The tuning parameters of PID controller are calculated by using the tuning rules provided in table (1). The tuning parameters Ultimate period and ultimate gain are obtained by conducting the relay feedback test to the process.

TABLE 2: Tuning rules for PID Controller

Tuning rule	K_c	T_i	T_d
Z-N Closed loop method	$0.6K_U$	$0.5P_u$	$0.125P_u$

B. RESULTS:

The open loop response of the CSTR process is shown in fig-9 & 10. From Fig-9 we can observe that decrease in the inlet temperature of CSTR by adding the coolant flow to the process. Fig-10 represents the slightly increase in the concentration of CSTR process. The response of the process related to the Auto tuning method is shown in fig 11. From the fig.11 i.e, continuous sustained oscillations find the value of Ultimate gain(Ku) and Ultimate period (Pu). Zeigler-Nicholos tuning rules are used for tracking the servo response is shown in fig 12. From the fig.12 we analyse that the Zeigler-Nicholos tuning rules provides ocillatory response to track the set point change in process. The servo and regulatory response of CSTR process is shown in fig 13. The controller response also shown in fig 14. From the fig : 13 we can analyse that oscillatory response exhibit in the process for set point tracking and it takes more time to track the set point even in the presence of the disturbance in the process.

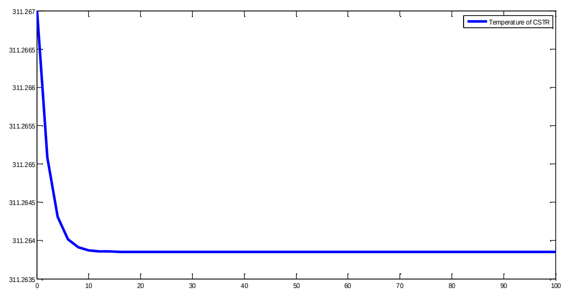


Figure.9 Open loop response for Temperature control of CSTR.

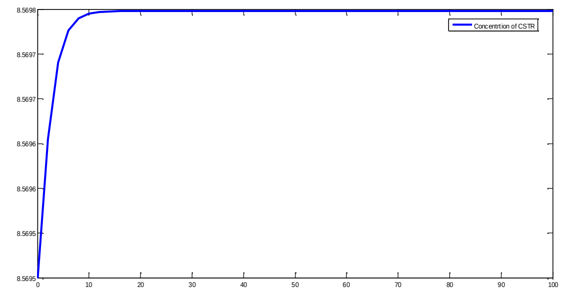


Figure.10. Step response for Concentration control of CSTR.

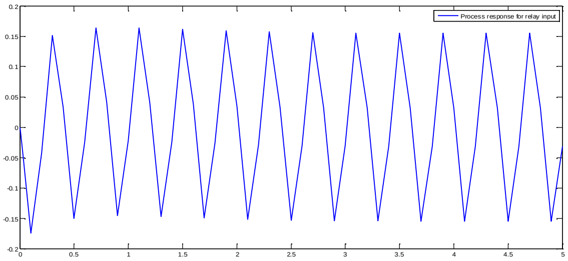


Figure 11: Process response for relay feedback test.

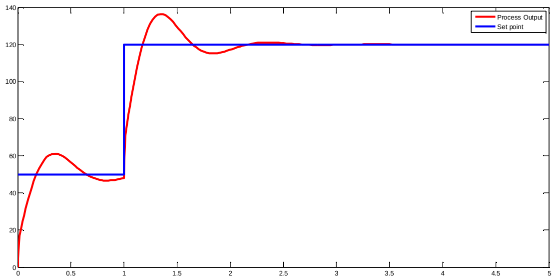


Figure 12: Servo response for Temperature control of CSTR process.

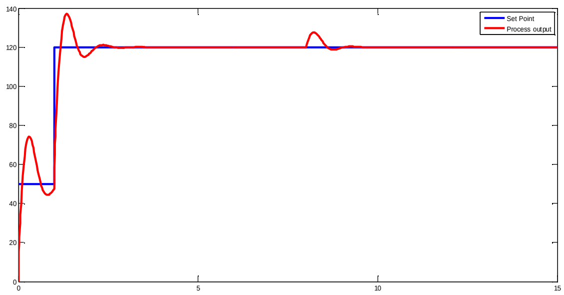


Figure 13: Servo response and regulatory response for Temperature control of CSTR Process.

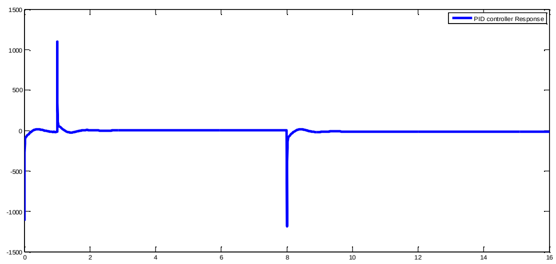


Figure 14: PID controller response for CSTR for servo and regulatory response.

C. *MODEL PREDICTIVE CONTROLLER:*

The implementation of Model predictive control for temperature control of CSTR process is implemented in Matlab. The MPC is implemented by considering the parameters of Prediction Horizon (P) = 20, Control Horizon (M) = 2, Control interval=0.1 and objective function is Quadratic Objective to minimise the error, to track the multi changes in set point and also the change in load disturbance. The multi set point tracking of temperature of CSTR process by using MPC controller is shown in fig-15. From fig 15 we can observe that no oscillations occurred in the process and also it takes less time to track the changes occur in the input of the CSTR process.

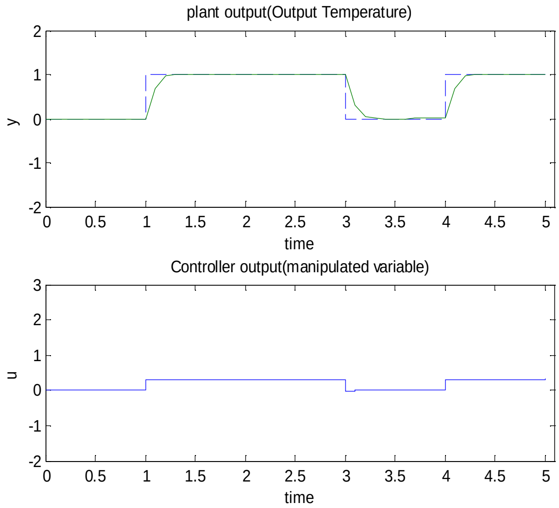


Figure 15: Multi set point tracking using MPC for CSTR.

VI. CONCLUSION:

The CSTR process is identified as a non-linear system. The modeling of CSTR process is implemented with the help of first principle differential equation. MATLAB (Simulink) is used to solve the differential equation. The conventional PID controller is implemented based on the auto tuning method by conducting the Relay Feedback test to track the set point changes in temperature of CSTR process. The relay feedback test conducted to the process to identify the tuning parameters of PID structure. The MPC Controller is implemented to track the servo response and regulatory response. The simulation results proven that the MPC control method is an easy-tuning and more effective way to enhance stability of time domain performance of the temperature control of CSTR process.

VII. FUTURE WORK

The Controlling of CSTR process be implemented by using constraints on Model Predictive Control to track the servo response and regulatory response. The performance comparison will also be carried out by using qualitative and Quantitative analysis**.** The adaptive Controllers like Self tuning regulator, Model Reference Adaptive Controller etc can be implemented for temperature control of CSTR process for satisfactory desired performance .

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