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An Adaptive Control design for a Continuous Stirred Tank Reactor (CSTR)

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Abstract : Every process is needed to control to get the desired outcome from the process. The control action over the process parameters is so called process control. Adaptive control is the control method used by a controller which must adapt to a controlled system with parameters which vary, or are initially uncertain. In this work, an adaptive control design for a linear PI controller is attempted. Continuous Stirred Tank Reactor (CSTR) plays an important role in the processing industries. It helps for maintaining the temperature of the liquid in the reactors. In this work a CSTR process is modeled in nonlinear differential equation form and also linearized plant model form. Then, the plant is controlled by designing and implementing a conventional PI controller, Multi-model PI controller and an Adaptive PI controller. The performances of the process with conventional PI controller and the adaptive controller are analyzed from the responses, to show that the Adaptive PI controller outperforms the linear PI controller. Also the adaptive PI controller meets with the desired performance criteria. A simulation is made using MATLAB and the results were analyzed. Hence it proves that the response of adaptive PI control is better than the other PI controlled control system. Thus the designed Adaptive PI controller is suitable to control the CSTR process**.**

***IndexTerms* – Adaptive control, Continuous Stirred Tank Reactor, PI controller**

I. INTRODUCTION

Continuous stirred tank reactors (CSTRs) belong to a class of nonlinear systems where both steady-state and dynamic behaviour are nonlinear. Their models are derived and described in e.g. (Ogunnaike and Ray, 1994), (Schmidt, 2005) and (Corriou, 2004). The process nonlinearities may cause difficulties when controlling using conventional controllers with fixed parameters. One possible method to cope with this problem is using adaptive strategies based on an appropriate choice of an external linear model (ELM) with recursively estimated parameters. These parameters are consequently used for parallel updating of controller‘s parameters. The control itself can be either continuous-time or discrete. While for design of a continuous-time controller, it is necessary to know a continuous-time ELM and its parameters, a discrete-time controller requires knowledge of a discrete ELM. Experiences of authors in the field of control of nonlinear technological processes indicate that the continuous time (CT) approach gives better results when controlling processes with strong nonlinearities. In the case of discrete control in order to cope with the nonlinearity, it is necessary to sample signals very frequently. However, it is well known from the properties of transfer functions in the z-domain that a sampling period cannot be shortened too much. For the CT ELM parameters estimation, either the direct method or application of an external delta model with the same structure as the CT model can be used.

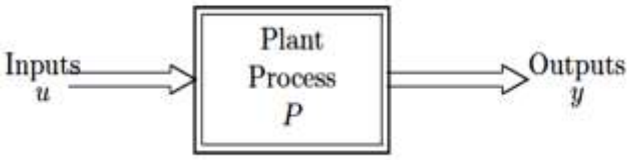

Fig. 1.1 Plant representation

The procedure based on direct CT ELM parameter estimation was described in (Dostál et al., 2001). The basics of delta models have been described in e.g. (Middleton and Goodwin, 1990), (Mukhopadhyay et al., 1992) and (Goodwin et al., 2001, Ortega and Kelly, 1984, Kučera, 1993). The design of a controller that can alter or modify the behavior and response of an unknown plant to meet certain performance requirements can be a tedious and challenging problem in many control applications. By plant its mean any process characterized by a certain number of inputs *u* and outputs *y*, as shown in Fig. 1.1. The plant inputs *u* are processed to produce several plant outputs *y* that represent the measured output response of the plant. The control design task is to choose the input *u* so that the output response *y* satisfies certain given performance requirements. Most of the plant processes are complex, i.e., they may consist of various mechanical, electronic, hydraulic parts, etc., the appropriate choice of *u* is in general not straightforward. The control design steps often followed by most control engineers are to choose the input *u*.

II. ADAPTIVE CONTROL

The area of adaptive control has grown to be one of the richest in terms of algorithms, design techniques, analytical tools, and modifications. The design of autopilots for high-performance aircraft was one of the primary motivations for active research on adaptive control in the early 1950s. Aircraft operate over a wide range of speeds and altitudes and their dynamics are nonlinear and conceptually time varying. For a given operating point, specified by the aircraft speed (Mach number) and altitude, the complex aircraft dynamics can be approximated by a linear model of the form as (1). For example, for an operating point *i*, the linear aircraft model has the following form.

$$\dot{x} = A_i x + B_i u, \qquad x(0) = x_0$$
$$y = C_i^T x + D_i u \qquad (1)$$

where A_i; B_i; C_i, and D_i are functions of the operating point *i*.

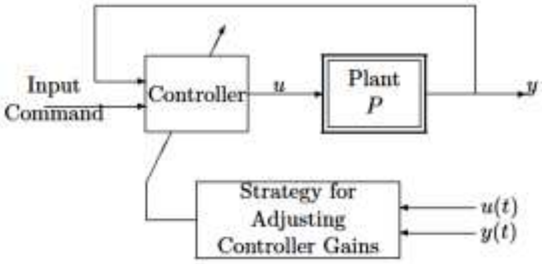

Fig. 1 Controller structure with adjustable controller gains

As the aircraft goes through different flight conditions, the operating point changes leading to different values for A_i; B_i; C_i, and D_i. Because the output response *y* carries information about the state *x* as well as the parameters, one may argue that in principle, a sophisticated feedback controller should be able to learn about parameter changes by processing *y* and use the appropriate gains to accommodate them. This argument led to a feedback control structure on which adaptive control is based. The controller structure consists of a feedback loop and a controller with adjustable gains as shown in Fig. 1. The way of changing the controller gains in response to changes in the plant and disturbance dynamics distinguishes one scheme from another.

An adaptive controller is thus a controller that can modify its behavior in response to changes in the dynamics of the process and the character of the disturbances. Since ordinary feedback also attempts to reduce the effects of disturbances and plant uncertainty, the question of the difference between feedback control and adaptive control arises.

In practice there are many difference sources of variation, and they are usually due to a mixture of different phenomena. When the dynamics of the process is reasonably well known, it is possible to determine suitable controller parameters for different operating condition by linearising the models and using some methods for control law design. Adaptive controllers can be a good alternative in such cases.

III. CONTINUOUS STIRRED TANK REACTOR PROCESS

The complexity of the problem has been enhanced in this chapter by changing simple tank to a reactor carrying out known reaction and also controller (both Adaptive PI and conventional PI controller) mechanism has been adopted. Develop the mathematical model describing the behavior of the entire reactor tank when the system is disturbed using change in inlet conditions. The block schematic representation of the CSTR process is shown in Fig. 2.

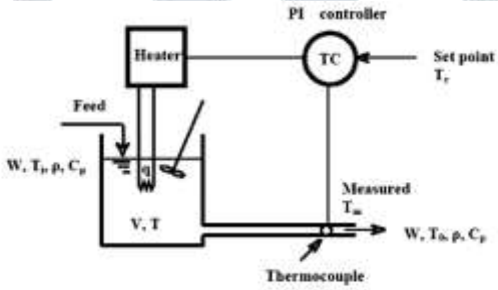

Fig. 2 Block schematic representation CSTR process

A continuous stirred tank reactor with a non isothermal reaction A + B→ Products and with first order rate equation ((-rA) = kCA) is considered. The tank has external heating coil with heat input Q (kJ/min) and the tank temperature is controlled by a PI controller in the closed loop feedback circuit as depicted in Fig. 2. The temperature of the tank is measured at the outlet. When the system is disturbed using change in inlet condition. The heat of reaction is assumed to be constant over the temperature range.

IV. DIFFERENT CONTROLLER TYPES

Various controllers used to control the CSTR process concerned in this project work are,

1) PI controller

2) Multi-model switching controller

3) Adaptive PI controller

4.1 PI Controller

The combined action of Proportional and Integral action is called proportional Integral mode. A Proportional and Integral (PI) controller is one of the most widely used conventional controllers in process industries for the control of temperature process. A PI controller inherently reduces the offset at the cost of oscillation. The output of the controller is

$$C(t) = k_c e(t) + k_i \int e(t)dt + c(0) \qquad (2)$$

A PI controller inherently reduces the offset at the cost of oscillations. The transfer function of a PI controller is as follows:

$$G_c(s) = K_c e\left(1 + \frac{k_i}{s}\right) \qquad (3)$$

Where,

K_c - Proportional gain

K_i - Integral gain and

e - Error, which is the difference between set point and controlled variable

The proportional gain, K_c and Integral gain, K_i of the controller are determined using Z-N method.

4.2 Multi-Model PI Controller

The switching action combined with the selection of PI controllers for various operating conditions based on the operating conditions, the model of the corresponding controller are selected by proper switching action in Multi-model PI controller. They are designed for linearized plant models. The controllers perform better than a linear single PI controller in a closed loop control system.

The control objective during the "cold start" is often different from the "normal operation" and that this is also true for many general systems. For example, a system to have a fast response time initially, but then put more emphasis on reducing steady-state error. Fast response time and small steady-state error are often conflicting objectives and require different set of parameters for the PI controller. When the operating conditions changes during normal operation the different set of PI controller parameters would take care of the control action. While the operating condition changes the selection of controller parameters is done by switching the appropriate controller for the concerned model of plant. The implementation of multi-model PI controller is shown in the block diagram representation as in the following Fig. 5.1.

Table 1 Multi model Controller parameters

Controller parameters	Model 1	Model 2	Model 3
K_c	63.314	159.76	730.33
K_i	4133.31	25932.96	548295.8

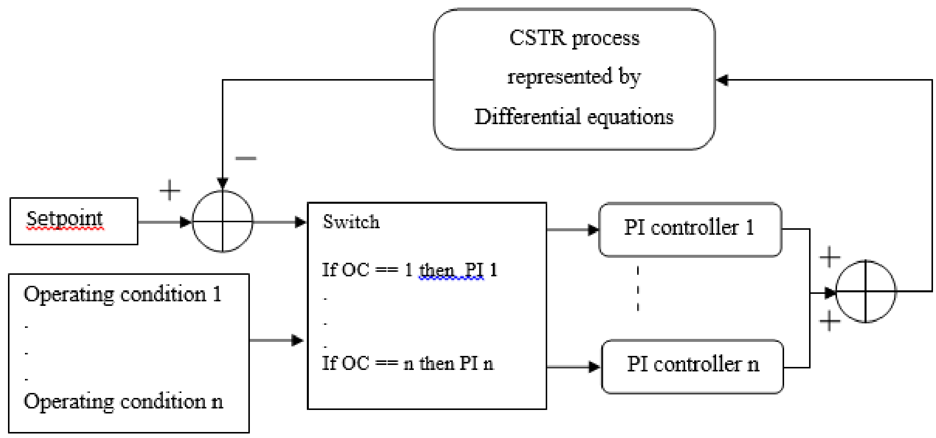

Fig. 3 Block diagram representation of Multi-model PI controller in closed loop structure

V. Adaptive PI Controller

The controlled system is decomposed into three subsystems consisting of the plant, the proportional and integral control. The parameters of the PI control, K_c , K_i are viewed as the interactions between these three subsystems. A general adaptation algorithm is developed in the theory of adaptive interaction which is applied for determination of these coefficients. The algorithm is simple and effective.

The performance of a system can be inferred from the evolution of polynomials of the controller parameters with respect to the system's parameters, that's through the excel spread sheet against the relationship between the controller parameters and the process operating conditions for processes with parametric uncertainties. The algorithm for designing adaptive PI controller through polynomial approach is shown in the flow chart as Fig. 4.

Table 2 Controller parameters for different Operating condition

Flow rate	1500	2000	2500
K_c	63.314	159.76	25932.96
K_i	4133.31	730.33	548295.8

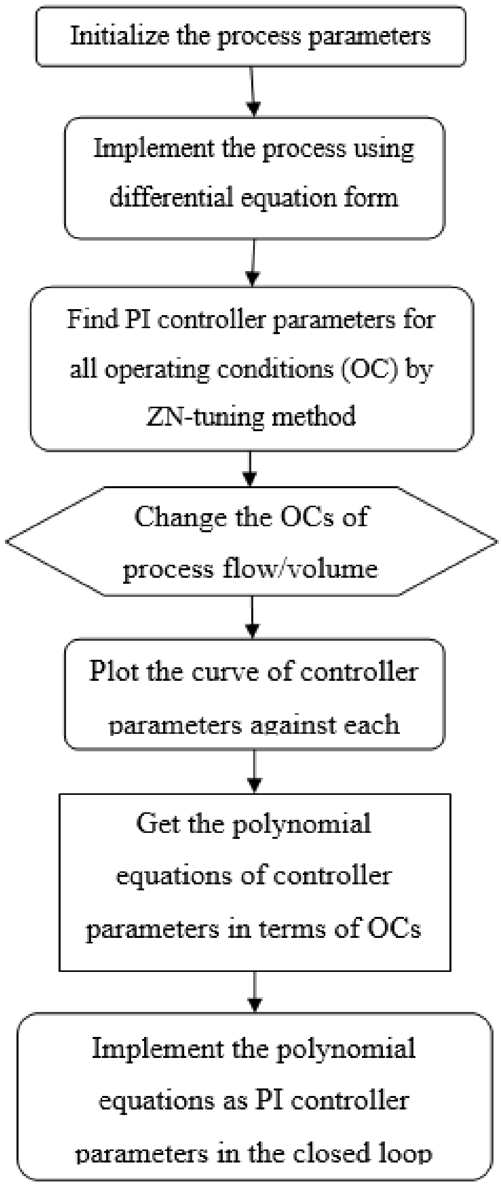

Fig. 4 Flowchart of the robust optimal PI controller design using polynomials

VI. Results and Discussion

This section presents servo and regulatory response of the process with PI controller, and an adaptive PI controller. Response of CSTR process with PI controller of those regarding operating conditions for a set point of (200^{0}c). Fig. 5 displays the closed loop response of CSTR under various operating conditions.

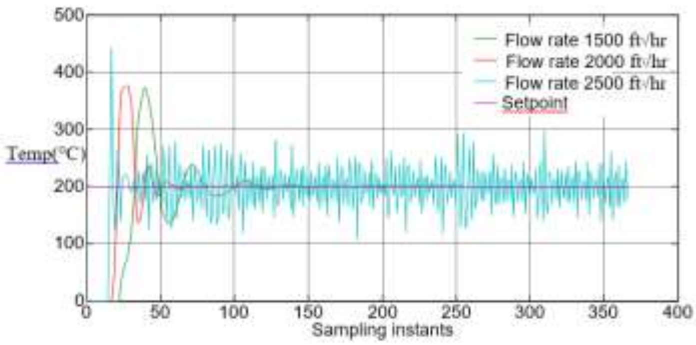

Fig. 5 Closed loop response of the linearized process with PI controller for various operating conditions

The process is initially at 0^{0}c. A set point of 200^{0}C is given at 0th sampling instant. For this disturbance, the PI controller in the loop has taken action to bring the process output to the reference after 79 sampling instants.

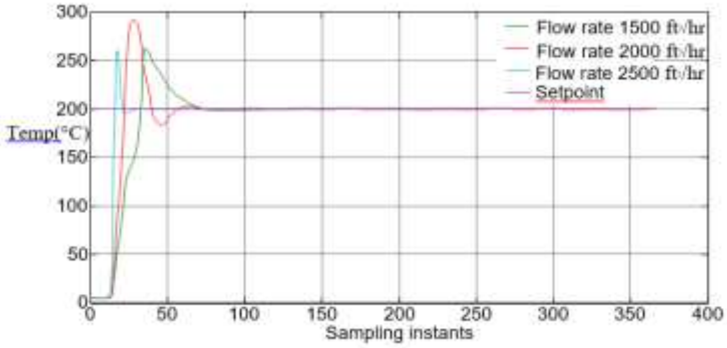

Fig. 6 Closed loop response of the nonlinear process with PI controller for various operating conditions

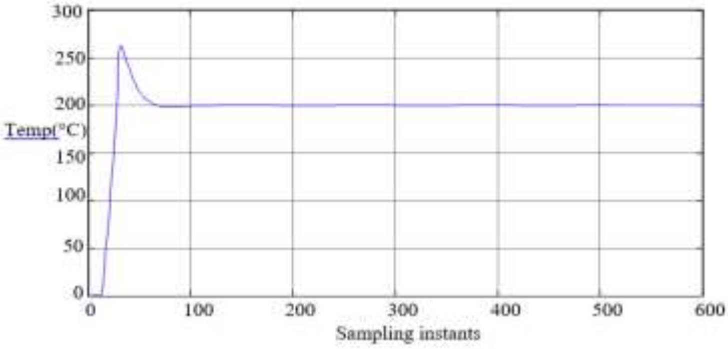

Fig. 7 Closed loop response with PI controller of nonlinear model 2 for flow rate 2500 ft^3/hr

The Fig. 7 above shows that response for the plant under 2500ft^3/hr flow rate, the nonlinear plant model is obtained for the flow rate of 2000ft^3/hr. The dead time is 20 sampling instants and the first peak has 20% overshoot and settles at 80 sampling instants.

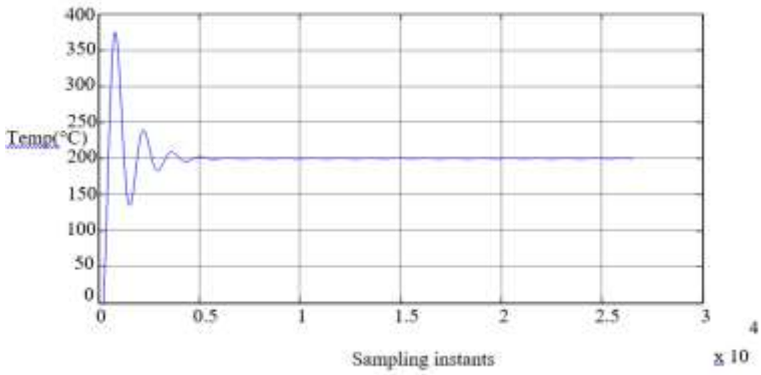

Fig. 8 Closed loop response with PI controller of linear model 2 for flow rate 2500 ft^3/hr

In the Fig. 8 the response of plant under 2500ft^3/hr flow rate, the dead time is 500 sampling instants with linearized model for flow rate of 2000 ft^3/hr. The first peak has about 80% overshoot and has decaying oscillations. The settling time is about 5000sampling instants.

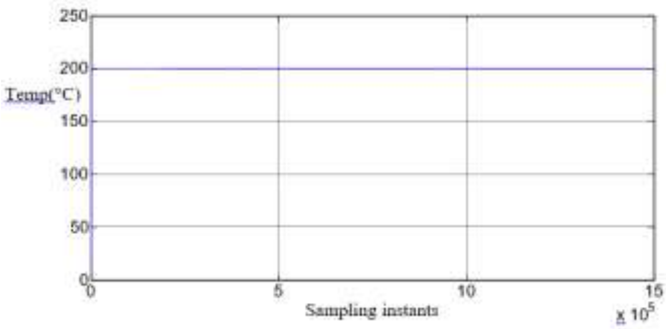

Fig. 9 Step response of nonlinear process with API controller for various operating conditions

In the above Fig. 9 the response is for the closed loop response of CSTR under all Operating conditions with Adaptive PI controller. The flow rate is set to 1500 ft^3/hr at 0 sampling instant, and its changed to 2000 ft^3/hr at 0.1 sampling instant. The flow rate is again changed to 2500 ft^3/hr at 0.2 sampling instants. The dead time is about 10 sampling instants and settles at 20 sampling time without any oscillation.

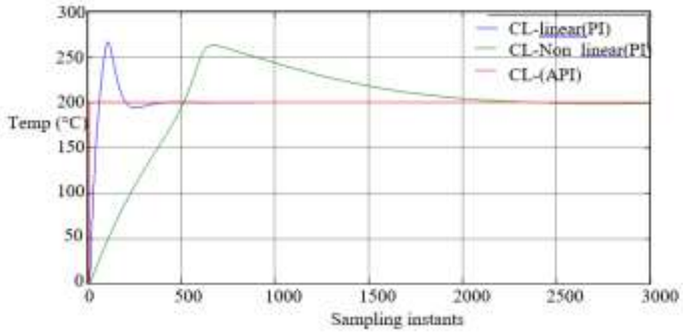

Fig. 10 Comparison of various CL responses with Adaptive-PI controller set point 200°C

The Figs. 10 and 11 shows the comparison of various closed loop responses with PI controller of linearized, nonlinear model and adaptive PI controller. Here the adaptive PI controller shows very less ISE, the settling and rise time is lesser than the other controller structure, which shows that its better than other PI control system.

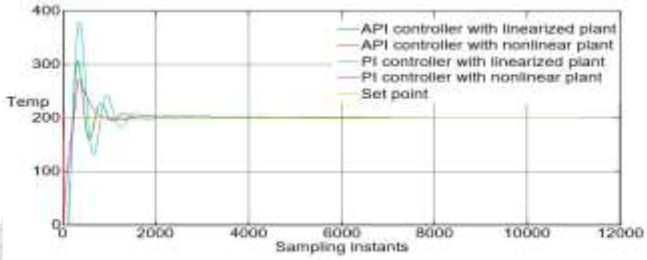

Fig. 11 Comparison of PI controller with nonlinear process/linearized process model and API controller CL responses.

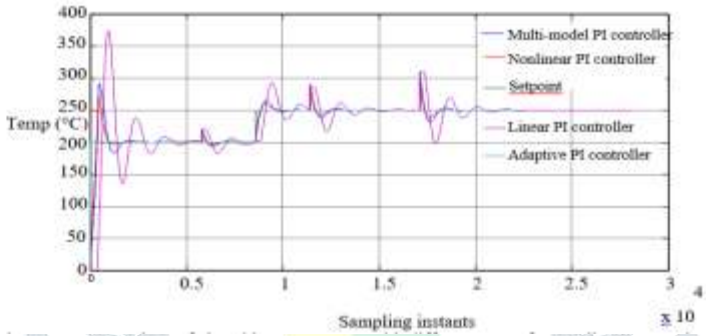

Fig. 12 Comparison of closed loop responses with different type of controllers concerning the servo and regulatory responses

The response in the Fig. 12 shows that the comparison of closed loop responses with different type of controllers concerning the servo and regulatory responses. The servo response is shown as the set point is given as 200°C at 0 sampling instant and it will be changed to 250°C at 800 sampling instants. And for regulatory action of the controllers, the load of 10% at 600 sampling instants, 20% at 1200 sampling instants and 30% at 1700 sampling instants of set point value has given. The PI controller with linearized model shows more oscillating responses than other controlled system. The adaptive PI controller shows the best results for servo and regulatory action, which quickly reacts to set point changes and for the load applied.

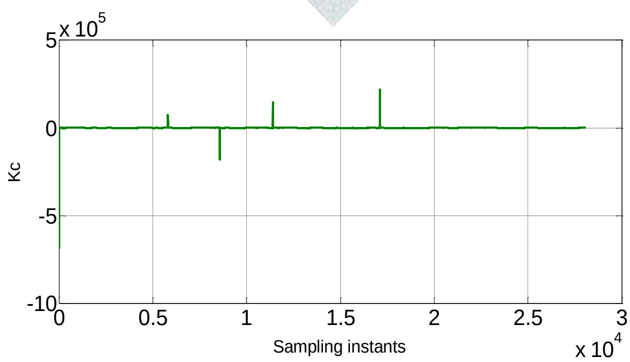

Fig. 13 K_c value for flow rate 2000 ft^3/hr

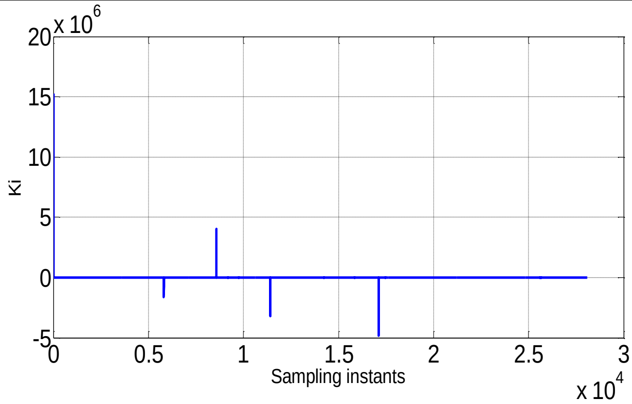

Fig. 14 K_i value for flow rate 2000 ft^3/hr

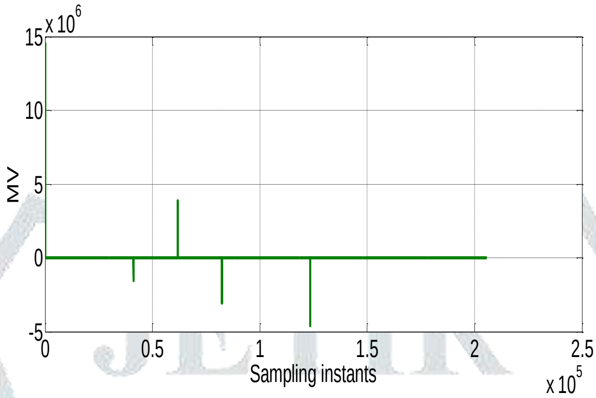

Fig. 15 Manipulated variable for operating condition of flow rate 2000 ft^3/hr

The adaptation of adaptive PI controller parameters K_c and K_i has been shown in the Figs. 13 and 14, its easily seen that the adaptation happens at the moment of set point change and load applied. In Fig. 16 its shown that the manipulated variable changes for servo and regulatory response under the flow rate 2000 ft^3/hr of CSTR process.

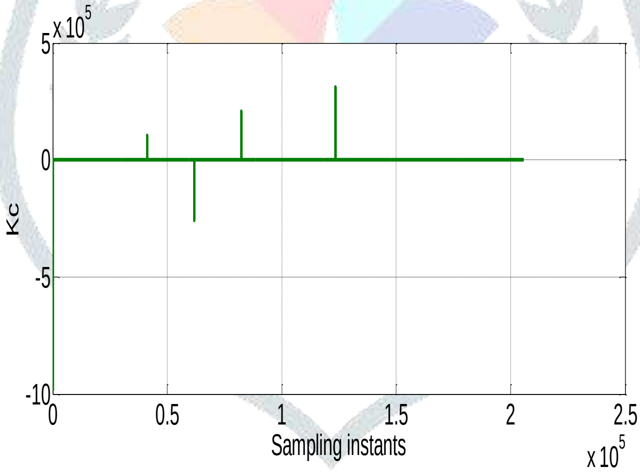

Fig. 16 K_c value for flow rate 2500 ft^3/hr

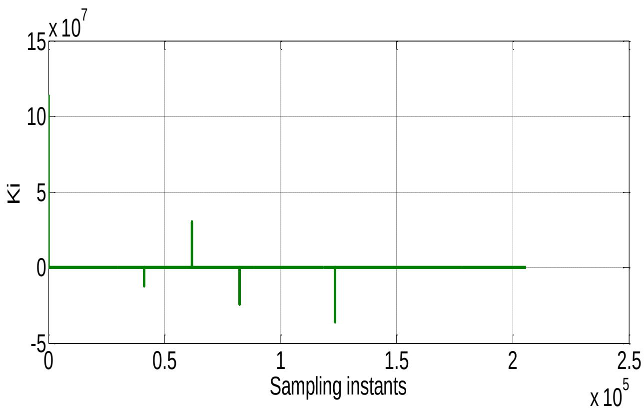

Fig. 17 K_i value for flow rate 2500 ft^3/hr

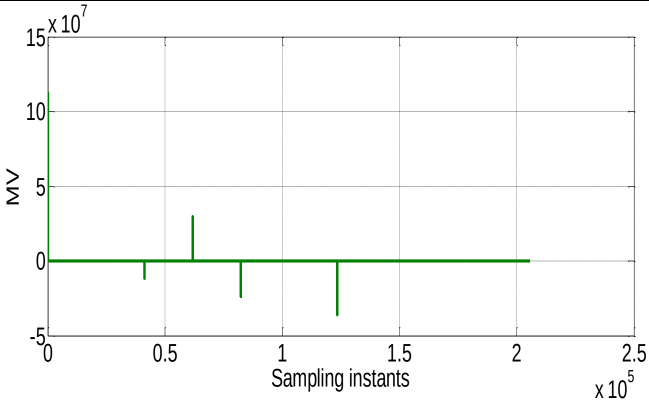

Fig. 18 Manipulated variable for operating condition of flow rate 2500 ft^3/hr

In the Figs. 16, 17 and 18, the adaptation of adaptive PI controller parameters K_c and K_i, and the manipulated variable for operating condition of flow rate 2500 ft^3/hr has been shown. The following Fig. 19, 20 and 21 also shows the same of adaptive PI controller parameters and the controller output. It can be seen that the adaptation of controller parameter for various condition.

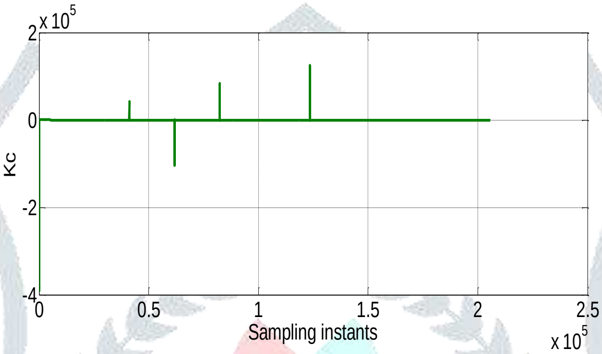

Fig. 19 K_c value for flow rate 1500 ft^3/hr

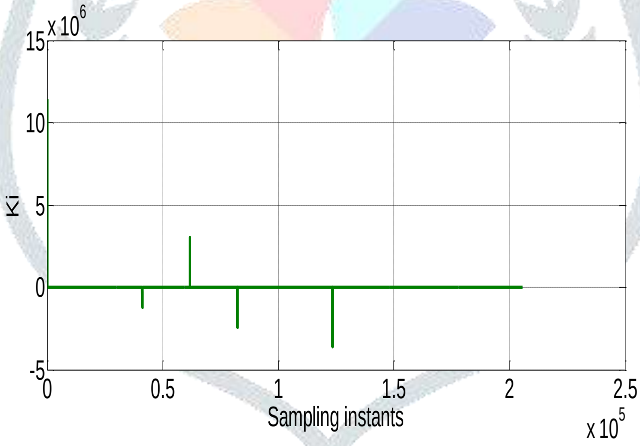

Fig. 20 K_i value for flow rate 1500 ft^3/hr

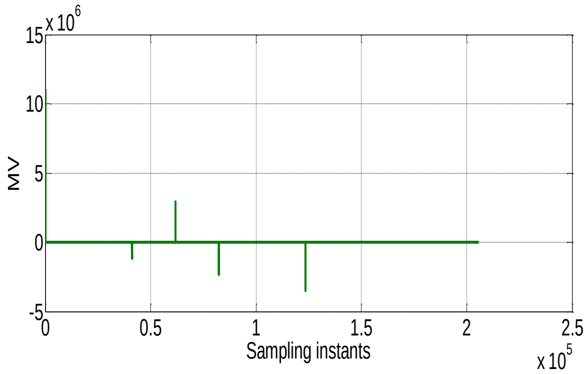

Fig. 21 Manipulated variable for operating condition of flow rate 1500 ft^3/hr

Table 2 Comparison of controller parameter for different operating condition

Operating condition Flow rate (ft^3/hr)	K_c	K_i
1500	-4e5	12e6
2000	-6e5	12e7
2500	-10e5	15e6

Table 3 Performance of different type of controllers comparison

Controller Structure	ISE	IAE
Mutimodel PI Controller	143.9	1.752
PI Controller with Linear Model	599.2	7.377
PI Controller with Nonlinear Model	112.5	2.103
Adaptive PI Controller	0.0911	0.002321

VII. CONCLUSIONS

The controlled system is decomposed into three subsystems consisting the plant, the proportional and integral control. The parameters of the PI control, K_c, and K_i are viewed as the interactions between these four subsystems. A general adaptation algorithm developed in the theory of adaptive interaction is applied to self-tuning these coefficients. The algorithm is simple and effective. Another way to investigate the adaptive controller is to view the self-tuning PI controller as a nonlinear controller because the parameters K_c, and K_i are changing continuous according to the adaptation dynamics. In general, it does not require that K_c, and K_i convergent to some constants. In fact, it will let them change as the inputs or disturbances change. Because of this property, the adaptive PI controllers can do more than conventional PI controllers. For example, they can stabilize systems than cannot be stabilized by conventional PI controllers. The effectiveness of the adaptive PI controllers had been investigated by simulation for a nonlinear plant and it's been found that any case where the closed loop systems is unstable. The PI tuning algorithm proposed in this project work has many advantages in applications, most notably, its simplicity and independence of the plant model. The simulation results shows that it performs very well under various situations. A further proof of this applicability, the tuning mechanism remains unchanged.

REFERENCES

[1] Ogunnaike, B.A. and W.H. Ray (1994). Process dynamics, modelling, and control. Oxford University Press, New York.
[2] Schmidt, L.D. (2005). The engineering of chemical reactions. Oxford University Press, New York.
[3] Corriou, J.P. (2004). Process control. Theory and applications. Springer-Verlag, London.
[4] Dostál, P., V. Bobál and M. Blaha (2001). One approach to adaptive control of nonlinear processes. In: Proc. IFAC Workshop on Adaptation and Learning in Control and Signal Processing ALCOSP 2001, Cernobbio-Como, Italy, 407-412.
[5] Middleton, R.H. and G.C. Goodwin (1990). Digital Control and Estimation - A Unified Approach. Prentice Hall, Englewood Cliffs.
[6] Mukhopadhyay, S., A.G. Patra and G.P. Rao (1992). New class of discrete-time models for continuostime systems. International Journal of Control, 55, 1161-1187.
[7] Goodwin, G.C., S.F. Graebe and M. E. Salgado (2001). Control System Design. Prentice Hall, New Jersey.
[8] Stericker, D.L. and N.K. Sinha (1993). Identification of continuous-time systems from samples of input-output data using the δ-operator. Control- Theory and Advanced Technology, 9, 113-125.
[9] Ortega, R. and R. Kelly (1984). PID self-tuners: Some theoretical and practical aspects. IEEE Trans. Ind. Electron., Vol. IE-31, 332-338.
[10] Kučera, V. (1993). Diophantine equations in control – A survey. Automatica, 29, 1361-1375.
[11] Bobál, V., J. Böhm, J. Fessl and V. Macháček (2005). Digital self-tuning controllers. Springer Verlag, Berlin.