International Journal of Pure and Applied Mathematics
Volume 117 No. 22 2017, 59-63
ISSN: 1311-8080 (printed version); ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue
ijpam.eu

A COMPARATIVE ANALYSIS OF VARIOUS CONTROL STRATEGIES ON HEAT EXCHANGER SYSTEM

Shennes Mathew, T. Janani
Assistant Professor, Department of Electronics and Communication Engineering,
Karpagam College of Technology, Coimbatore, Tamil Nadu, India

***Abstract-* A heat exchanger is a device which transfer heat from a hot fluid to a cooler fluid, so that we can make the outlet fluid temperature in control. First of all simple conventional PID controller can be used to control the temperature of outlet fluid of the exchanger system a. Conventional PID control techniques has a lot of disadvantages by its performance, so that model based control technique is employed and thus an internal model controller is developed to control the temperature of outlet fluid of the exchanger system. An advanced controller called Model Predictive Controller is used to control the temperature of the same and finally all the three controllers were compared with their performances. The parameters like Settling time, overshoot, ISE, IAE and ITAE errors are used for the analysis. From the simulation results, it is found out that the Model Predictive Controller out performs other feedback PID controllers whereas IMC-PID provides a satisfactory performance.**

Keywords: Internal Model Controller, Model Predictive Controller, PID Controller, Heat exchanger

1.INTRODUCTION

A heat exchanger allows heat from a liquid to pass to another liquid without mixing those two liquids. It is the process of taking off heat from a hot liquid and passing it to another liquid, by reducing the heat from the primary liquid. MPC is based on open loop control and close loop control method. It generates an online feedback control by using the open-loop optimization. The basic concept involved in MPC design is to predict the future plant response by the help of a process model and always trying to minimize a finite horizon objective function which consists of a sum of future predicted errors and control moves. A chemical reactor called "stirring tank" is depicted in the figure below. Liquid will be allowed to enter through the top inlet of the tank. Steam has been supplied to the tank of the heat exchanger through the control valve, and on varying the amount of it, so that tank liquid temperature can be maintained at a constant level. The main disturbances in this process are the temperature variations in the input flow. This example shows how to include feedback and feed-forward compensators in a process to regulate the temperature of a chemical reactor through a heat exchanger. This paper presents specific details about the simulated case study of MPC, over the Heat Exchanger model. A MPC controller for the heat exchanger model performance is comparing with the different PI controller tuning techniques and advancements. Then comparing all the performance results like s conventional PI controller. The MPC simulation was performed using MATLAB and the Model Predictive Control Toolbox. In order to reduce the simulation time needed to explore a variety of design options and design parameters, MPC was employed. The goal of this paper is to understand the design and performance of model predictive controller i.e., maintaining the output with respect to disturbance and manipulated variables and compare its performance with other controllers.

2.HEAT EXCHANGER SYSTEM

A. Process Description

Suppose we have a gas central heating furnace (boiler) that heats hot-water radiators in various rooms in your home. It works by burning natural gas, making a line or grid of hot gas jets that fire upward over water flowing through a network of pipes. When water flows through the pipes, it absorbs the heat energy and heats up. This arrangement is the basic design concept of heat exchanger: the gas jets cool down and the water heats up. And now the hot water is removed from the total system.

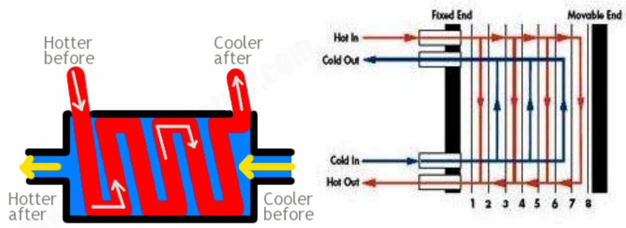

Fig.1: Schematic Diagram of Heat Exchanger

A heat exchanger is a device that transfers the heat from a fluid to pass to the second fluid without mixing or direct contact. The principle of a heat exchanger is that it transfers the heat without transferring or mixing up the fluid that carries the heat.

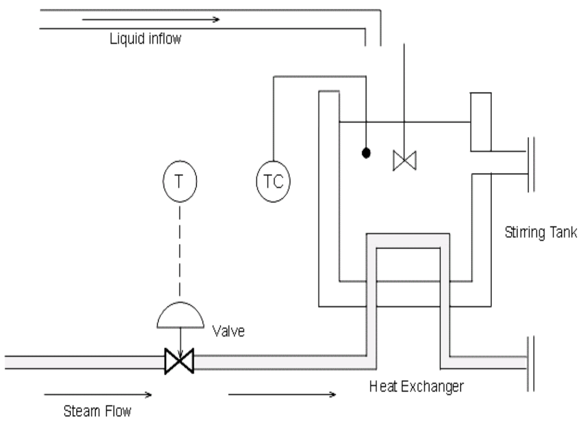

Fig 2 Schematic Diagram for Heat Exchanger

B. Determine Process Variable

The heat exchanger model we had taken for the study is described with the transfer function. A block diagram representation of the open-loop process is shown below.

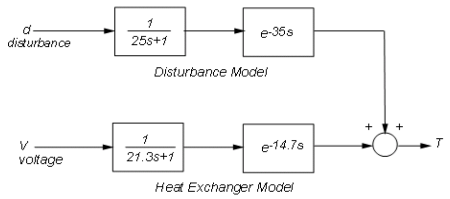

Fig.3.System Model

3.CONTROLLER DESIGN

A. Concept

MPC also known as Receding horizon control or Moving horizon control. It uses an specially designed dynamic plant model to predict the effect of future reactions of the manipulated variables on the output and the control signal obtained by minimizing the cost function. This predication is based on the constraints on both the inputs and outputs of the process. An optimal input sequence is calculated. The measurements are then sent back to the controller, and a new optimizing problem is solved [1].

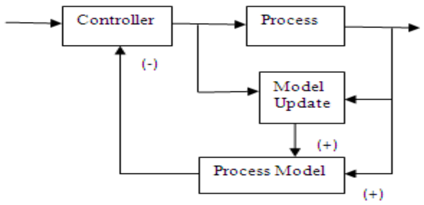

Fig.4: Structure of MPC controller

B. Overview

MPC is a feedback implementation of optimal control using:

- Finite prediction horizon
- on-line computation

MPC controller uses a process model and a constrained, on-line optimization to determine the optimal future control move sequence while using linear and dynamic systems.. The first control move is implemented and the calculations are then repeated at the next control calculation interval. Three variants of MPC algorithm (linear MPC, multiple MPC and Non-linear MPC) for power plant boiler and compared in the terms of control performance versus complexity trade-off in [1].

C. Principle of MPC

MPC is fully iteration based and also finite horizon optimization of a plant model. At time t, the state is sampled and a cost minimizing control strategy of optimization is computed for future prediction.

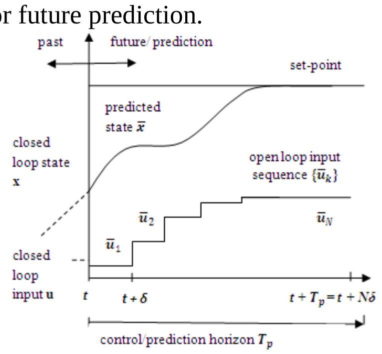

Fig 5: Principle of MPC

MPC control algorithm is calculating the optimum control moves based on the described model for the system, also based on the past control moves and an optimization cost function J over the receding prediction horizon.

The optimization cost function is:

$$J = \sum_{i=1}^{N} \omega_{xi} (r_i - x_i)^2 + \sum_{i=1}^{N} \omega_{ui} \Delta {u_i}^2 \qquad (3)$$

without changing constraints where

x_i is i-th controlled variable
r_i is i-th reference variable
u_i is i-th manipulated variable
ω_{xi} is weighting coefficient for the relative importance of x_i
ω_{ui} is weighting coefficient of relative big changes in u_i

This model can be made into a step-response model. The final discrete step-response model will be on the form:

$$y_{k+1} = \sum_{i=1}^{R-1} a_i \Delta u_{k-i+1} + a_R u_{k-R+1} + y^1 \qquad (4)$$

Where y_{k+1} is the output at time k+1,
a is step-response coefficient
y^0 is the outputs initial conditions
R is a constant.

The MPC controller trying to minimize a quadratic object functions.

$$\min_{u_k^N} \phi_k = \sum_{i=0}^{P} \left(\left(y_{k+i} - y^r\right)^T Q \left(y_{k+i} - y^r\right) + \left(u_{k+i} - u^r\right)^T R \left(u_{k+i} - u^r\right) \right) \qquad (5)$$

Subject to the constraint $\Delta u \geq c_{k+1}$ (6)

Where P is the prediction horizon
N is the control horizon,
y^r is the reference output
u^r is the reference input
Q is the weights on the outputs
R is the weights on the inputs

Quadratic solver can be used to solve the function so as to ensure fast optimizing.

While minimizing the object function, or the required function, the tuned prediction horizon (P) depicts the controller how many sample steps ahead should be used. The control horizon (M) gives the controller how many control steps should be used when minimizing the function. The larger M is compared to P, the bigger the chance is that the controller will find an input sequence to minimize the function. But that may lead to an aggressive use of input and an unstable system. The values of these parameters will be a trade-off between good performance and time limits.

A MPC-controller can take constraints both for the inputs and outputs. The constraints will be formulated like

$$u_{k+1}^{min} \leq u_{k+1} \leq u_{k+1}^{max} \qquad (7)$$

$$y_{k+1}^{min} \leq y_{k+1} \leq y_{k+1}^{max} \qquad (8)$$

MPC development time is much shorter than compared to other advanced control methods. This is by optimizing a finite time-horizon. Its ability to predict the future events and can take control action accordingly.

4.SIMULATION AND RESULTS

A. Case Study System

The Heat Exchanger model is taken as study case, which is a 2×2 transfer function model of a pilot plant distillation column that separates methanol and water. The system outputs are the distillate and bottoms compositions, xD and xB, which are controlled by the reflux and steam flow rates, R and S.

B. PI Controller Tuning

PI Controller tuning is the process of finding the values of proportional and integral gains of a PI Controller to achieve desired performance and meet design requirements. Here we had tuned PI controller for the heat exchanger model. We have used Ziegler Nichols tuning method to finding out the K_p, K_I values.

$$K_I = \frac{K_p}{\tau_I} \tag{9}$$

C. Direct Synthesis PI Controller Tuning

The controller designing method is based on a model of the system and a required closed-loop transfer function in Direct Synthesis (DS) method . The latter is usually specified for set-point changes, but responses to disturbances can also be utilized (Chen and Seborg, 2002). The transfer function will be then as

$$\frac{y}{r} = \frac{G_p G_c}{1+G_p G_c} \tag{10}$$

It can be rearranged as

$$G_c = \frac{\left(\frac{y}{r}\right)}{G_P\left[1-\left(\frac{y}{r}\right)\right]} \tag{11}$$

Let $\left(\frac{y}{r}\right)_d$ as the desired closed-loop transfer function for the change in set point and we are assuming the system model as

$$G_c = \frac{\left(\frac{y}{r}\right)_d}{G_{P1}\left[1-\left(\frac{y}{r}\right)_d\right]} \tag{12}$$

Since $\left(\frac{y}{r}\right)_d$ have a direct effect on the resulting controller, it should be chosen so that the closed-loop performance is better and the resultant design of the controller is practically realizable. The DS controller in last equation results in the following closed loop transfer function

$$\left(\frac{y}{r}\right)^{DS} = \frac{G_p\left(\frac{y}{r}\right)_d}{G_{P1}+\left(\frac{y}{r}\right)_d(G_P-G_{P1})} \tag{13}$$

$$\left(\frac{y}{r}\right)^{DS} = \frac{G_{P1}G_d\left(\frac{y}{r}\right)_d}{G_{P1}+\left(\frac{y}{r}\right)_d(G_P-G_{P1})} \tag{14}$$

For the ideal case where the process model is perfect (i.e., $G_P = G_{P1}$), the closed loop transfer function become

$$\left(\frac{y}{r}\right)^{DS} = \left(\frac{y}{r}\right)_d \tag{15}$$

$$\left(\frac{y}{d}\right)^{DS} = G_d\left[1-\left(\frac{y}{r}\right)_d\right] \tag{16}$$

respectively.

D. IMC-PI Design

The IMC-PID tuning rules reveal good set point tracking nevertheless sluggish disturbance rejection, which becomes severe when a process has a small time-delay. The simulation studies of several process models show that the proposed design method affords improved disturbance rejection for lag-time dominant process, when the various controllers are all tuned to have the same degree of sturdiness permitting to measure of maximum sensitivity.

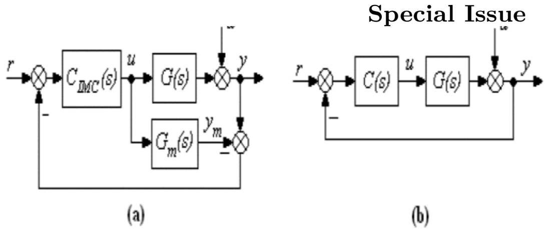

Fig.6. (a) Internal Model Control configuration
(b) Conventional configuration

The goal of control system design is to accomplish a wild and accurate set-point tracking. This implies that the effect of external disturbances should be amended as proficiently as possible and also being assured of tactlessness to modeling error. The PID parameter tuning law based on the relationship of the IMC and the PID controller has been proposed by Rivera *et al.* [1986]. PID control structure is shown in Fig.3 (a), where g_c and g_c^*. are the PID controller and the controlled process, respectively. They are given by

Proportional gain (K_c) = $\frac{T+0.5\theta}{K(\lambda+0.5\theta)}$ (17)

Integral Time (T_i) = $T + 0.5\theta$ (18)

Derivative Time (T_d) = $\frac{T\theta}{2T+\theta}$ (19)

E. MPC Tuning Parameters

The closed-loop MPC simulation was performed using MATLAB and the Model Predictive Control Toolbox. The manipulated variables (MV's) and the controlled variables (CV's) of heat exchanger is taken to Model predictive controller with constrains.

The tuning of MPC Controller for the heat exchanger system taken here is based upon [ ]. MPC values are tuned for: Control Horizon (M), Prediction Horizon, and for Control Interval.

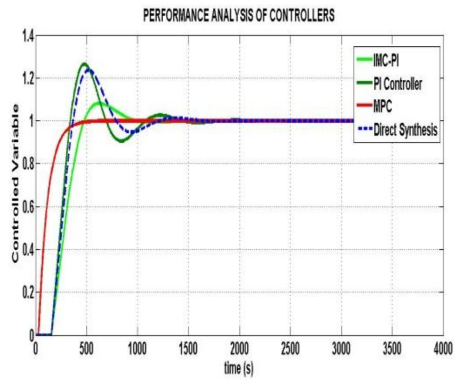

Fig.7. Comparison chart for various controller over the modeled heat exchanger system.

Table.1: Performance of different controllers over the heat exchanger system.

PARAMETER	PI CONTROLLER	DIRECT SYNTHESIS PI	IMC-PI	MPC
Settling Point	1700	1550	1000	600
Maximum Peak Overshoot	1.25	1.2	1.08	1.0
ISE	21.9	20.3	15.65	4.7
IAE	32.19	28.33	20.84	3.6
ITAE	649.9	465.5	231.9	67.1

5. CONCLUSION

Heat Exchanger model is taken as the primary system model. This system is controlled with conventional PI controller, Direct Synthesis PI controller, IMC-PI controller and MPC controller. Performance indices like settling point, overshoot, and ISE, IAE, ITAE errors of MPC controller is compared with other PI controllers. The result depicts MPC is far better than the conventional in all manners as it provides smooth reference tracking with reduced peak overshoot and better closed loop performances such as ISE, IAE, ITAE. The closed-loop MPC simulation was performed using MATLAB and with Model Predictive Control. This shows why MPC is much suitable for industrial applications. Model Predictive Controller tuning based on the paper [6] has been used for this heat exchanger process. Prediction horizon is tuned and taken the values. Control horizon value is taken within a range of 1-6. Along with the tuning parameters, control interval, weights, and gain also having a great effect on the total performance of the system.

REFERENCE

[1] Sivakumar, R.; and Shennes Mathew (2013). Design and Development of Model Predictive Controller for Binary Distillation Column, *International Journal of Science and Research*, 2(12), 445-451

[2] Frank Allgöwer, Rolf Findeisen, and Zoltan K. Nagy "Nonlinear Model Predictive Control: From Theory to Application" ; Institute for Systems Theory in Engineering, University of Stuttgart, Germany. J. Chin. Inst. Chem. Engrs., Vol. 35, No. 3, 299-315, **2004**

[3] I-Lung Chien Hsiao-Ping Huang, and Jen-Chien Yang; "A Simple Multiloop Tuning Method for PID Controllers with No Proportional Kick"; Ind. Eng. Chem. Res., **1999**, 38 (4), 1456-1468

[4] Mayne D.Q, Rawlings J. B., Rao C.V., Scokaert P. O. M.; "Constrained model predictive control: Stability and optimality"; Survey Paper -Automatica 36 ; **2000**; 789-814

[5] Michael L. Luyben, William L. Luyben; "Essentials of Process Control"; McGraw-Hill, **1997.**

[6] Rahul Shridhar and Douglas J. Cooper; "A Tuning Strategy for Unconstrained SISO Model Predictive Control" 2nd. Eng. Chem. Res.,**1997**, 36, 729-746

[7] Sigurd Skogestad; **"**Dynamics and control of distillation columns - A tutorial introduction"; IChemE, 75, Part A., **1997**, 539-562

[8] R. Sivakumar, K. Suresh Manic,V.Nertiga, R.Akila, K.Balu; "Application of Fuzzy Model Predictive Control in Multivariable Control of Distillation Column"; International Journal of Chemical Engineering and Applications, Vol. 1, No. 1, June **2010**, 38-42

[9] Wayne Bequette. B., "Process Control Modelling design and simulation", PHI Publication.,**2003**.

[10] Dale E. Seborge, Thomas F. Edgar, Duncan A.Mellichamp; "Process Dynamics and Control", Singapore, John Wiley &Sons.,**2004**.