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Block-Box Modelling and Control a Temperature of the Shell and Tube Heatexchanger using Dynamic Matrix Controller

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Abstract: This paper describes the Dynamic Matrix Control (DMC) indented for Shell and tube Heat exchanger. Essentially in many cases the conventional controller like PID doesn't provide the satisfactory control action for a highly nonlinear system. So that here DMC is designed and it is used to control the outlet temperature of a tube side by varying the inlet cold fluid through the shell side. Here Recursive least Square technique used to estimate the parameters and build the extract model of a process. The MATLAB platform is used and accomplished of the DMC and Conventional PID controller.
Keywords: Heat exchanger, Dynamic Matrix control (DMC), Recursive least square (RLS).

I. Introduction:

Heat exchanger is one of the key elements of the petrochemical industries and thermal plants, which is having nonlinear, multivariable and non-stationary process. Both modeling and controlling a Shell and tube Heat exchanger is a very difficult task because it is highly nonlinear system purpose of heat exchanger is transfer the heat from one fluid to another with minimum loss [1-3]. There are different types of heat exchangers used in industries here we are used in shell and tube heat exchanger because it is higher efficiency [4-6]. Actually tubes of heat exchanger are fixed inside the shell. Both having separate inlets and outlets, no mixing and direct contact among the fluids. Hot fluid is flow through the tube and cold fluid flowing through the shell. In industries, large heat exchanger networks are engaged to operate wasted heat energy. Actually heat transfer process is highly nonlinear in nature. In many cases conventional PID controllers are used in industry, but they face difficulties in controlling non-linear process and cannot predict immediate change in an input [7-9]. To overcome these difficulties MPC controller is used and it is mainly used for industries side [10].

Actually Heat exchanger mathematical model needs to be implemented the predictive controller so that here the real time data will be taken from the Heat exchanger and the model will be developed from with the help of system identification technique [11-12].Some review articles consider MPC on academic perspective. Some paper deal with (SMPC) simplified model predictive control algorithm [13].Dynamic matrix control (DMC) is the most popular controller and it's generally used it can be accept the state space representation models and reduce the computational time [14-15].

II. Recursive Least Square:

Linear model can be obtained by two ways one is system identification and another one is linearization of a nonlinear model. System identification techniques used through experimental study is possible, but the nonlinear model of the process having different open loop and closed loop studies as possible [16,17]. Actually linear block box model can be developed by correlating sequence relationship between input and output data. After obtaining the data model has been developed by using a Recursive least square algorithm (RLS) [18]. The many practical causes it is necessary that parameter estimation takes place concurrently system operation it is parameter estimation problem is called online identification and it is methodology usually leads to recursive procedure for every new measurement for this region is also called as recursive identification. Fig.1 shows that experimental setup of heat exchanger.

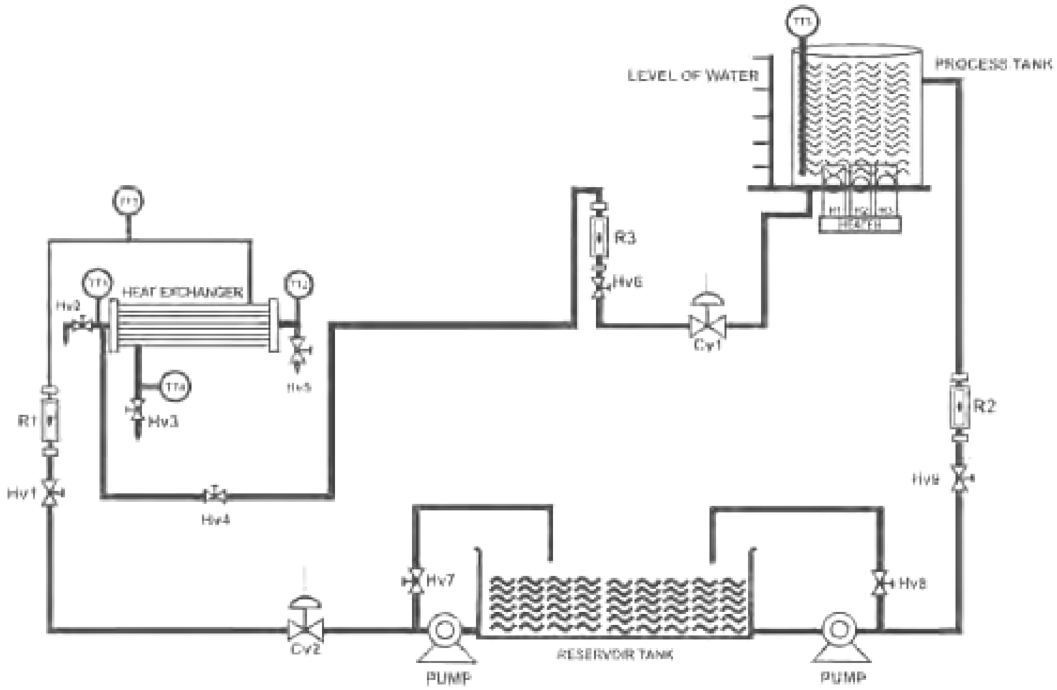

Fig.1. Heat exchanger Experimental setup

R1 – cold water flow rate
R2 – Tank filling water flow rate
R3 – Hot water flow rate
TT1 – Tube inlet temperature
TT2 – Tube outlet temperature
TT3 – Shell inlet temperature
TT4 – Shell outlet temperature
TT5 – Tank temperature
Cv1 – Tube flow control valve
Cv2 – Shell flow control valve
Hv1, Hv2, Hv3, Hv4, Hv5, Hv6 – Hand valves

Where is change in θ(N) because of the new (n+1) measurement

$$\theta(t) = \left(\sum_{k=1}^{t} \phi(K)\,\phi(K)^{T}\right)^{-1} \left(\sum_{k=1}^{t} \phi(K)\,y(K)\right)$$

Define P (t) as

$$P(t) = \left(\sum_{k=1}^{t} \phi(t)\,\Psi(K)^{T}\right)^{-1} \quad (1)$$

$$P(t)^{-1} = P(t-1)^{-1} + \phi(K)\,y(K) \quad (2)$$

θ is denoted as the estimated parameter vector

$$\theta(t) = P(t)\left(\sum_{k=1}^{t} \sum_{k=1}^{t}\phi(K)\,y(K)\right) + \phi(t)\,y(t) \quad (3)$$

$$\sum_{k=1}^{t-1} \phi(K)\,y(K) = P(t-1)^{-1}\,\theta(t-1) \quad (4)$$

$$= P(t)\,P(t-1)^{-1}\,\theta(t-1) + P(t)\,\phi(t)\,y(t)$$

$$P(t-1)^{-1} = P(t)^{-1} - \phi(t)\,\phi^{T}(t)$$

$$= P(t)\left(P(t)^{-1} - \phi(t)\,\phi^{T}(t)\right)\theta(t-1) + \phi(t)\,y(t) \quad (5)$$

We will obtain new estimate to θ denoted as θ (N+1)

$\theta(t) = P(t)\,((P^{-1}(t)\ \theta(t-1) - \phi(t)\,\phi^{T}(t)\ \theta(t-1) + \phi(t)\,y(t)$ (6)

$\theta(t) = \theta(t-1) - P(t)\,\phi(t)\,\phi^{T}(t)\ \theta(t-1) + P(t)\,\phi(t)\,y(t)$

$\theta(t) = \theta(t-1) + P(t)\ \phi(t)\ (y(t) - \phi^{T}(t)\ \theta(t-1))$ (7)

$E(t) = y(t) - \phi^{T}(t)\ \theta(t-1)$

$U(t) = \phi(t)\,\phi(t)$ (8)

III. Dynamic Matrix Control Design (DMC):

Dynamic Matrix control (DMC) algorithm is designed to predict the future response of the plant [19,20]. It is mainly used in industries especially in chemical industries. Now days it is mainly used in model identification and global optimization. DMC is the unconstrained multivariable control algorithm. DMC algorithm, key futures are, we are taking the linear step response model of the plant, prediction horizon performance over the quadratic problem and the least square problem is the solution of computed optimal inputs [21]. The main objective of DMC is the future response of the plant output behavior trying to follow set point as close as possible to the least square sense with the manipulated variable (MV) moves. The manipulated variable is selected to minimize a quadratic objective it can be considered to minimize the future error. DMC control algorithm started from similar cases of a system without constraints and it extended to multivariable constraint cases.

The step response model employed as

$$y(t) = \sum_{i=1}^{\infty} g_i\,\Delta u(t-i) \quad (9)$$

Predicted values along the horizon

$$\hat{y}\left(t+\frac{k}{t}\right) = \sum_{i=1}^{\infty} g_i\,\Delta u(t+k-i) + \hat{n}\left(t+\frac{k}{t}\right) = \sum_{i=1}^{k} g_i\,\Delta u(t+k-i) + \sum_{i=k+1}^{\infty} g_i\ \Delta u(t+k-i) + \hat{n}\left(t+\frac{k}{t}\right)$$
(10)

Here the disturbance s considered to constant that is, $\hat{n}\left(t+\frac{k}{t}\right) = \hat{n}\left(\frac{t}{t}\right) = y_m t - \hat{y}\left(\frac{t}{t}\right)$ it can be written as

$$\hat{y}\left(t+\frac{k}{t}\right) = \sum_{i=1}^{k} g_i\ \Delta u(t+k-i) + \sum_{i=k+1}^{\infty} g_i\,\Delta u(t+k-i) + y_m(t) - \sum_{i=1}^{\infty} g_i\,\Delta u(t-i) = \sum_{i=1}^{k} g_i\ \Delta u(t+k-i) + f(t+k)$$

F(t+k) considered as free response of the system and the part of response not depend on the future control action that is given by

$$Xf(t+k) = y_m(t) + \sum_{i=1}^{\infty} (g_{k+i} - g_i)\,\Delta u(t-i) \quad (11)$$

The system is the system is stable the co-efficient g_I of step response to be constant after the value of N-sampling periods, so it can be considered as

$$X\ g_{k+i} - g_i \approx 0, i > n \quad (12)$$

That fore free response f(t+k) computed as

$$f(t+k) = y_m(t) + \sum_{i=1}^{N} (g_{k+i} - g_i)\,\Delta u(t-i) \quad (13)$$

The m-control actions the prediction can be computed as the prediction horizon k=(1,…………………,p) it can be derived as

$$\hat{y}\left(t+\frac{1}{t}\right) = g1\,\Delta u(t) + f(t+1)$$

$$\hat{y}\left(t+\frac{2}{t}\right) = g2\,\Delta u(t) + g1\,\Delta u(t+1) + f(t+2)$$

$$\vdots$$

$$\hat{y}\left(t+\frac{p}{t}\right) = \sum_{i=1}^{m} g_i\,\Delta u(t+p-i) + f(t+p)$$

The system dynamic matrix G is given by

$$G = \begin{bmatrix} g_1 & 0 & \cdots & 0 \\ g_2 & g_1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ g_m & g_{m-1} & \cdots & g_1 \\ \vdots & \vdots & \ddots & \vdots \\ g_p & g_{p-1} & \cdots & g_{p-m+1} \end{bmatrix}$$

Then it can be written by

$$\hat{y} = Gu + f \qquad (14)$$

This expression related the future outputs of the control increments, so that it will be use to calculate the necessary action to achieve a system behavior.

Control algorithm equations derived by

$$J = \sum_{j=i}^{p} [\hat{y}]\left(t+\frac{j}{t}\right) - w(t+j)]^2 \qquad (15)$$

The control effort include and it present the generic form

$$J = \sum_{j=1}^{p} [\hat{y}]\left(t+\frac{j}{t}\right) - w(t+j)]^2 + \sum_{j=1}^{m} \lambda[\Delta u(t+j-1)]^2 \qquad (16)$$

The minimization of cost function $J=ee^T+\lambda uu^T$ and the vector future errors of the prediction horizon and the u vector is composed future control increments and it can be obtained compute the J and it equal to zero and it provides the result as

$$Xu = (G^T G + \lambda I)^{-1} G^T (w - f) \qquad (17)$$

IV. Results and Discussion:

The real time data are taken from the experimental Shell and tube Heat exchanger Table (I) shown shell flow rate and sampling instants and fig (2) shows that Temperature response of the process. The PID is adjusted by the Ziegler-Nicholas (Z-N) method. Both the PID controller and DMC controller for the Shell and tube heat exchanger validated using MATLAB environment and the result is obtained. The Shell flowrate sampling instants tabulated in Table (I) and performance indicates in tabulated in Table (II).The DMC and PID response shown in fig (2) positive disturbance response shown in fig (3) and the negative disturbance response plotted in the fig (4) and different step changes response shown in fig (5) and fig (6) from the responses we prove that DMC gives fast response and quick setting time of the PID.

Table.I. Shell Flow Rate and Sampling Instants

Shell inlet Flow rate (LPH)	Sampling Instants
650	4000
650-600	4000-4500
600-550	4500-5000
550-500	5000-5500
500-450	5500-6000

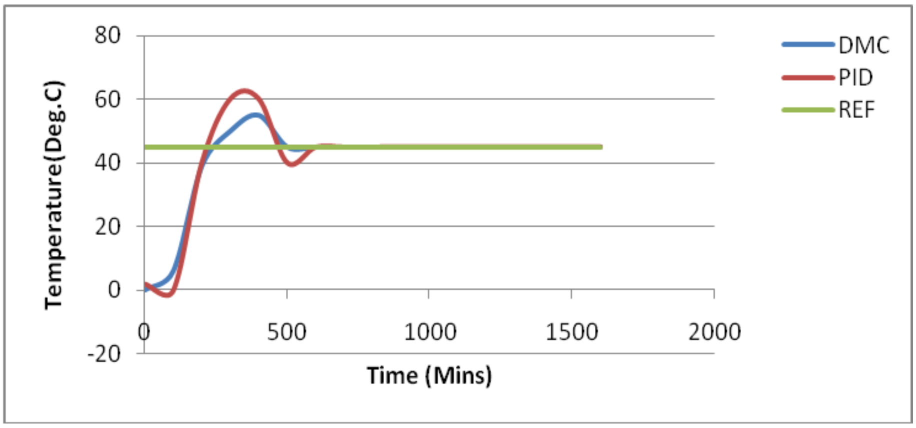

Fig.2. PID and DMC response of the Heat exchanger

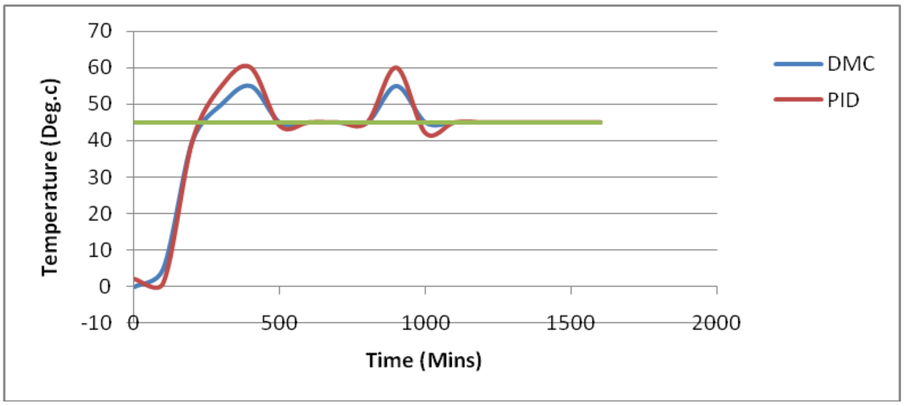

Fig.3. PID and DMC positive distrubance response of Heatexchanger

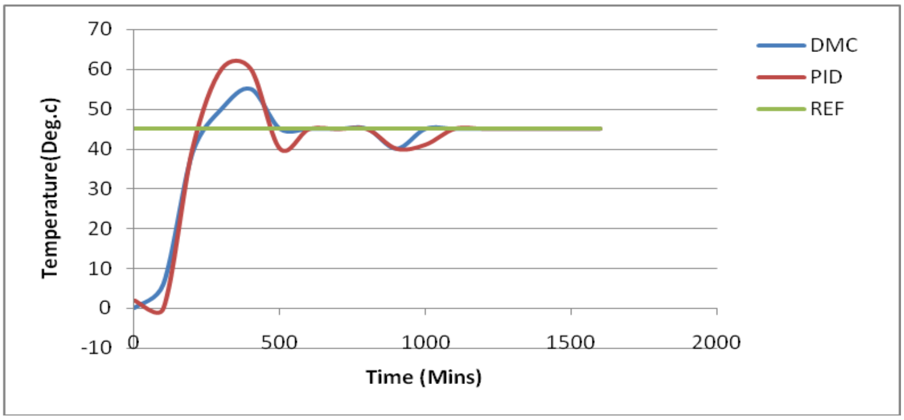

Fig.4. PID and DMC positive distrubance response of Heatexchanger

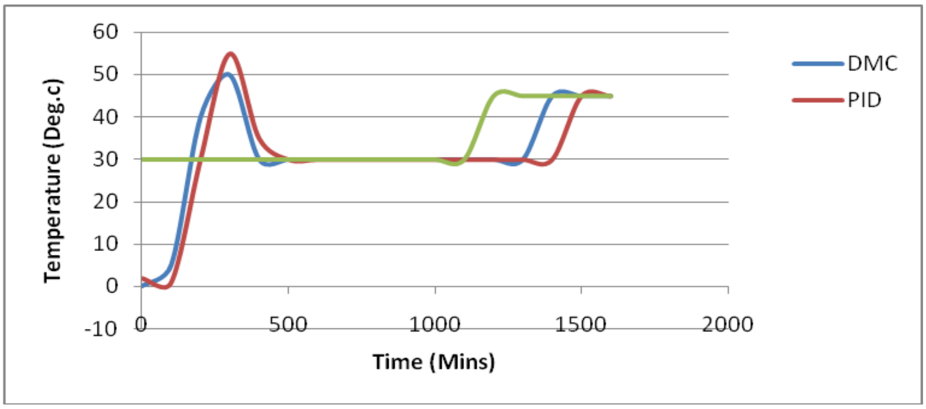

Fig.5. PID and DMC positive setpoint change response of Heatexchanger

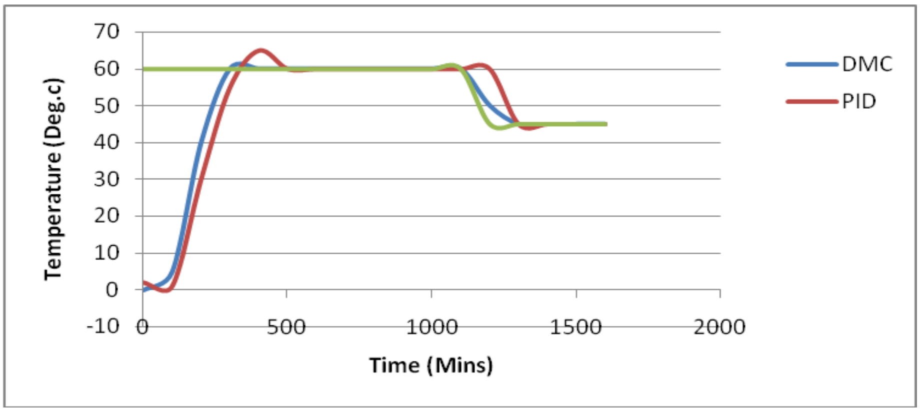

Fig.3. PID and DMC Negative setpoint change response of Heatexchanger

Table II: Performance Measure Characteristics

Controller	ISE	IAE	ITAE
DMC	200.760	600.50	6.520
PID	230.540	325.56	4.575

V. Conclusion:

In this work DMC is designed and control a shell and tube heat exchanger and its response compared with an PID. The comparison has been done between DMC and PID, it shows that DMC provided better performance than PID by observing ISE (Integral square error), IAE (Integral absolute error) and ITAE (Integral time- weighted absolute error).

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