Implementation of Decentralized Control Scheme to Control a MIMO System using Response Optimization Toolbox in MATLAB

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Abstract: In this paper, Model based approach is implemented to control a heat exchanger prototype using optimization technique for parameter tuning of PID controller. Mathematical modelling of heat exchanger is done using mechanical specifications and differential equations of "Shell and Tube heat exchanger". Optimally tuned PID controller is used to control the process model. Output response of optimal PID controlled model is compared with ordinary PID controlled model's output response in results. Response optimization technique is implemented in this process to tune the parameters of the PID controller. It makes the response as a settled one on the desired value and also gives the stable response.

Keywords : PID Tuning, Response Optimization, Shell and Tube Heat Exchanger, Control.

I. INTRODUCTION

Optimal control methods are essential in designing MIMO systems as they reduce the degrees of freedom in the design iteration down to a manageable few. Generally, for linear, stationary systems the steady – state optimal control solution is satisfactory and far more than the true optimal – time varying gain solution. An optimal estimator is based on achieving the minimum mean square estimation error for a given level of process and measurement noise acting on the system. Optimal estimators are useful for SISO system design and essential for MIMO system design.

Exchanging heats is the process of transferring thermal energy from one medium to another. In this process, the mediums should not get mixed with each other. Every heat exchanging setups must consist at least two inputs and two outputs. One is high temperature path and another one is low temperature path. So, the model of heat exchanger also a MIMO system.

II. RELATED WORKS

In case of CNOPs, the original PSO algorithm needs to be vary to deal with constraints. A few thoughts from the constraints-handling methods can be accepted. The straightest one is the method based on stabilizing feasibility of solutions. In order to find the optimum in feasible solutions, each particle searches the whole space but only retains tracking feasible solutions [5].

III. MATHEMATICAL MODELLING

Modelling is the process of deriving response from the physical parameters. Energy balance equations are consider as differential equation. Those differential equations are given below,

$$T_{ho}(t) = \frac{W_h}{\rho_h V_h \left(T_{hi}(t) - T_{ho}(t)\right)} + \frac{U_h A_h}{\rho_h V_h C_{ph}\left(T_{ho}(t) - T_{co}(t)\right)}$$

$$T_{co}(t) = \frac{W_c}{\rho_c V_c \left(T_{ci}(t) - T_{co}(t)\right)} + \frac{U_c A_c}{\rho_c V_c C_{pc}\left(T_{ho}(t) - T_{co}(t)\right)}$$

where,

- T_{ci}, T_{co}, T_{hi} and T_{ho} are cold inlet, cold outlet, hot inlet and hot outlet fluid temperatures respectively (°C)
- W_c and W_h are cold fluid's mass flow rate and hot fluid's mass flow rate respectively (kg/sec)
- C_{pc} and C_{ph} are the cold fluid's heat capacity and hot fluid's heat capacity respectively (J/ kg. °C)
- V_c and V_h are cold fluid's volume and hot fluid's volume respectively (cm^3)
- A_c and A_h are cold fluid's heat transfer surface area and hot fluid's heat transfer surface area respectively (cm^2)
- U_c and U_h are the cold fluid's heat transfer coefficient and hot fluid's heat transfer coefficient respectively (W/cm^2 °C).
- ρ_c and ρ_h are cold fluid's density and hot fluid's density respectively (kg/ cm^3)

A. *Specifications*

Inner Diameter of the shell (D_s) = 150 mm

Length of the Shell (L) = 615 mm

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Number of Tubes	(n)	= 32 numbers
Tube inner Diameter	(d_i)	= 12.5 mm
Tube Outer Diameter	(d_o)	= 15.5 mm
Pitch	(P_T)	= 20 mm,Square
Baffle spacing	(B)	= 100 mm
Number of Baffles	(N)	= 4 numbers
Area of Collection Tank	(A_T)	= 0.04 sq. m

B. *Logarithmic Mean Temperature Difference (LMTD)*

$$U = \frac{Q}{A\Delta T_{LM}}$$

$$Q = q_m C_p (T_1 - T_2)$$

$$q_m = q_v \times \rho$$

$$q_v = F \times (1.667 \times 10^{-5})$$

$$A = \pi d_m L$$

$$L = n.l$$

$$d_m = 0.5(d_i + d_o)$$

$$\Delta T_{LM} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)}$$

$$\Delta T_1 = T_2 - T_3$$

$$\Delta T_2 = T_1 - T_4$$

where,

$U \rightarrow$ Overall heat transfer coefficient

$\Delta T_{LM} \rightarrow$ Logarithmic Mean Temperature Difference

$T_1 \rightarrow$ Temperature of hot inlet

$T_2 \rightarrow$ Temperature of hot outlet

$T_3 \rightarrow$ Temperature of cold inlet

$T_4 \rightarrow$ Temperature of cold outlet

$A \rightarrow$ Heat transmission area

$n \rightarrow$ Number of tubes

$l \rightarrow$ Length of each tube

$d_i \rightarrow$ Tube diameter (inside)

$d_o \rightarrow$ Tube diameter (outside)

$F \rightarrow$ Flow rate

$C_p \rightarrow$ Specific Heat capacity

$Q_e \rightarrow$ Heat transfer

IV. CONTROLLER DESIGN

The “LACEY” procedure is gives the knowledge about controller design for Multivariable systems. The steps are summarized below.

- Select control variables
- Select manipulated variables
- Eliminate unworkable variable parings
- Find the best paring from the remaining sets.

Several multivariable controllers have been proposed during the last few decades. The optimal control research of the 1960s used variational methods to produce multivariable controllers that minimized some quadratic performance index. The method is called linear quadratic. Here response optimization is used to tune the PID controllers which are in that decentralization control scheme.

Two responses are received from the model, one is for cold stream and another one is for hot stream. These responses are the manipulated variables of our process. That means controller should focus on these two response simultaneously. Multiple response optimization is implemented to solve this issue.

Response Optimization Tuning

Step1: Type `sdotool ('model name')` in comment window. Response Optimization tool will open (Fig.1).

Step 2: Select new in Design Variable Set. Create Design Variable set window will open.

Step 3: Chose the tunable parameters (Kp, Ki, Kd) and press OK.

Step 4: Select new in Requirements and then select Step Response Envelope. It will open a Create Requirement window.

Step 5: Enter the values depending upon our requirements and chose the signal which is to be in control.

Step 6: Select Plot Model Response in Response Optimization window. It will shows the current response of our model.

Step 7: Press Optimize button which is located in right corner of the Response Optimization window.

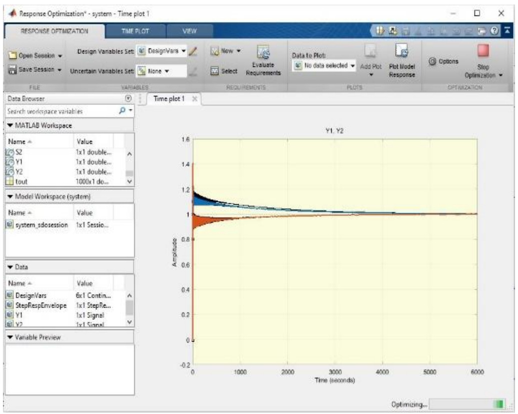

Fig.1 Response Optimization Window

V. RESULTS AND DISCUSSIONS

Results obtained is explained bellow, Figure 2 gives the idea about cold and hot output response vs time.

In this, red waveform shows the temperature of the hot outlet in heat exchanger model and blue waveform shows the temperature of the cold outlet in heat exchanger model.

Initial temperature of T_{co} is 0˚C and initial temperature of T_{ho} is 100˚C.

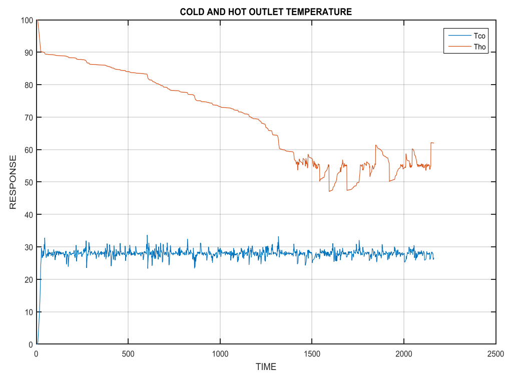

Fig.2 Outputs of Heat Exchanger model

Fig.3 shows the response of Y1 vs time with ordinary PID controller which is not settle in set point also the oscillations are very high.

Fig.4 is the settled response of Y1 with Optimally tuned PID controller, by using optimal PID output Y1 is settled in 2500 sec approximately.

Fig.5 is non settled response of output Y2 with normal PID controller. Figure 6 gives the Settled output Y2 with optimal PID controller. Tuned parameters are shown below,

Table.1 shows the tuning parameters of controller which are tuned using response optimization technique. The optimized values are in the Table.1. Since it is PID controller, the tuning parameters are proportional, integral and derivative gains.

Table.1 Optimized Tuning Parameters of Controllers

	Controller 1	Controller 2
Kp	0.3674	0.0980
Ki	2.1552	1.0923
Kd	1.0215	0.2533

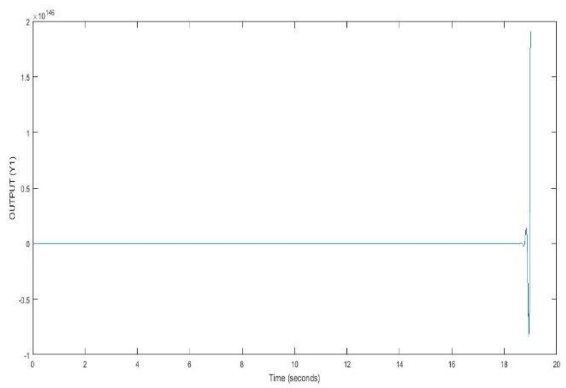

Fig.4 Outputs Y1 of Transfer Function Model with Optimal PID

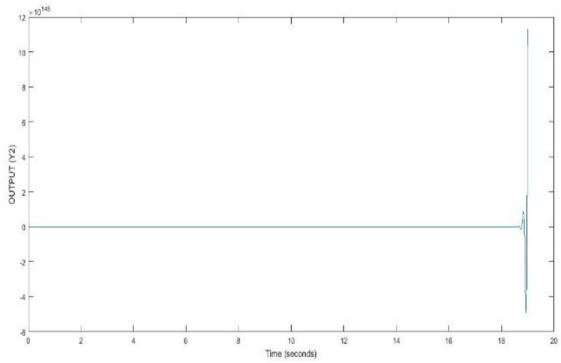

Fig.5 Outputs Y2 of Transfer Function Model with Normal PID

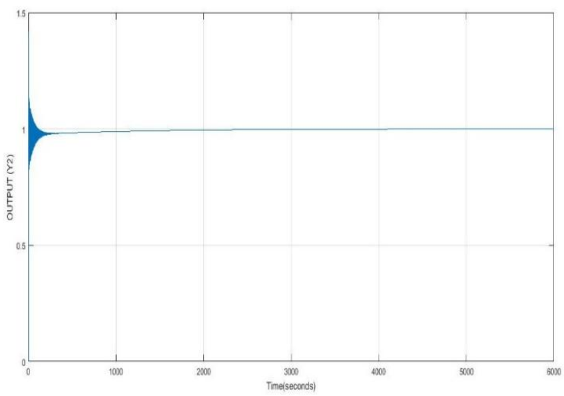

Fig.6 Outputs Y2 of Transfer Function Model with Optimal PID

VI. CONCLUSION

In this paper optimal tuning of PID controller is illustrated. Particularly Response Optimization technique is implemented to tune the parameters of controller. By using this technique process interactions are reduced and makes the system response as a settled one.
The final result of system was settled in the set point but the settling time was very high. To reduce that advanced algorithms can be implement in future. That will be the future enhancement of this project.

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