PARAMETER IDENTIFICATION AND CONTROL OF A SHELL AND TUBE HEAT EXCHANGER

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ABSTRACT

In this work, we discuss about the process parameter identification and control of a Counter Flow Shell and Tube Heat Exchanger using Recursive Least Square Algorithm(RLS) and Self Turning controller respectively. Here, we model the process with the help of experimental data using RLS Algorithm. Then an ST controller which comes under adaptive controller is used to control the process. With the help of STC, the tube outlet temperature is controlled by adjusting the flow of cold fluid through the shell side. In conventional way a PID controller is also tuned, and the performance is compared with STC using MATLAB simulations.

Keywords :- Heat Exchanger, RLS, STC, PID.

INTRODUCTION

Heat Exchangers are used in the industries to transfer heat from one fluid to another with minimum loss. They are used in petrochemical industries, thermal power plants, domestic purpose and has wide range of applications. There are different types of heat exchangers of which we are working on a shell and tube heat exchanger. Tubes are fixed inside the shell. Both having separate inlets and outlets, no mixing or direct contact between the fluids. Hot fluid is flowing through the tube and cold fluid through the shell. The fluids can be of different kind depends on the process such as water, coolants, oil etc . Heat transfer takes place between the fluids by the heat transfer laws . In industries large heat exchanger networks are employed to utilize wasted heat energy. Shell and tube heat exchangers are preferred in industries as it has higher efficiency.

The heat transfer process is highly nonlinear in nature. Conventionally PID controllers are used[1],which are simple but lacks performance. For effective control, a good model of the process is required. The system is tested with set of known inputs and correspond output readings are measured and with the help of RLS algorithm, process parameters are identified and a SISO model is developed[2].

An STR controller is employed to control the heat exchanger[3]. The parameter estimation and adaptive control strategies are discussed in [4].Application of STR is discussed by Thomas James Harris in his thesis[5].Different STR simulink concepts are proposed by Vladimir Bobál[6].

HEAT EXCHANGER PROCESS DESCRIPTION

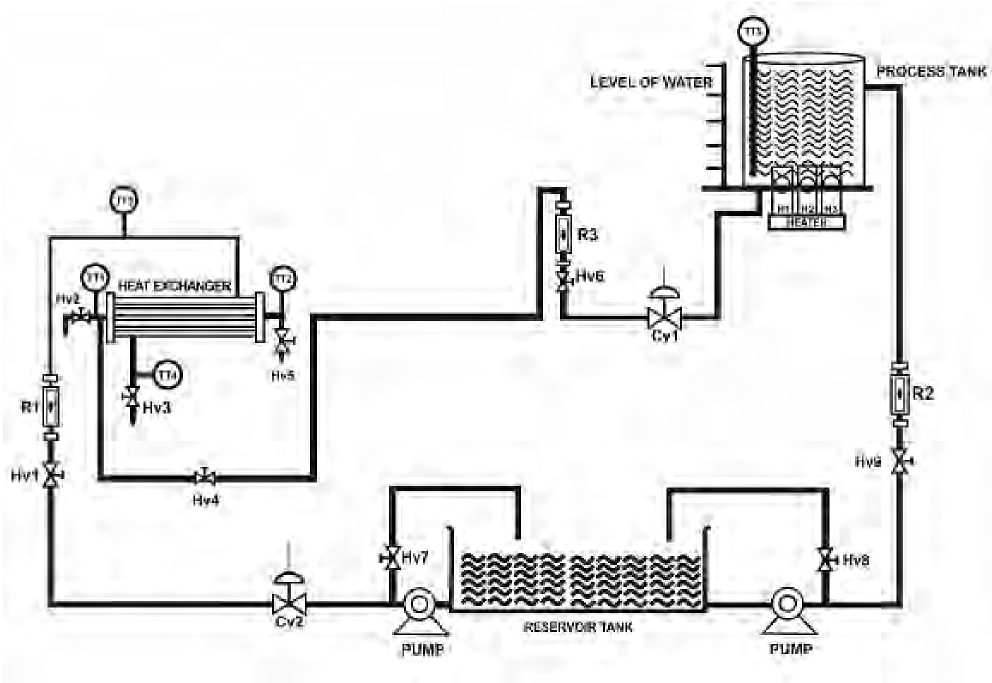

Fig.1 Experimental setup

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

The schematic of the laboratory setup of counter flow heat exchanger is shown in the above figure. Water is used as the fluid steam flowing through both shell and tube. Hot water flows through the tube and cold water through the shell. Heat transfer takes place between the fluids through the walls. In this experiment, we control the outlet temperature of the tube fluid by controlling the flow of water in the shell. Water in the tank for the tube is heated to a desired temperature with the help of three heating coils and controlled by separate PID controllers. Separate pneumatic control valves are provided for controlling cold and hot water. RTDs measure the temperature and flow rate is given by ratometer.

SYSTEM MODELING

Here for modeling, we consider the system as a black box system. Different flow rate of cold flow is applied for specific time intervals and corresponding tube outlet temperature is measured. Least square algorithm is used for parameter identification and thus modeling the system with the help of data obtained from the experiment.

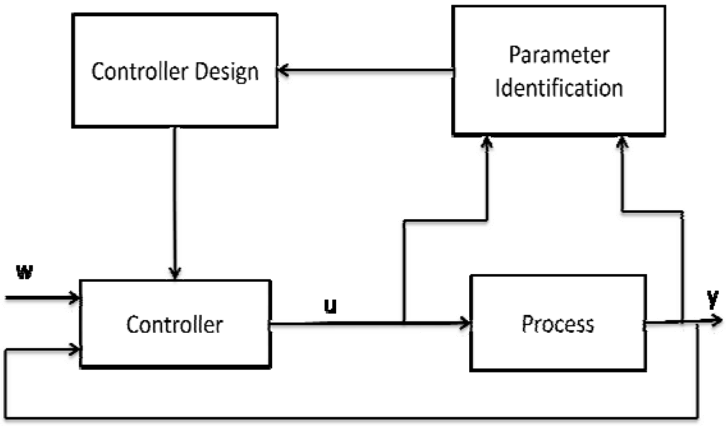

Fig. 2. Parameter updating and STC

Table. 1. Shell flow rate and duration

Shell inlet flow rate(LPH)	Sampling Instants
350	1800
350-250	1800-3600
250-150	3600-5600

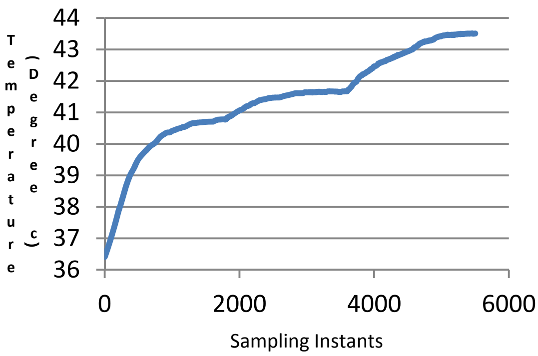

Fig. 3. Temperature profile for Table. 1

LEAST SQUARES ALGORITHM

The general equation of the model is

$$y(k) + a_1\, y(k-1) = b_1 u(k-1) \qquad (1)$$

$$y(0) + a_1 y(-1) = b_1 u(-1)$$
$$y(1) + a_1 y(0) = b_1 u(0)$$
$$y(2) + a_1 y(1) = b_1 u(1)$$
$$\vdots$$
$$y(N) + a_1 y(N-1) = b_1 u(N-1) \qquad (2)$$

The parameter and Regression vectors

$$\theta = \begin{bmatrix} a_1 \\ b_1 \end{bmatrix} \quad , \quad Y = \begin{bmatrix} y(1) \\ \vdots \\ y(N) \end{bmatrix}$$

$$\varphi = \begin{bmatrix} -y(0) & u(0) \\ -y(1) & u(1) \\ \vdots & \vdots \\ -y(N-1) & u(N-1) \end{bmatrix} \qquad (3)$$

$$Y = \varphi\theta \qquad (4)$$

The error is given as

$$e = y_d - Y \quad , \quad e^T = [e(1)\, e(2)\, \dots e(N)]$$

The cost function is given as

$$J = \sum_{k=1}^{N} e^2(k) \qquad , J = (y_d - \varphi\theta)^T (y_d - \varphi\theta)$$

By minimizing the cost function we obtain the Parameters

$$\frac{\partial J}{\partial \theta} = -2\varphi^T (y_d - \varphi\theta) \qquad (5)$$

$$\theta = (\varphi^T \varphi)^{-1} \varphi^T y_d \qquad (6)$$

Transfer function in z domain

$$G(z) = \frac{b_1 z^{-1}}{1 + a_1 z^{-1}} z^{-d} \qquad (7)$$

For every set of input, output data the process parameters are identified and are used to update the control parameters. As the system is nonlinear and undergoes different working conditions in terms of temperature and pressure, the process parameters are subject to change. So for effective controlling the process parameters are to be updated and with that the control parameters.

SELF TUNING CONTROLLER

STC is used to control the Heat Exchanger. In this type of controllers, as the process parameters changes, the control parameters are modified to provide the best possible control action. Here we are using a tool box for STC in MATLAB[11]. MATLAB is interfaced with the Heat Exchanger system. With the help of S function the tool box for STC is developed. Here a control law is employed to update the control signal with respect to changes in process parameters, reference and output to achieve better performance.

CONTROL LAW

$$u_k = q_0 e_k + q_1 e_{k-1} + q_2 e_{k-2} - p_1 u_{k-1} - p_2 u_{k-2} \qquad (8)$$

$$e_k = w_k - y_k \quad q_0 = \frac{k_1}{\hat{b}_1} \quad , q_1 = q_0 \hat{a}_1, \quad q_2 = q_0 \hat{a}_2$$

$$\gamma = \frac{\hat{b}_2}{\hat{b}_1} \quad k_1 = \frac{1}{2(d+1)-1} \quad p_1 = -1 + \gamma \, , \; p_2 = -\gamma$$

Where e_k is the error between output and reference (w_k),d is the dead time. $\frac{\hat{b}_2}{\hat{b}_1}$ − New process parameters

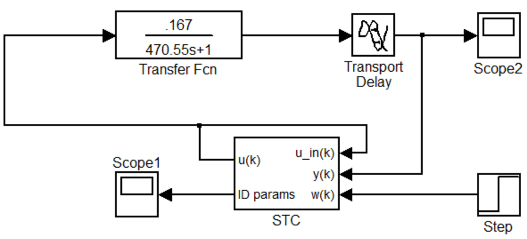

Fig. 4. Simulation using STC

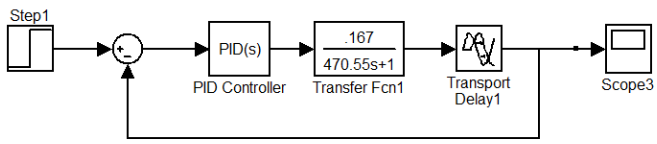

Fig. 4. Simulation using PID

RESULTS AND CONCLUSIONS

Here we control of a counter flow shell and tube Heat Exchanger. The process parameters are identified for modeling the process by implementing Least Square Algorithm. Fig. 1 shows the graph obtained for different working regions given in table.1. A Self Tuning Controller is designed based on the control law to control the process. An STC tool box is employed for simulation. A PID controller is also tuned with Z-N technique for the control purpose.

In figure 3 the outputs of STC and PID are compared and in figure 4 a process disturbance rejection comparison is made. Table 2 and 3 shows a comparison of the performance indices.

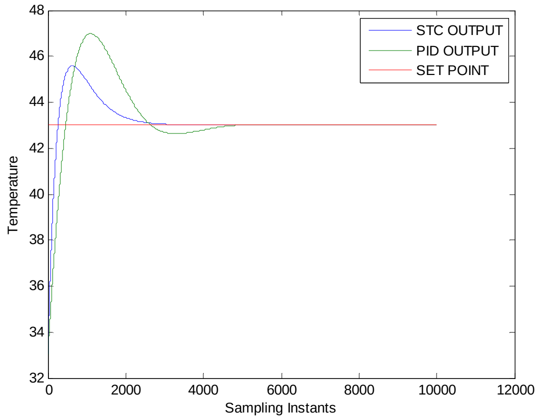

Fig. 3. Output comparison of STC with PID

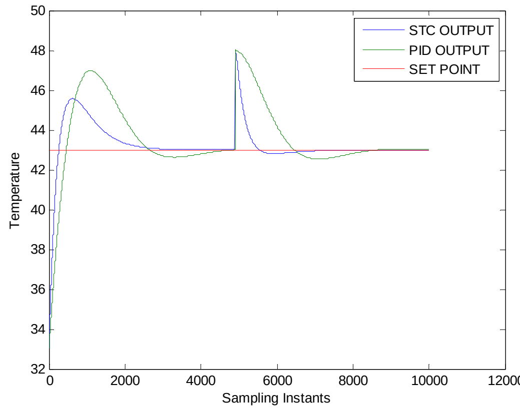

Fig. 4. Comparison of STC with PID with a process disturbance

Table. 2. Performance Indices

Controller	Rise Time(s)	Overshoot (%)	Settling Time
STC	130	4	900
PID	460	9.3	1250

Table. 3. Performance Indices

Controller	IAE	ISE	ITAE
STC	80	385	2368
PID	210	415	3312

By the analysis of the graphs and tables it is clear that STC is showing a better performance in this case of controlling the counter flow Shell and Tube Heat Exchanger.

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