Dead Time Compensation in Shell and Tube Heat Exchanger System Using Smith Predictor

Sarabeevi G M[1], Riya Mary Francis[2]

[1, 2]T.K.M. College of Engineering, Electrical and Electronics Engineering, Kollam, Kerala

Abstract: ***The main purpose of heat exchanger is to maintain specific temperature conditions, which is achieved by controlling the exit temperature of the process fluid. Among wide variety of heat exchangers, Shell and Tube heat exchangers are used in first hand because of well established procedures for design and manufacture from a wide variety of materials, many years of satisfactory service, availability of codes and standards for design and fabrication and can sustain wide range of temperature and pressure. The problem of Dead Time in heat exchanger is an everlasting problem which is of primary importance in process control. Dead-time compensators can be used to improve the closed-loop performance of classical controllers (PI or PID controllers) for processes with delay. The Smith Predictor, was the first dead-time compensation structure used to improve the performance of the classical controllers and became the most known and used algorithm to compensate dead time in the industry.***

Keywords: Heat Exchanger**,** Zeigler-Nichols Method (II), Tyreus Luyben Method, Dead Time Compensator, Smith Predictor

1. Introduction

Most industrial processes present dead time in their dynamics. Generally, dead times are caused by the time needed to transport energy, mass or information, but they also can be caused by processing time or by accumulation of time lags in a sequence of simple dynamic systems interconnected in series .The presence of dead times in the control loops has two main consequences: it greatly complicates the analysis and the design of feedback controllers and it makes satisfactory control performance more difficult to achieve. Dead-time compensators can be used to improve the closed-loop performance of classical controllers (PI or PID controllers) for processes with delay [5].

The major difficulties in controlling dead-time processes are as
1) The effect of the disturbances is not felt until a considerable time has elapsed
2) The effect of the control action takes some time to be felt in the controlled variable
3) The control action that is applied based on the actual error tries to correct a situation that originated some time before.

In this paper, PI controllers are tuned using Ziegler-Nichols (Method II) and Tyreus-Luyben Methods and are combined with Smith Predictor control structure to compensate the problem of dead time in Shell and Tube heat exchanger system.

2. Mathematical Modeling of Heat exchanger System

We can obtain the transfer function of the system as,

$$F(s) = \frac{Y(s)}{U(s)} = \frac{K_p}{\tau_p s+1}. \tag{1}$$

One of the major characteristics of heat exchanger process is the presence of time delay.

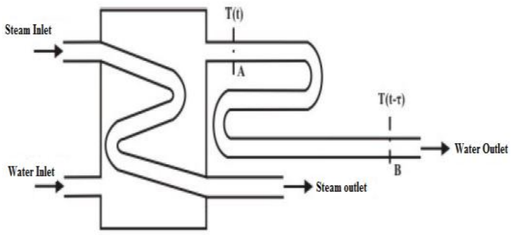

Figure 1: Time delay of heat exchanger system

The transducer should be placed at a location in the water outlet line just after the tank (location A in Fig .1). But suppose, due to the space constraint, the transducer was placed at location B, at a distance L from the tank. In that case, there would be a delay sensing this temperature. If *T(t)* is the temperature measured at location A, then the temperature measured at location B would be $T(t-\tau_d)$. The time delay term τ_d can be expressed in terms of the physical parameters as: $\tau_d = \frac{L}{V}$where *L* is the distance of the pipeline between locations A and B; and *V* is the velocity of fluid through the pipeline.By taking the Laplace Transformation,

$$\mathrm{L}f(t-\tau_d) = e^{-s\tau_d}F(s) \tag{2}$$

Thus the Transfer function of the shell and Tube tube heat exchanger, from (1) can be written as

$$F(s) = \frac{Y(s)}{U(s)} = \frac{K_p}{\tau_p s+1} e^{-s\tau_d} \tag{3}$$

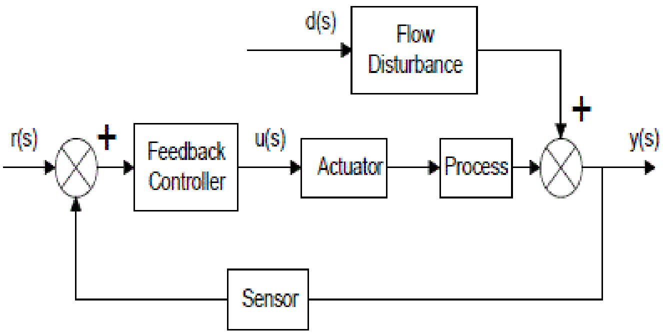

Figure 2: Block diagram of temperature control loop

3. Smith Predictor

The Smith Predictor (SP) , proposed in the late 1950s by Smith , was the first dead-time compensation structure used to improve the performance of the classical controllers and became the most known and used algorithm to compensate dead time in the industry[6].

When dead time is very small and for slow variations of the output signal PID control is a better choice but when dead time is long enough the control performance obtained with a proportional-integral derivative (PID) controller is limited. Predictive control is required to control a process with a long dead time efficiently. Therefore, if a PID controller is applied on this kind of problems, the derivative part is mostly switched off and only a PI controller without prediction is used.

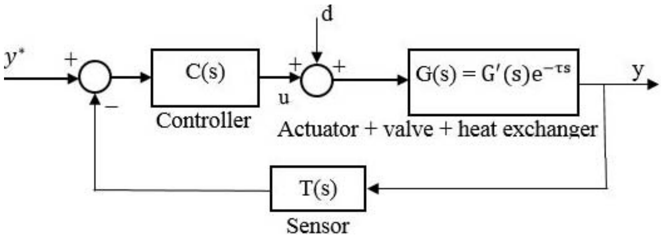

Figure 3: Block diagram of standard control scheme

The main idea behind the Smith predictor is the use of a control structure, which extracts the time delay out of the control loop and allows a feedback design based on a delay free system. In other words the Smith predictor enables the prediction of the states of the system at a given time instant in the future. This prediction allows the implementation of a non-causal control law that can be used to control a system when it is subject to a time delay.

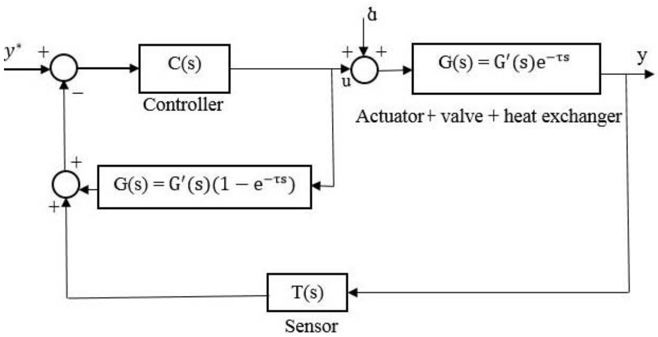

Figure 4: Smith predictor control structure

Although Smith predictor was firstly introduced in late 1950's, it is still a fundamental and basic tool for handling systems with time delay. In the ideal case, the Smith predictor predicts the output after the time delay allowing the resulting system after prediction to be treated as a delay free system. The Smith predictor compensator contains a model of the process with the time delay in an inner loop and can easily be implemented. If the Smith predictor parameters easily match the plant parameters, the time delay is easily eliminated from the characteristic equation. In this perfectly matching case, the controller can easily implemented without considering the time delay.

4. PI Controller Tuning

A PID controller is a general feedback control loop mechanism widely used in industrial process control system. A PID controller corrects the error between a measured process variable and desired setpoint by calculating the value of the error [1].

4.1 Ziegler-Nichols Method(II)

Ziegler and Nichols published a paper in 1942, where they described two methods for tuning the parameters of P, PI and PID controllers.

Table 1: Ziegler-Nichols table for calculation of PID parameters

Type of Controller	K_p	T_i	T_d
P	$0.5\ K_{cr}$	α	0
PI	$0.45K_{cr}$	$\frac{1}{1.2}P_{cr}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

$$\frac{G(s)}{1+G(S)H(S)} = 0 \quad (4)$$

From (4) Characteristic equation is , $1 + G(S)H(S) = 0$

$$\text{i.e; } 1 + \frac{0.78K_{cr}}{(3s+1)(30s+1)(10s+1)} = 0$$

Which is equal to

$$900s^3 + 420s^2 + 43s + 0.78K_{cr} + 1 = 0 \quad (5)$$

By using Routh-Hurwitz criterion, obtained K_{cr} as 24.44
Put s=$j\omega$ in (5), we obtain

$$\omega_{cr} = 0.218 \quad \text{and} \quad P_{cr} = \frac{2\pi}{\omega_{cr}} = 28.82 \text{ s}$$

Then calculate parameters as prescribed by Ziegler and Nichols table, the parameters are obtained as in the Table 2.

Table 2: Values of PID parameters obtained by Ziegler-Nichols method II

Type of Controller	K_p	T_i	T_d
P	12.22	α	0
PI	10.998	24.01	0
PID	14.66	14.41	3.6

$$P = K_p \qquad I = \frac{K_p}{T_i} \qquad D = K_p T_d$$

For PI Controller, P=10.998, I=0.458,D=0

4.2 Tyreus-Luyben Method

This method was proposed by B.D Tyreus and W.I Luyben in 1997.It is quite similar to Z-N closed loop method but the final controller settings are different. Also this method only proposes settings for PI and PID controllers.

Table 3: Tyreus-Luyben table for calculation of PID parameters

Type of Controller	K_p	T_i	T_d
PI	$\frac{K_{cr}}{3.2}$	$2.2P_{cr}$	0
PID	$\frac{K_{cr}}{2.2}$	$2.2P_{cr}$	$\frac{P_{cr}}{6.3}$

For PI Controller, P=7.6375, I=0.12,D=0

5. Results and Discussions

The simulations for the control mechanisms discussed above were carried out in Simulink and the simulation results have been obtained.

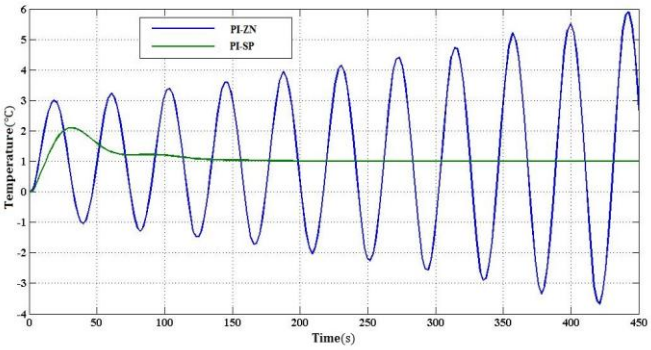

Figure 5: Response of PI controller tuned with ZN method combined with Smith predictor control structure

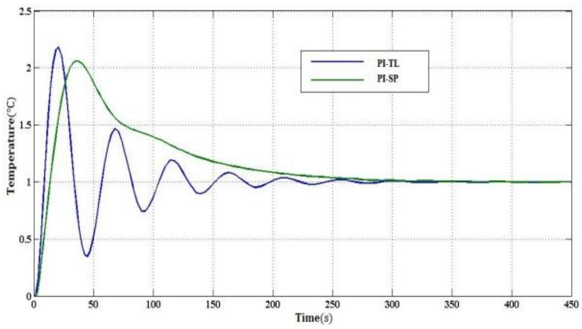

Figure 6: Response of PI controller tuned with TL method combined with Smith predictor control structure

From the simulation results we can observe that PI controller tuned with Zeigler-Nichols method results in oscillatory response of slowly increasing amplitude which is highly undesirable. The PI controller tuned using Tyreus-Luyben method results in response with large number of overshoots and high settling time also acceptable stability is not obtained with PI controllers tuned with both methods. These limitations are overcome by combining Smith Predictor control structure with PI controllers. Time domain specifications like maximum peak overshoot, settling time and peak time are improved by using Smith Predictor control structure.

6. Conclusions

This paper evaluates different methods to control the outlet fluid temperature of Shell and Tube heat exchanger. PI controllers tuned using Zeigler-Nichols and Tyreus Luyben methods are combined with Smith Predictor control structure for dead time compensation.When a comparison is made between the performance of PI controller and Smith Predictor for long dead time processes, better results are obtained with Smith Predictor.

References

[1] Subhransu Padhee, "Controller design for temperature controlof heat exchanger system",WSEAS Trans.on systems and control,volume 9 , 2014.

[2] Amit Kumar, K.K Garg, "Comparison of Ziegler-Nichols, Cohen-Coon and Fuzzy Logic Controllers for Heat Exchanger Model", International Journal of Science, Engineering and Technology Research (IJSETR), Volume 4, Issue 6, June 2015, pp. 1917-1920

[3] B.Wayne Bequette,"Process Control - Modelling, Design and Simulation", PHI Learning Private Limited Publications,2013.

[4] Shanu Khan, "Analysis of Heat Exchanger Process with Long Dead Time", International Journal for Research in Applied Science and Engineering Technology, ISSN: 2321-9653,Vol. 2 , July 2014

[5] Pradeep Kumar Juneja, A. K. Ray, R. Mitra ,"Deadtime Modeling for First Order Plus Dead Time Process in a Process Industry", International Journal of Computer Science and Communication, , pp. 167-169,Vol. 1, July 2010

[6] Varun Sharma and Veena Sharma, "Dead Time compensators for Stable Processes", J. Acad. Indus. Res. Vol. 1(7), ISSN: 2278-5213, Dec. 2012