International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 15 (2015) pp 35914-35917
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Application of Feed-Forward Internal Model Control To Time Varying FOPDT Temperature Process

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Abstract-- This paper deal with the study of the performance of the Feedforward Internal Model control (IMC) applied to time varying First Order plus Dead Time (FOPDT) temperature process. For a complex system with the operating point range changing such as heat exchanger system, large delay time and varying time constant characteristics, it has a certain degree of difficulty to be controlled. The usage of variable structure controller such as internal model control to deal with this kind of control system issues is effective. According to different model of temperature process design corresponding controller, it can be obtained by weighting the parameters of internal model control. System simulation results of heat exchanger system as a case study show that the Feedforward Internal Model control method has better control performance, and it is a viable method for dealing with such problems. The simulation using MATLAB software verifies the results very well.

Keywords-- Internal Model Controller (IMC), Nonlinear Control Technique, Chemical Temperature Process, Heat Exchanger Model, First Order Plus Dead Time (FOPDT) system.

1. Introduction

Time-delay commonly exists in various engineering systems, for example, the turbojet engine, aircraft systems, microwave oscillator, nuclear reactor, rolling mill, heat exchanger process, chemical process, manual control, and long transmission line in pneumatic, hydraulic systems [1-3, 4, 6]. The existence of time delay in a system frequently becomes a source of instability. Conventional non-Linear controllers can yield a satisfactory response if the process is operated close to a normal steady state value or a fairly linear region. But design of intelligent controllers gives a satisfactory response for nonlinear system with a reduced overshoot and oscillations, thus improving the stability of the system [2]. The internal model control (IMC) algorithm is widely used in dead-time process industries because of its simplicity and practical success. A well-designed IMC controller has been proved to be sufficient for a large number of dead-time control loops. However, when dead-time variation is present, although advanced control techniques can provide significant improvements, in general the output of a conventional IMC cannot adapt quickly enough to reflect the current system conditions and results in a significant overshoot [7]. This paper has five different sections. section 2 describes internal model control (IMC) theory, Section 3 deals with heat exchanger system as case study for FOPDT, section 4 explains the design of the proposed IMC design , section 5, provides simulation results of a proposed different IMC is identified from the transient response performance and error criteria. Section 6 contains the conclusion of the paper.

2. Internal Model Control (IMC) theory

To apply IMC design scheme a perfect model is required. However, in real time applications, it is difficult to get a perfect model. So, generally the process is approximated as first-order or second-order plus dead time (FOPDT) model. Since the IMC controller needs inverse plant model, and the inversion of delay terms for controller design leads to predictor action. Moreover, most often the obtained transfer function is of higher-order which sometimes leads to unrealizable controller and results into slower response, and more complex computation. Thus, there is a need of model-order reduction techniques to develop causal, realizable, and lower-order process models. Internal model control is basically a model based approach; the process model can be a forward model or reverse model. The controller is carved out from the inverse model whereas the forward model is placed in parallel with the actual process. The block diagram of internal model controller is shown in Fig. 1.

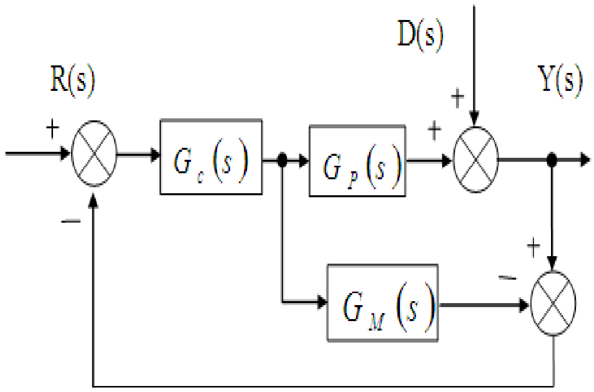

Figure 1: Basic Internal Model Control (IMC) Structure

The IMC structure is characterized by a control device consisting of the feedback controller $G_C(s)$, the real plant to be controlled $G_P(s)$, and a predictive model of the plant, i.e., the internal-model $G_M(s)$. The internal-model loop uses the difference between the outputs $G_M(s)$ of $G_P(s)$ .This difference commonly known as an error, represents the effect of disturbances $D(s)$ and plant/model mismatch if exists. The IMC design procedure consists of the following four steps [4]:

i. Factor the process model into invertible $G_{M-}(s)$ and noninvertible $G_{M+}(s)$ has time delays and RHP zeros) elements.

$$G_M(s) = G_{M+}(s) + G_{M-}(s) \qquad (1)$$

This factorization is performed so that the resulting controller will be stable.

ii. Form the idealized IMC controller. The ideal internal model controller is the inverse of the invertible portion $G_{M-}(s)$ of the process model.

$$G_C(s) = G_{M-}^{-1}(s) \qquad (2)$$

iii. Add a filter to make the controller proper. A transfer function $G_f(s)$ is proper if the order of the denominator polynomial is at least as high as the numerator polynomial

$$G_C(s) = G_{M-}^{-1}(s)\ G_f(s) \qquad (3)$$

iv. If it is most desirable to track step set-point changes, the filter transfer function usually has the form

$$G_F(s) = 1/(1+\lambda)^n \qquad (4)$$

The filter order *n* is selected to make the controller proper (or semi proper). If it is most desirable to track ramp set-point changes (often used for batch reactors or transition control problems), then

v. Adjust the filter tuning parameter λ to vary the speed of response of the closed-loop system. If the λ is small, the closed-loop system is fast, if λ is large, the closed-loop system is more robust (insensitive to model error). λ can be adjusted on-line to compensate for plant/model mismatch in the design of the control system.

3. Heat Exchanger System Modeling

Most industrial processes can be modeled by First-Order-Plus-Dead time (FOPDT) models. The system identification can be done mainly in three ways one is the mathematical modeling [6, 9] and the other is the empirical modeling. The third method make use of some system identification tool box for obtaining the transfer function model of the system. The open loop response of the system was obtained and the process reaction curve method was used to obtain the time constant, process gain and dead time. The temperature process was modeled using the experimental data collected and the model developed in transfer function form was used to simulate the system and finally the simulated controller values were used in testing the system in real-time. The heat exchanger system is considered here as the temperature process, in this section we have presented a mathematical model of the heat exchanger system, actuator, valve, sensor [3, 8]. The transfer function model of the individual systems are generated which in turn combined to acquire the transfer function of the whole system, from the experimental data the transfer function model of the system is derived as follow [3]:

Transfer function of heat exchanger model is

$$G_M(s) = \frac{13.3e^{-30S}}{231s+1} \qquad (5)$$

Transfer function of actuator element “valve” is

$$G_V(s) = \frac{0.133}{3s+1} \qquad (6)$$

Transfer function of sensor “thermocouple” is

$$G_S(s) = \frac{0.16}{10s+1} \qquad (7)$$

Gain of I/P converter is

$$G_{conv}(s) = 0.75 \qquad (8)$$

4. Design of IMC for Heat Exchanger System

In the present control study; the transfer function of the heat exchanger model is shown in figure 2, the parameters used for the heat exchanger model are the values $K = 1.0, T = 12.56$ and a delay time value of 23.6 i.e. $\tau = 23.6$. [8]:

$$G_M(s) = \frac{Ke^{-\tau s}}{Ts+1} = \frac{e^{-23.6s}}{12.56s+1} \qquad (9)$$

From the last equation; we obtain the transfer function $G_C(s)$ of IMC is designed as follow:
Do the factorization $G_M(s)$

$$\therefore\ G_M(s) = \begin{cases} G_{M+}(s) = \dfrac{1}{12.56s+1} \\ G_{M-}(s) = \exp(-23.6s) \end{cases} \qquad (10)$$

To achieve a smooth system, we add a filter in front of the IMC. Now, set $G_C(s)$ to be the inverse of $G_{M+}(s)$ in series with a low pass filter transfer function $G_f(s)$ with value of $\lambda = 1$ and $n = 1$.

$$G_F(s) = \frac{1}{s+1} \qquad (11)$$

$$\because G_C(s) = G_{M+}^{-1}(s) \cdot G_f(s)$$

$$\therefore G_C(s) = \frac{12.56s+1}{s+1} \qquad (12)$$

5. Simulation Results and Discussion

The system equations in previous sections are used to obtain the simulated results. Figure 2 shows the simulink implementation of the closed loop feedback control system, the simulink implementation of the open loop feedforward control system and the simulink implementation of feedback feedforward control system. Whereas the control systems responses are depicted in figures (3-6)

From the below figures it is clear that in IMC in feedback loop the heat exchanger produces an overshoot is 38.38%. To compensate this kind of high overshoot a feedforward controller in conjunction with the IMC in feedback loop is implemented. By implementing this method the system overshoot was reduced to 30%, an improvement of 21%. Though the overshoot has somewhat decreased, it can be further decreased by implementing feedforward internal model, by implementing feedforward internal model the overshoot reduces to zero.

In feedback IMC controller the settling time was 115.2 sec where as in feed forward plus feedback controller the settling time decreases to 91.34 sec, an improvement of 20.7%. By implementing feedforward internal model the settling time decreases by 63.8 sec. From these observations it is clear that feedforward internal model is a much better option for control rather than IMC feedback and feedback plus feed forward controller

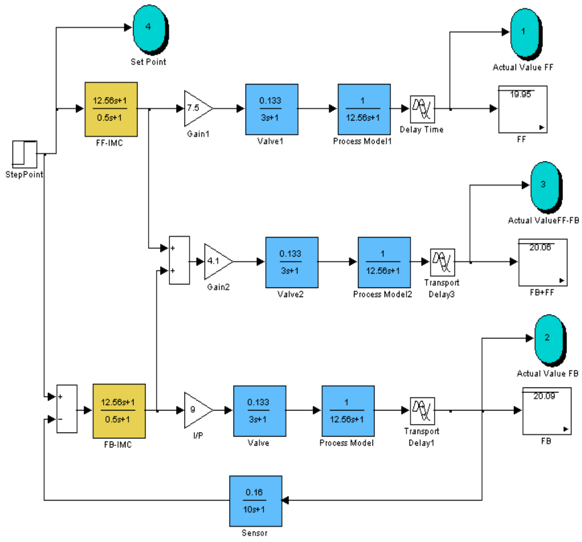

Figure 2: Simulink diagram of internal model control systems.

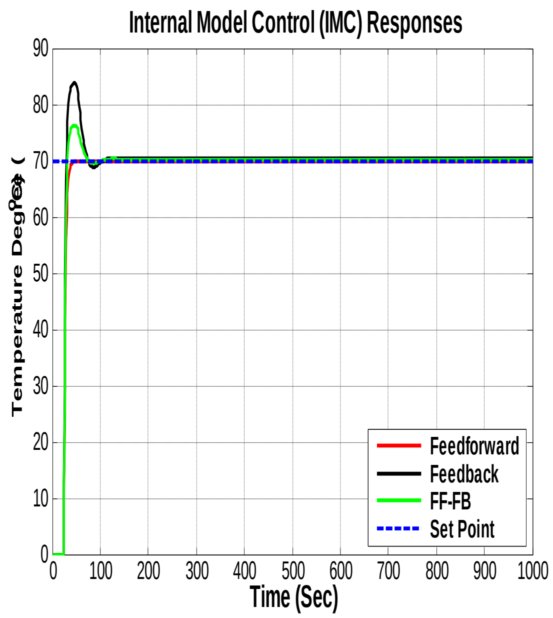

Figure 3: Response of internal model control systems (set point = 70 ^{o}C)

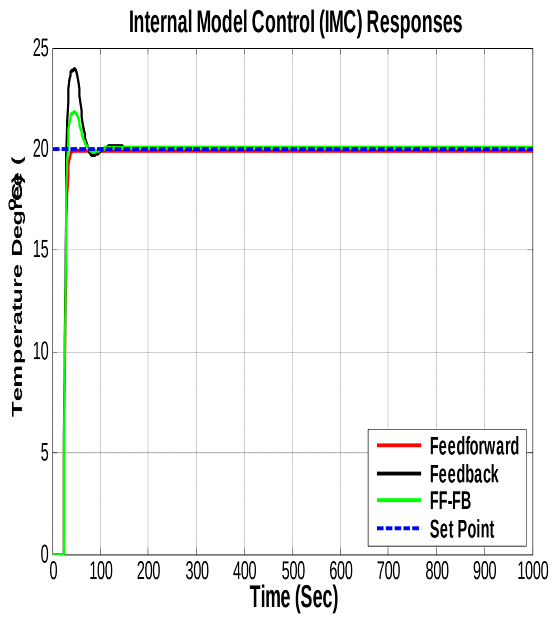

Figure 4: Response of internal model control systems (set point = 20 ^{o}C)

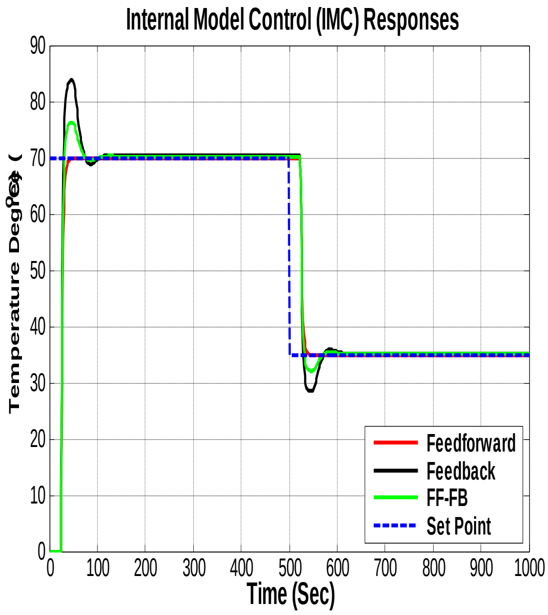

Figure 5: Response of internal model control systems for tracking set point

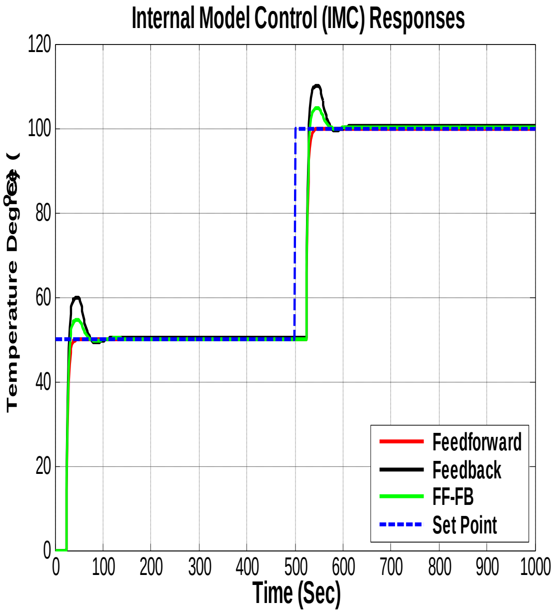

Figure 6: Response of internal model control systems for tracking set point

6. Conclusion

In this work, the feedback IMC, feedforward IMC, and feedforward feedback IMC are developed for a heat exchanger system. When comparing the performance of three IMC controllers, it is observed that feedforward IMC gives better performance than feedback and feedforward feedback controllers for servo problem in terms of overshoot, settling time value.

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