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Original

Comparison among some well known control schemes with different tuning methods

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Abstract

This paper presents a comparison between some well-known control schemes such as feedback, feedback plus feed-forward, cascade and cascade plus feed-forward for controlling a third-order process. The controller applied in various control schemes is a PID controller that has been tuned using Ziegler Nichols (ZN) and relay auto-tuning (RA) methods. The comparative analysis is based upon various performance measures such as rise time (t_r), settling time (t_s), maximum overshoot (M_p), steady-state error (e_{ss}), integral of absolute error (IAE), integral of square error (ISE), integral of time square error (ITSE), and integral of time absolute error (ITAE). Simulation results show that the RA method provides superior performance in case of feedback plus feed-forward and cascade control schemes. On the other hand, the ZN method proves to be better in case of cascade plus feed-forward control scheme.

Keywords: Feedback; Feed-forward; Cascade; PID controller; Ziegler Nichols; Relay auto-tuning

1. Introduction

In Process industry generally, the processes are complex, having time delays, and may have different type of nonlinearities. Therefore, it is not always possible to control them with a classical control scheme such as a feedback control scheme. Therefore to control such type of systems advance control schemes such as feedback plus feed-forward, cascade and cascade plus feed-forward may be required.

The most frequently implemented controller in different control schemes is the PID controller, due to its simple configuration and easy implementation (Astrom & Hagglund, 1995). A PID controller, also known as a three-term controller, has three principal control actions, i.e. the proportional action, the integral action and the derivative action. All of these control actions are summed up together to obtain a single control effort. The proportional action provides a change in the manipulated variable relative to the error signal and is used to remove a large amount of error; the integral action provides a signal proportional to the time integral of error, and its main function is to reduce the steady-state error or offset, while the derivative action provides a signal proportional to the derivative of error, and its function is to reduce maximum overshoot. Mathematically, the output from a PID controller is given as:

$$u(t) = K_c\left(e(t) + \frac{1}{\tau_I}\int e(t)\,dt + \tau_D\frac{de(t)}{dt}\right) \tag{1}$$

where $u(t)$ is the control signal, $e(t)$ the error signal defined as the difference between the set-point and the output.

K_c = proportional gain.

τ_I = integral time.

τ_D = derivative time.

Various tuning methods have been discussed within the literature for finding out the parameters of a PID controller (Tan et al., 2006; Chopra et al., 2014). The stereotypical tuning methods include Ziegler Nichols (ZN), relay auto-tuning (RA), pole placement and internal model control (IMC). While the intelligent methods make use of fuzzy logic, genetic algorithms (GA), artificial neutral networks and particle swarm optimization (PSO) for finding the PID parameters.

Brown et al. (1993) proposed a PID self-tuning controller based on pole placement method for controlling an aluminum rolling mill. Zhuang and Atherton (1993) proposed tuning of PID controller with time integral performance criteria.

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ZN method was used to determining the controller parameters. Sousa et al. (1997) proposed internal model controller (IMC) with a fuzzy model for air-conditioning system. Different control schemes have been discussed within the literature by various researchers. Peng et al. (2013) proposed an internal model based robust inversion feed-forward and feedback control approach for LPV system while Zhang et al. (2014) presented a discrete feed-forward and feedback optimal tracking control scheme for a steel jacket plat subjected to external wave force. Zhong and Luo (2011) presented a comparative analysis between a single-loop control system and a cascade control system for a third-order process. Zhong et al. (2012) proposed model matching methods and approximate dynamic inversion techniques for designing feed-forward controllers. A feed-forward velocity control scheme for a DC motor based on the inverse dynamic model has been presented in the literature by Barakat and Rajagopalan (1996). A robust cascade control system has been implemented for controlling central air-conditioning system by Wang et al. (2008). Mohammadzaheri et al. (2009) proposed a feed-forward control law based upon the concept of control equilibrium point.

This paper presents a comparison among different control schemes such as feedback, feedback plus feed-forward, cascade and cascade plus feed-forward using PID controllers.

The paper is organized as follows: section 2 gives a brief introduction to different control schemes; in section 3 tuning of PID controller, using ZN and RA methods has been discussed; the simulation results are given in section 4, and finally the paper is concluded.

2. Control Schemes

2.1. Feedback Control

A feedback control system maintains a prescriptive relationship between the process output and set point by comparing them and using the error signal as a means of control. It is the simplest form of closed loop control scheme (Bandi & Mehta, 2012). Feedback control system has many daily routine applications; for instance, consider an automobile speed control or an air conditioner temperature control system which uses the difference between the actual and the desired speed or temperature to change the manipulated variable. Since the system output is used to regulate its input, such a device is said to be a closed-loop control system. The block diagram of a feedback control system is shown in Figure 1.

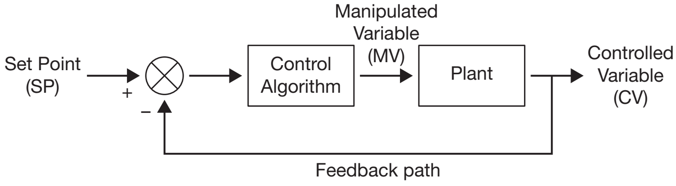

Fig. 1. Feedback control system.

From Figure 1, it can be observed that the error signal which is the difference between the set-point and the output variable acts on the input for the controller which can be a PID controller. The controller generates the manipulated variable to obtain the desired plant output.

2.2. Feed-forward Control

The objective of feed-forward control is to measure disturbances and remunerate for them before the controlled variable varies from the set point. The basic approach is to measure a disturbance directly and take control action to erase its impact upon the process output (Bequette, 2003). The performance of the feed-forward scheme depends on the accuracy of the process and the disturbance models. Feed-forward control has the possibility for impeccable control. However, because of modeling errors and unmeasured disturbances, a flawless feed-forward control cannot be achieved. Feed-forward control cannot be used alone and is used in combination with feedback control. The role of a feedback controller is to take care of the modeling errors and unmeasured disturbances which insure offset-free control. Feed-forward control acts immediately on occurrence of disturbance, without waiting for a change to the process variable (Bequette, 2003). The block diagram of a feed-forward control scheme is shown in Figure 2.

From the block diagram, it can be revealed that the feed-forward controller takes immediate action in response to a disturbance acting upon the system.

2.3. Feed-forward Plus Feedback

A combination of feed-forward plus feedback control strategy has been shown in Figure 3. Here the feed-forward controller will reduce or eliminate the effect of outer disturbances acting upon the system while the feedback control loop is a simple closed-loop control loop which will respond with a change in the set point (Bequette, 2003).

Feed-forward plus feedback control is one of the commonly used advanced control techniques. Combining feed-forward with the feedback control scheme can significantly give better performance over simple feedback control under the effect of a

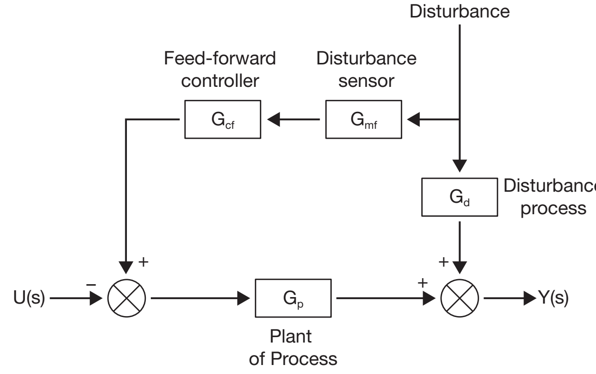

Fig. 2. Feed-forward control (Bequette, 2003).