Chapter

Introductory Chapter: PID-Based Industrial Process Control

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1. Introduction

A PID controller is an instrument used in industrial control applications at the regulatory level to regulate process variables e.g., temperature, pressure, flow, etc. To meet the continuously evolving challenges in industrial process control, it is essential to formulate control strategies which can yield improved performance. Proportional-integral-derivative (PID) controllers are still very much preferred in industries due to their simplicity and ability to yield reasonable closed-loop performance. A recent study has concluded that the preference for the PID, advanced and model predictive control in industries fall in the ratio 100:10:1 [1]. Another study states that about 90% industrial controllers are of PID type [2] to meet the requirement.

1.1 Literature review of PID control strategies

Majority of the control schemes use PID controllers in a unity feedback configuration [3]. However, unity feedback schemes are not suitable for plants having large time delays (LTD) and disturbances [4]. Hence, attempts have been made to design double-degree-of-freedom (DDOF) control schemes by adding additional controllers [4–12].

If an intermediate process output is available, cascaded control (CC) is more capable of giving better closed-loop performance compared to the DDOF control structures mentioned above. Based on the mode of operation, there are two varieties of CC strategies: serial and parallel [13, 14]. In practice, time delays occur in transport and composition examination loops [4]. The control schemes reported in [15–17] fails to provide good servo response for processes with LTD. To compensate LTD, Smith predictor (SP) based schemes are reported in the literature [6]. However, SP based control strategies fails to yield satisfactory regulatory performance for processes having LTD in the presence of disturbances [18]. Hence, SP can be combined with cascade control to achieve both satisfactory servo and regulatory performance [18–20].

Plant like boilers and reactors are often modeled as unstable processes having time delay [4]. In contrast, paper drum drier cans and boiler steam drums are of integrating type [4]. Having poles in the right half of the s-plane and origin makes unstable and integrating (UI) plants difficult to control. To control UI processes, modifications are required in single-loop, DDOF, CC and SP bases strategies [8, 13]. Hence, a lot of research is still being carried out in the aforementioned domains.

1.2 Requirements for industrial process control

It is essential that a control strategy must be capable of eliminating the load disturbances and tracking the reference input. Moreover, it must be robust towards uncertainties in process dynamics and noise that enters the system. Response of a control system to setpoint changes and disturbances are termed servo and regulatory responses, respectively. In process industries, changes in setpoint happen only when the production rate is altered. Mostly the production rate remains unaltered for years together. On the other hand, closed-loop performance is more frequently hindered by disturbances entering the system. Therefore, disturbance elimination is comparatively more vital than reference following [21]. The essential requirements for a PID control strategy are discussed below.

1.2.1 Disturbance rejection

The system output deviates from the desired value due to load disturbances which are of low frequency. Hence, rejecting such load disturbances is a primary task of a properly designed controlled system. The instantaneous error $e(t)$ is the deviation of setpoint (r_1) from controlled output (y_1) at time 't'. Using $e(t)$, the performance of a closed-loop control system can be characterized by computing the following measures:

Integrated absolute error (IAE)

$$\text{IAE} = \int_0^\infty |e(t)|dt \tag{1}$$

Integrated squared error (ISE)

$$\text{ISE} = \int_0^\infty e(t)^2 dt \tag{2}$$

and Integrated time-weighted absolute error (ITAE)

$$\text{ITAE} = \int_0^\infty t|e(t)|dt \tag{3}$$

Small values of (1) to (3) indicates better control performance.

1.2.2 Setpoint tracking

Whenever there is a change in the setpoint (reference input), it is expected that the system output should immediately follow the new reference value. The reference-tracking capability of a closed-loop system is characterized by its rise-time (t_r) and settling-time (t_s). t_r is the time consumed in system output raising from 10% to 90% of the expected value. Moreover, t_s is the time consumed in system output to reach up to (and stay within) ±2% or ±5% of the final value. The system output is expected to have less overshoot, t_r, t_s and steady state error (error 'e' after reaching steady state) during a change in setpoint. In addition to the above, performance measures like IAE, ISE and ITAE are also used to characterize the servo performance.

1.2.3 System robustness

The plant model (G_{om}) used to design controllers is an approximate version of the actual plant dynamics (G_{o}). Therefore, it is important to ensure that the controller designed using G_{om} to be robust enough to control G_{o}. As per [22], the rule to achieve closed-loop robust stability is

$$\|l_{\mathrm{m}}(s)T_{\mathrm{d}}(s)\| < 1\forall\omega \in (-\infty,\, \infty) \tag{4}$$

Here, $T_{\mathrm{d}}(s = j\omega)$ denotes complementary sensitivity function. $l_{\mathrm{m}}(s = j\omega)$ is the multiplicative uncertainty as given below:

$$l_{\mathrm{m}}(s) = \left|\frac{G_{\mathrm{o}}(s) - G_{\mathrm{om}}(s)}{G_{\mathrm{om}}(s)}\right| \tag{5}$$

From the magnitude plots of T_{d} and l_{m}, the robust stability of a system is analyzed graphically. Furthermore, system robustness can be measured with maximum sensitivity (M_{s}).M_s is defined as the inverse of the shortest distance from the Nyquist curve of the loop transfer function to the critical point '−1'. For an unity feedback system having a controller G_{c} and process model G_{p}, M_{s} is obtained as follows:

$$M_{\mathrm{s}} = \max{}_{\omega}\left|\frac{1}{1 + G_{\mathrm{c}}(j\omega)G_{\mathrm{p}}(j\omega)}\right| \tag{6}$$

It is expected for M_{s} to remain within 1.2 and 2 to ensure a good tradeoff between performance and robustness for stable plants with time delay [4].

1.2.4 Control signal

Softness of the control action $u_2(t)$ is computed by its total variation (TV). Mathematically, TV is given as

$$\mathrm{TV} = \sum_{i=1}^{\infty} |u_2(i+1) - u_2(i)| \tag{7}$$

Moreover, the maximum magnitude of the control signal is given by $u_{2\max}$ $=\max\{u_2(t)\vee\}$. TV and $u_{2\max}$ must remain as small as possible in practice.

1.3 Motivation for this book

The following observations are made from the contemporary works pertaining to PID-based industrial process control:

i. While many authors report performance improvement by using complex control strategies that require large number of controller and filter parameters [23], simple and effective PID control schemes are more feasible in practical scenarios [13].

ii. The studies discussed in [3–23] use linearized plant models which have its own limitations when employed for controlling nonlinear systems that occur in practice. Hence, PID controller design for nonlinear processes have attracted good research attention in recent times [24].

iii. Many of the control strategies discussed in this chapter are limited to single-input single-output systems. Therefore, they require careful re-designing to be extended for multi-input-multi-output systems (MIMO) [25].

iv. Advanced control strategies like active disturbance rejection control (ADRC) [26] is widely preferred these days to achieve improved disturbance rejection which is vital in process industries.

v. Recently, auto-tuning strategies using relay feedback mechanism has also received much attention [27].

Motivated by the above, the subsequent chapters of this book are presented to introduce the readers to some simple PID controller design strategies for unstable processes, nonlinear systems and MIMO systems. Also, considerable attention has been given to familiarize the reader with the concept of ADRC and relay-based auto tuning strategies.

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