A new two-degree-of-freedom level control scheme

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Abstract

In this paper, a two-degree-of-freedom level control scheme for delay free processes is analyzed. The nominal performance and robustness are examined. And sufficient and necessary conditions for robust stability are derived. An alternative level control scheme is developed for processes with dead time and suboptimal controllers that can produce smooth response are derived analytically based on the internal model control. The scheme has an important feature in that it is simple and transparent in design and in the corporation of performance and robust stability issues. Numerical examples are provided to compare the proposed scheme with those developed. © 2002 ISA—The Instrumentation, Systems, and Automation Society.

Keywords: Two-degree-of-freedom; Level control; Optimal control; Dead time; IMC

1. Introduction

Numerous papers have been written on the subject of controlling and monitoring liquid level in different industrial processes [1–3]. Depending on whether the level after a step change of the process input tends towards a new stationary final value or not, one generally distinguishes between the controlled system with and that without recovery. The former is a self-regulating process. In the latter case, the transfer function of the controlled system contains an integrator. It is an integrating process.

Luyben and Buckley [4] proposed a feedforward/feedback scheme called proportional-lag (PL) control for level systems without recovery. In PL control, the proportional control based the feedback loop provides flow smoothing while the feedforward compensation eliminates the steady offset in the liquid level. The PL control utilizes the unique characteristic of level systems and integrator processes and thus the scheme can be designed in a transparent manner [4,7]. Similar to PL control, a proportional plus set-point ramp control is proposed for providing smooth flow [5]. McAvoy [6] also proposed a general methodology for assessing the viability of plant wide level control scheme. Recently, an extension was made to the PL level control by Wu et al. [7]. A two-degree-of-freedom scheme is proposed for level systems. It is shown by the author that the scheme gives satisfactory responses for both systems without dead time and with small dead time.

Due to transportation delay, there may exist dead time in level systems. Several papers have been devoted to the control of the process with an integrator and dead time [8–10]. Astrom et al. [11] presented a new structure of Smith predictor for the control of the process with an integrator and dead time. This structure isolates the disturbance response from the set point response, and gives better responses to the set point and the dis-
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2. Analysis of the original system

The two-degree-of-freedom control structure proposed by Wu et al. [7] is shown in Fig. 1, where \( G_p(s) = K_p/s \) is the process, \( G_m(s) = K_m/s \) is the process model, \( K_f(s) \) is the proportional controller for disturbance rejection, and the load estimator, \( K_c(s) \) is the proportional controller for set-point tracking, and \( y(s), d_e(s), d_i(s) \) represent the Laplace transformed level, outflow, and inlet flow, respectively. The structure can be understood in this way: the process \( G_p(s) \) is first stabilized by the controller \( K_f(s) \). The resultant augment process \( \frac{1}{K_f} \) can be written as

\[
\frac{1}{K_f} = \frac{1}{s^2(1/K_pK_f + 1)}.
\]

Then a PI controller,
\[ K_c \left[1 + G_m(s)K_f\right] = K_c \left(1 + \frac{K_mK_f}{s}\right). \]  

(2)

is used for controlling the augment process.

Assume that the process model is a perfect representation of the real process, i.e., \( G_p(s) = G_m(s) \). The set-point response is

\[ H_r(s) = \frac{y(s)}{r(s)} = \frac{1}{s/K_mK_c + 1}. \]  

(3)

By inverse Laplace transform, its time domain response is

\[ h_r(t) = 1 - e^{-K_mK_c t}. \]  

(4)

The load response is given in the form of

\[ H_d(s) = \frac{y(s)}{d(s)} = \frac{s/K_mK_fK_c}{(s/K_mK_c + 1)(s/K_mK_f + 1)}. \]  

(5)

Its time domain response is

\[ h_d(t) = \frac{1}{K_f - K_c} (e^{-K_mK_f t} - e^{-K_mK_c t}), \text{ } K_f \neq K_c. \]  

(6)

or

\[ h_d(t) = K_mte^{-K_mK_c t}, \text{ } K_f = K_c. \]  

(7)

The closed-loop system is stable if \( K_mK_c > 0 \) and \( K_mK_f > 0 \). It is seen that the response depends on not only \( K_f \) but also \( K_c \). Hence, strictly speaking, the structure of Fig. 1 is not a two-degree-of-freedom system.

There always exists uncertainty in practice. Wu et al. [7] have shown that the zero steady-state offset can be retained by the scheme when the modeling uncertainty in the steady-state gain is considered. As a matter of fact, the zero steady-state offset is an elemental feature of feedback structures. If the nominal system possesses the property, the zero steady-state offset will be retained even when there exists uncertainty.

A natural question concerning the scheme is when is the system robust stable? Define

\[ \Delta(\omega) = \left| \frac{G_p(j\omega) - G_m(j\omega)}{G_m(j\omega)} \right| = \left| \frac{K_p}{K_m} - 1 \right|, \]  

(8)

where \( \Delta(\omega) \) is the bound on the multiplicative uncertainty. The transfer function from the output disturbance to the process output is

\[ H_d(o) = \frac{y(s)}{d(s)} = \frac{s^2/K_m^2K_fK_c}{(s/K_mK_c + 1)(s/K_mK_f + 1)}. \]  

(9)

which is in fact the sensitivity transfer function. The robust stability of the system is equivalent to that of the system shown in Fig. 2 with

\[ K_0 = K_mK_fK_c/s + K_f + K_c. \]  

(10)

Morari and Zafiriou [18] shows that the system is robust stable if and only if

\[ |1 - H_d(o)| < \Delta^{-1}(\omega), \text{ } \forall \omega, \]  

(11)

or equivalently,

\[ \frac{(1/K_c + 1/K_f)j\omega + K_m}{(j\omega/K_c + 1)(j\omega/K_f + 1)} < \left| \frac{1}{K_p - K_m} \right|, \text{ } \forall \omega. \]  

(12)

3. New level control scheme

In this section, a new two-degree-of-freedom level control scheme is presented, which is shown in Fig. 3. The new scheme can be regarded as an extension of Ref. [19]. Here, \( G_p(s) \) is a general process with an integrator and a dead time \( \theta_p \). \( K_i(s) \) is the controller for the disturbance rejection, or the load estimator, and \( K_c(s) \) is the controller for the set-point tracking. They are generally dynamic controllers. Based on the IMC,
analytical design procedure will be developed. The resultant controller is optimal or suboptimal.

The object of IMC is to minimize the effect of the disturbance on process output [18]. The design procedure is divided into two steps. First, factor the plant model,

$$G_m(s) = G_+(s)G_-(s),$$

such that $G_+(s)$ is all pass and contains all of dead times and right half plane zeros. Second, define the IMC controller as follows:

$$Q(s) = J(s)/G_-(s),$$

where $J(s)$ is a low pass filter and usually chosen as

$$J(s) = \frac{1}{(\lambda s + 1)^m}$$

for a type-I process or

$$J(s) = \frac{(m\lambda + \theta_m)s + 1}{(\lambda s + 1)^m}$$

for a type-II process. A system is said to be of type $n$ if it has $n$ poles at the origin [18]. $m$ is chosen such that $Q(s)$ is proper. $\lambda$ is a positive real constant. When $\lambda \rightarrow 0$, the performance tends to be optimal. If the controller we need is a classical feedback controller, denoted by $C(s)$, it can be obtained by

$$C(s) = \frac{Q(s)}{1 - G_m(s)Q(s)}.$$

Although the IMC cannot be used for implementing the controller of systems with an integrator, it can be utilized for the analysis and design of the system. Consider the design of the disturbance loop. The transfer function from the disturbance $d_o(s)$ to the process output $y(s)$ is

$$H_{d_o}(s) = \frac{1}{1 + G_m(s)K_f(s)}.$$ 

The IMC controller for the disturbance loop is

$$Q_f(s) = J_f(s)/G_-(s)$$

with

$$J_f(s) = \frac{(m_f\lambda + \theta_m)s + 1}{(\lambda_f s + 1)^{m_f}}.$$ 

This leads to

$$K_f(s) = \frac{Q_f(s)}{1 - G_m(s)Q_f(s)} = \frac{Q_f(s)}{1 - G_+(s)J_f(s)}. \quad (21)$$

To obtain a realizable controller, the $K_f(s)$ should be realized in discrete form or approximated by a rational transfer function, as well as the controllers of Refs. [11,12]. Here we expand it in Maclaurin series [20]. Let

$$K_f(s) = f(s)/s.$$ 

We have

$$K_f(s) = \frac{1}{s} \left[ f(0) + f'(0)s + \frac{f''(0)}{2!}s^2 + \cdots \right]. \quad (23)$$

The first three terms of the above expansion can be interpreted as the standard PID controller given by

$$K_f(s) = k \left( 1 + \frac{1}{\tau_s} + \tau_ds \right), \quad (24)$$

where

$$k = f'(0), \quad \tau_i = f'(0)/f(0), \quad \tau_d = f''(0)/2f'(0). \quad (25)$$

A similar procedure can be developed for the design of the set-point loop. The transfer function from $r(s)$ to $y(s)$ is

$$H_r(s) = K_r(s)G_m(s). \quad (26)$$

To achieve the suboptimum performance, the $K_r(s)$ should be designed such that

$$K_r(s) = \frac{J_r(s)}{G_-(s)}$$

with

$$J_r(s) = \frac{1}{(\lambda_r s + 1)^{m_r}}. \quad (28)$$

4. Discussion

To illustrate the method, we will perform the design for the process described by

$$G_m(s) = \frac{K_m}{s} e^{-\theta_m s}. \quad (29)$$
The process $G_m(s) = K_m/s$ is a special case of the process. The IMC controller for disturbance loop is

$$Q_f(s) = \frac{s[(2\lambda_f + \theta_m)s + 1]}{K_m(\lambda_f s + 1)^2}. \quad (30)$$

This implies that load response is

$$H_{dI}(s) = \frac{K_m}{s} e^{-\theta_m s} \left[ 1 - \frac{(2\lambda_f + \theta_m)s + 1}{(\lambda_f s + 1)^2} e^{-\theta_m s} \right] \quad (31)$$

of which the time domain response is

$$h_{dI}(t) = \begin{cases} 0, & t < \theta_m \\ t - \theta_m, & \theta_m \leq t < 2\theta_m \\ \theta_m e^{-(t-2\theta_m)\lambda_f} + \frac{\lambda_f + \theta_m}{\lambda_f} (t - 2\theta_m) e^{-(t-2\theta_m)\lambda_f}, & t \geq 2\theta_m. \end{cases} \quad (32)$$

Then we get

$$K_f(s) = \frac{Q_f(s)}{1 - G_+(s)J_f(s)} = \frac{1}{K_m} \frac{s[(2\lambda_f + \theta_m)s + 1]}{(\lambda_f s + 1)^2 - [(2\lambda_f + \theta_m)s + 1] e^{-\theta_m s}}. \quad (33)$$

Expanding it in Maclaurin series yields that

$$k = \frac{2(12\lambda_f^2 + 30\theta_m \lambda_f^2 + 24\theta_m^2 \lambda_f + 5 \theta_m^3)}{3K_m(2\lambda_f^2 + 4\theta_m \lambda_f + \theta_m^2)^2},$$

$$\tau_i = K_m k(2\lambda_f + 4\theta_m \lambda_f + \theta_m^2)/2,$$

$$\theta_m^2 (288\lambda_f^4 + 768\lambda_f^3 \theta_m + 702\lambda_f^2 \theta_m^2 + 252\lambda_f \theta_m^3 + 31 \theta_m^4).$$

The controller for the set-point loop is

$$K_c(s) = \frac{J_c(s)}{G_-(s)} = \frac{1}{K_m} \frac{s}{\lambda_c s + 1}. \quad (34)$$

A direct implement of the scheme will cause the internal stability problem. However, if $G_p(s)$ is

stabilized by $K_f(s)$, the problem can be overcome. The set-point response can be expressed as

$$H_{cI}(s) = \frac{1}{\lambda_c s + 1} e^{-\theta_m s}. \quad (35)$$

and its time domain response is

$$h_{cI}(t) = \begin{cases} 0, & t < \theta_m \\ 1 - e^{-(t-\theta_m)\lambda_c}, & t \geq \theta_m. \end{cases} \quad (36)$$

Wu et al. [7] suggests that controllers should be designed according to two rather operational specifications: maximum rate of change in outflow (MRCO) and maximum peak height (MPH) for a given inlet flow variation. The transfer function from $d_i(s)$ to $y(s)$ is $H_{dI}(s)$ and the transfer function from $d_i(s)$ to $d_e(s)$ is

$$H_{se}(s) = G_+(s)J_f(s) = \frac{(2\lambda_f + \theta_m)s + 1}{(\lambda_f s + 1)^2} e^{-\theta_m s}. \quad (37)$$

of which the time domain response is

$$h_{se}(t) = \begin{cases} 0, & t < \theta_m \\ 1 - e^{-(t-\theta_m)\lambda_f} + \frac{\lambda_f + \theta_m}{\lambda_f^2} t e^{-(t-\theta_m)\lambda_f}, & t \geq \theta_m. \end{cases} \quad (38)$$

Simple computations give

$$MRCO = \frac{2\lambda_f + \theta_m}{\lambda_f^2} e^{\theta_m/\lambda_f}, \quad (39)$$

$$MPH = k \frac{\theta_m + \lambda_f}{\lambda_f^2} e^{-(\theta_m + \lambda_f)\theta_m} \quad (40)$$

for a unit change on the load. It should be noted that both the MRCO and MPH only relate to $\lambda_f$. This implies that the set-point response can be free adjusted.

When there exists uncertainty, the robust stability is determined only by $\lambda_f$. The uncertainty profile is

$$\Delta(\omega) \approx \left| \frac{G_p(j \omega) - G_m(j \omega)}{G_m(j \omega)} \right| \quad (41)$$

Especially when only the gain is uncertain, the expression simplifies to
\[
\Delta(\omega) = \frac{k_p}{k_m} - 1 .
\]

When only the dead time is uncertain, the expression simplifies to
\[
\Delta(\omega) = \begin{cases} 
  |e^{-j(\theta_p - \theta_m)\omega} - 1|, & \omega \text{ max}(\theta_p - \theta_m) < \pi \\
  2, & \omega \text{ max}(\theta_p - \theta_m) \geq \pi .
\end{cases}
\]

(43)

The sufficient and necessary condition that guarantees the stability of the closed-loop system is
\[
\left| \frac{(2\lambda_f + \theta_m)\omega + 1}{(\lambda_f\omega + 1)^2} e^{-\theta_m\omega} \right| < \Delta^{-1}(\omega), \quad \forall \omega .
\]

(44)

The design for processes with inverse response is similar and briefly stated here. Suppose that the process model is
\[
G_m(s) = \frac{K_m(-a\tau s + 1)}{s(\tau s + 1)} .
\]

(45)

Such a process can be regarded as an approximation of the process
\[
G_m(s) = \frac{K_m(a\tau s + 1)}{s(\tau s + 1)} e^{-2a\tau s} .
\]

(46)

The IMC controller for the disturbance loop is
\[
Q_f(s) = \frac{s(\tau s + 1)((2\lambda_f + 2a\tau)s + 1)}{K_m(a\tau s + 1)(\lambda_f s + 1)^2} .
\]

(47)

The load response is
\[
H_{dl}(s) = \frac{K_m(-a\tau s + 1)}{s(\tau s + 1)} \times \left[ 1 - \frac{(-a\tau s + 1)((2\lambda_f + 2a\tau)s + 1)}{(a\tau s + 1)(\lambda_f s + 1)^2} \right].
\]

(48)

Then we get
\[
K_f(s) = \frac{Q_f(s)}{1 - G_+(s)J_f(s)}
\]

\[
= \frac{1}{K_m} \frac{(\tau s + 1)((2\lambda_f + 2a\tau)s + 1)}{s(\tau s + 1)(\lambda_f s + 1)^2} .
\]

(49)

The transfer function from \(d_i(s)\) to \(d_e(s)\) is
\[
H_{ie}(s) = G_+(s)J_f(s)
\]

\[
= \frac{(-a\tau s + 1)((2\lambda_f + 2a\tau)s + 1)}{(a\tau s + 1)(\lambda_f s + 1)^2} .
\]

(50)

The controller for set-point loop is
\[
K_c(s) = \frac{J_c(s)}{G_-(s)} = \frac{1}{K_m} \frac{s(\tau s + 1)}{(a\tau s + 1)(\lambda_c s + 1)}. \]

(51)

The set-point response can be expressed as
\[
H_s(s) = \frac{-a\tau s + 1}{(a\tau s + 1)(\lambda_c s + 1)}. \]

(52)

5. Numerical examples

**Example 1**

Consider a surge tank with the inlet flow rate \(d_i\), the outlet flow rate \(d_e\), the tank level \(y\), and the tank cross section area \(A\) [7]. Assume that the density is a constant. The system can be described by
\[
A \frac{dy}{dt} = d_i(t) + d_e(t) .
\]

Taking Laplace transform, the transfer function describing the system is
\[
y(s) = \frac{-1/A}{s} d_e(s) + \frac{-1/A}{s} d_i(s) .
\]

Let
\[
G_m(s) = \frac{-1/A}{s} = \frac{K_m}{s} .
\]

We have
\[
y(s) = G_m(s)d_e(s) + G_m(s)d_i(s) .
\]
Then, the compensation can be carried out in the configuration of Fig. 1 or Fig. 3. It is known that the cross-section area of the tank is $A = 1 \text{m}^2$, the working volume is $A \cdot y = 2 \text{m}^3$, the initial level is at 50%, the nominal flow rate is $-d_e = d_e = 1 \text{m}^3/\text{min}$, and the maximum expected change in the inflow is $1 \text{m}^3/\text{min}$. For this process the suboptimal controller is

$$K_f(s) = -\frac{2}{\lambda_f} \left(1 + \frac{1}{2\lambda_f s}\right) \quad \text{and} \quad K_c(s) = -\frac{s}{\lambda_c s + 1}$$

and

$$\text{MRCO} = \frac{2}{\lambda_f}, \quad \text{MPH} = \lambda_f e^{-1}.$$  

If a specification on the MPH is 18.4% of the tank height, i.e., MPH = $2 \times 18.4\%$, one obtains that $\lambda_f = 1$. Therefore

$$K_f(s) = -\frac{2s + 1}{s}.$$  

It is noted that the controller is identical to $K_a$ with $K_c = K_f = -1$ in Fig. 1. This implies that they will give the same responses (Fig. 4) and the result of Ref. [7] is suboptimal. The time domain responses can be written as

$$h_{i_f}(t) = 1 - e^{-t/\lambda_i},$$

$$h_{d_f}(t) = te^{-t},$$

$$h_{i_e}(t) = 1 - e^{-t} + te^{-t}.$$  

In Ref. [7], when the load response is determined according to the specification on MPH or MRCO, the set-point response is also determined. However, in the proposed scheme we can free adjust the set-point response without degrading the specification on MPH or MRCO.

There always exists uncertainty in practice. Suppose that $K_p$ is uncertain. The closed-loop system is robust stable if and only if

$$\left|\frac{1 + 2j \omega}{(1+j \omega)^2}\right| < \left|\frac{1}{K_p - 1}\right|, \forall \omega.$$  

The maximum scope of $K_p$ for robust stability is

$$K_p > 1 - \frac{(1 + \omega^2)^2}{\sqrt{1 + 6\omega^2 + 9\omega^4 + 4\omega^6}}, \forall \omega.$$  

In Ref. [7] the controllers for delay-free system is used for the control of the process with dead time. It is shown that the proposed scheme can give an exact solution to the specification on MPH and MRCO. For the process with dead time, $\text{MPH} = (\theta_m + \lambda_f) e^{-\lambda_f/(\lambda_f + \theta_m)}$. Let $\text{MPH} = 2 \times 18.4\%$, one obtains that $\lambda_f = 0.66$. Take $\lambda_c = 1$. Then

$$K_f(s) = -2.2953 \left(1 + \frac{1}{1.5038s}\right)$$

and

$$K_c(s) = -\frac{s}{s + 1}.$$  

**Example 2**

Consider the process with dead time:

$$G_m(s) = -\frac{1}{s} e^{-3.14s/20}.$$  

In Ref. [7] the controllers for delay-free system is used for the control of the process with dead time. It is shown that the proposed scheme can give an exact solution to the specification on MPH and MRCO. For the process with dead time, $\text{MPH} = (\theta_m + \lambda_f) e^{-\lambda_f/(\lambda_f + \theta_m)}$. Let $\text{MPH} = 2 \times 18.4\%$, one obtains that $\lambda_f = 0.66$. Take $\lambda_c = 1$. Then

$$K_f(s) = -2.2953 \left(1 + \frac{1}{1.5038s}\right)$$

and

$$K_c(s) = -\frac{s}{s + 1}.$$
Here, the derivative constant is very small and omitted. The time domain responses are

\[
h_r(t) = \begin{cases} 0, & t < 0.157 \\ 1 - e^{-(t - 0.157)/0.66}, & t \geq 0.157, \end{cases}
\]

\[
h_d(t) = \begin{cases} 0, & t < 0.157 \\ t - 0.157, & 0.157 \leq t < 0.314 \\ 0.157e^{-(t - 0.314)/0.66} + 1.2379(t - 0.314) \times e^{-(t - 0.314)/0.66}, & t \geq 0.314, \end{cases}
\]

\[
h_{ie}(t) = \begin{cases} 0, & t < 0.157 \\ 1 - e^{-(t - 0.157)/0.66} + 1.7904t \times e^{-(t - 0.157)/0.66}, & t \geq 0.157. \end{cases}
\]

The responses of the new scheme and that of Ref. [7] are shown in Fig. 5.

Reference [7] shows that the controllers for the delay-free system can only be used for the control of the process with small dead time due to the limitation of stability. The new scheme can be used for the control of the process with very large dead time. The specification that cannot be achieved can be easily distinguished.

**Example 3**

Consider the process with inverse response [7]:

\[
G_m(s) = \frac{0.5s - 1}{s(s + 1)}. 
\]

Reference [7] does not provide the design result for the required MRCO or MPH. For the new scheme, the load response is

\[
H_{di}(s) = \frac{(0.5s - 1)(0.5\lambda_f^2s + \lambda_f^2 + 2\lambda_f + 0.5)}{(0.5s + 1)(s + 1)(\lambda_f^2 + 1)^2} 
\]

of which the time domain response is

\[
h_{di}(t) = -\frac{1}{2} - 2\lambda_f - \lambda_f^2 + \frac{3\lambda_f^2 + 12\lambda_f + 3}{2(\lambda - 1)^2} e^{-t} 

- \frac{4\lambda_f + 1}{(2\lambda_f - 1)^2(\lambda_f - 1)^2} e^{-2t} 

+ \frac{4\lambda_f^6 - 4\lambda_f^5 - 15\lambda_f^4 + 0.5\lambda_f^2 + \lambda_f}{(2\lambda_f - 1)^2(\lambda_f - 1)^2} e^{-t/\lambda_f} 

+ \frac{(4\lambda_f^2 - 4\lambda_f - \lambda_f + 1)(\lambda_f^2 + 1.5\lambda_f + 1)}{(2\lambda_f - 1)^2(\lambda_f - 1)^2} 

\times t e^{-t/\lambda_f}. 
\]

The transfer function from \(d_i(s)\) to \(d_e(s)\) is

\[
H_{ie}(s) = G_+(s)J_f(s) 

= \frac{(-0.5s + 1)[(2\lambda_f + 1)s + 1]}{(0.5s + 1)(\lambda_f^2 + 1)^2}. 
\]
Its time domain response is

\[ h_{ie}(t) = 1 + \frac{8\lambda_f + 2}{(2\lambda_f - 1)^2} e^{-2t} - \frac{4\lambda_f^2 + 4\lambda_f + 3}{(2\lambda_f - 1)^2} e^{-t\lambda_f} - \frac{2\lambda_f^2 + 3\lambda_f + 1}{(2\lambda_f - 1)\lambda_f^2} t e^{-t\lambda_f}. \]

It is found that the time domain responses are very complicated. Computing the MRCO and MPH directly is very difficult. Fortunately, the responses have a monotonous relationship with \( \lambda_f \). Increasing the parameter from zero, one can easily obtain that \( \lambda_f = 0.1 \) for MPH = 2 × 18.4%. Certainly, we can also determine the parameter in examples 1 and 2 by the simple way. Take \( \lambda_c = 1 \). Then

\[ K_f(s) = -\frac{(s + 1)(1.2s + 1)}{0.71s} \quad \text{and} \quad K_c(s) = \frac{-s}{0.5s + 1}. \]

The responses of the new scheme are shown in Fig. 6. It is seen that the peak of the outlet flow rate is very large in this case.

6. Conclusions

In this paper, the two-degree-of-freedom level control scheme proposed by Wu et al. [7] is analyzed. Theoretical results on nominal time domain responses and a robust stability test are derived. A new two-degree-of-freedom scheme is then developed. Compared with that of Ref. [7], the controller of the new one is suboptimal, the set-point response can be free adjusted, and the performance and robustness can be easily analyzed. Controllers of level control systems are usually designed according to two rather operational specifications: MRCO and MPH. It is shown that the new scheme provides a simple way to obtain the required MRCO and MPH even for processes with dead time and high order complicated processes.

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References


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