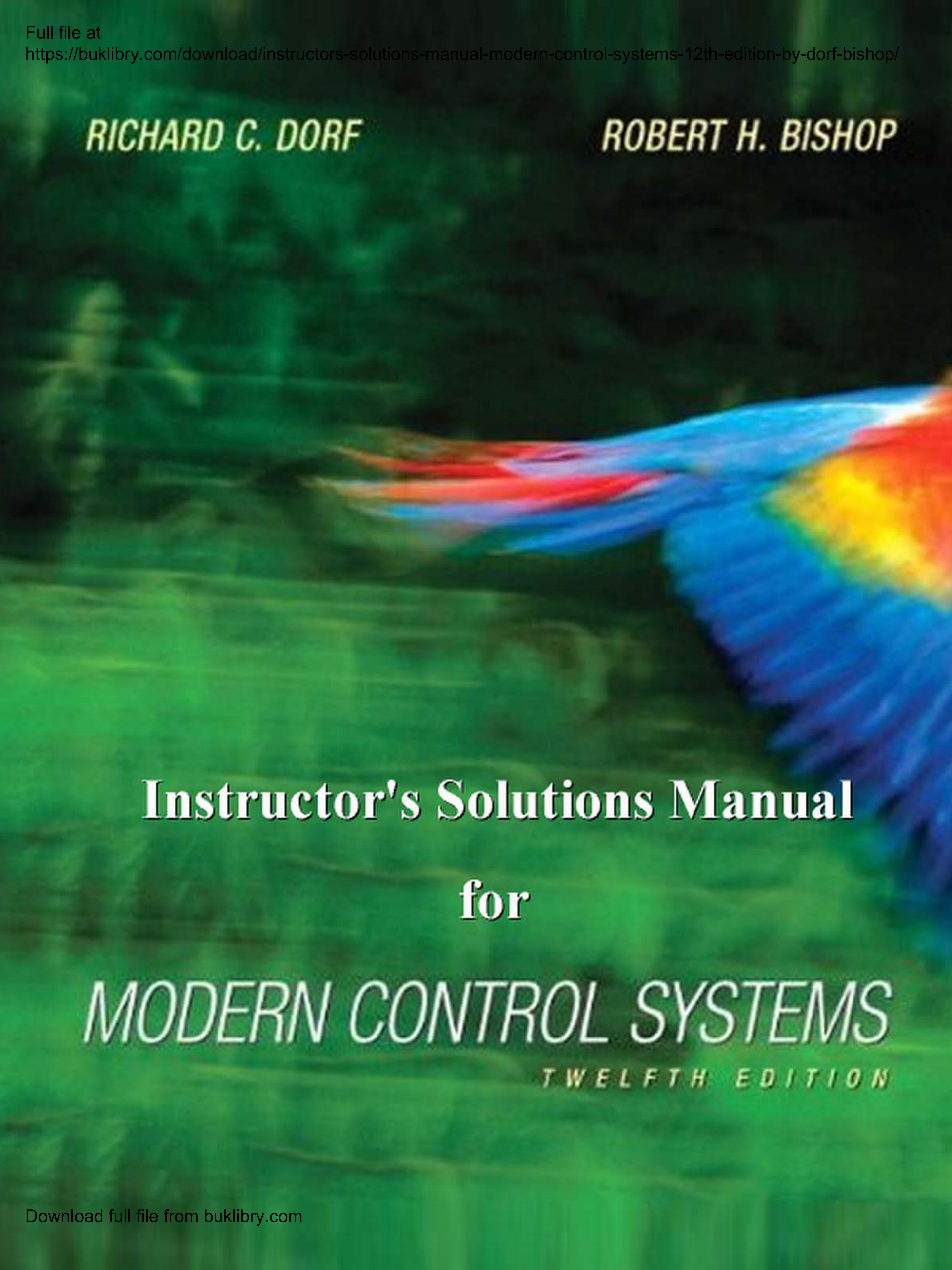

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ROBERT H. BISHOP

Instructor's Solutions Manual

for

MODERN CONTROL SYSTEMS

TWELFTH EDITION

MODERN CONTROL SYSTEMS

SOLUTION MANUAL

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A companion to

MODERN CONTROL SYSTEMS
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PREFACE

In each chapter, there are five problem types:

- Exercises
- Problems
- Advanced Problems
- Design Problems/Continuous Design Problem
- Computer Problems

In total, there are over 1000 problems. The abundance of problems of increasing complexity gives students confidence in their problem-solving ability as they work their way from the exercises to the design and computer-based problems.

It is assumed that instructors (and students) have access to MATLAB and the Control System Toolbox or to LabVIEW and the MathScript RT Module. All of the computer solutions in this *Solution Manual* were developed and tested on an Apple MacBook Pro platform using MATLAB 7.6 Release 2008a and the Control System Toolbox Version 8.1 and LabVIEW 2009. It is not possible to verify each solution on all the available computer platforms that are compatible with MATLAB and LabVIEW MathScript RT Module. Please forward any incompatibilities you encounter with the scripts to Prof. Bishop at the email address given below.

The authors and the staff at Prentice Hall would like to establish an open line of communication with the instructors using *Modern Control Systems*. We encourage you to contact Prentice Hall with comments and suggestions for this and future editions.

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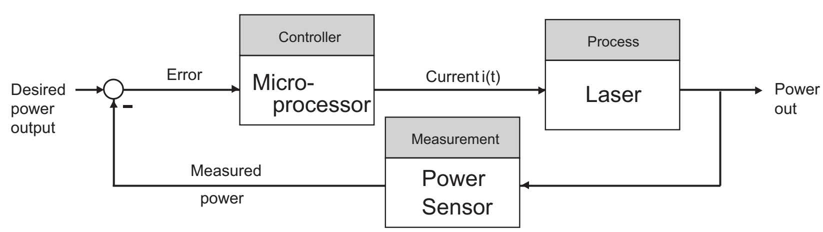
CHAPTER 1

Introduction to Control Systems

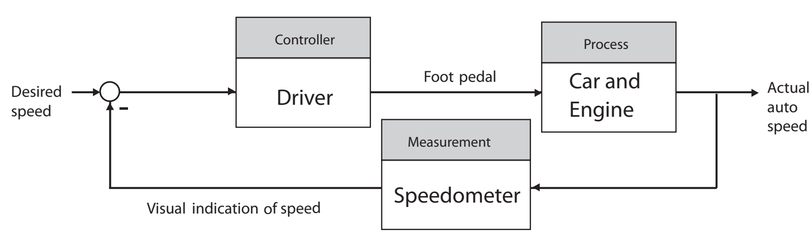
There are, in general, no unique solutions to the following exercises and problems. Other equally valid block diagrams may be submitted by the student.

Exercises

E1.1 A microprocessor controlled laser system:



E1.2 A driver controlled cruise control system:



E1.3 Although the principle of conservation of momentum explains much of the process of fly-casting, there does not exist a comprehensive scientific explanation of how a fly-fisher uses the small backward and forward motion of the fly rod to cast an almost weightless fly lure long distances (the

Problems

P3.1 The loop equation, derived from Kirchoff's voltage law, is

$$\frac{di}{dt} = \frac{1}{L}\, v - \frac{R}{L}\, i - \frac{1}{L} v_c$$

where

$$v_c = \frac{1}{C}\int i\; dt\ .$$

(a) Select the state variables as $x_1 = i$ and $x_2 = v_c$.

(b) The corresponding state equations are

$$\dot{x}_1 = \frac{1}{L}\, v - \frac{R}{L}\, x_1 - \frac{1}{L}\, x_2$$
$$\dot{x}_2 = \frac{1}{C}\, x_1\ .$$

(c) Let the input $u = v$. Then, in matrix form, we have

$$\dot{\mathbf{x}} = \begin{bmatrix} -R/L & -1/L \\ 1/C & 0 \end{bmatrix} \mathbf{x} + \begin{bmatrix} 1/L \\ 0 \end{bmatrix} u\ .$$

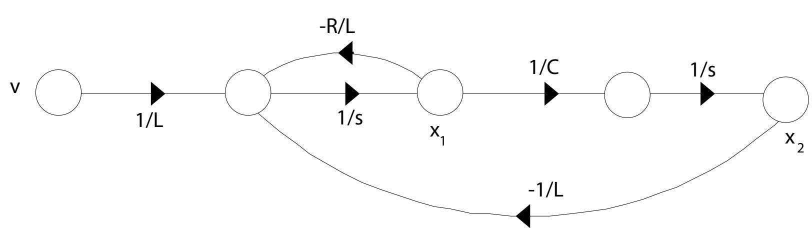


FIGURE P3.1
Signal flow graph.

P3.2 Let

$$a_{11} = \frac{-2}{(R_1+R_2)C}\ , \qquad a_{22} = \frac{-2R_1R_2}{(R_1+R_2)L}\ ,$$
$$b_{11} = b_{12} = \frac{1}{(R_1+R_2)C}\ , \quad b_{21} = -b_{22} = \frac{R_2}{(R_1+R_2)L}\ .$$

The corresponding block diagram is shown in Figure P3.2.

$$= \lim_{s \to 0} \frac{Is + K_1K_2K_3}{Is^2 + K_1K_2K_3s + K_1K_2} = K_3 \ .$$

But we desire $e_{ss} = 0.01$ m, so $K_3 = 0.01$.

(b) For $P.O. = 10\%$, we have $\zeta = 0.6$. Also,

$$2\zeta\omega_n = \frac{0.01K_1K_2}{25}$$

and

$$\omega_n^2 = \frac{K_1K_2}{25} \ .$$

Thus, solving for K_1K_2 yields $K_1K_2 = 36 \times 10^4$.

P5.8 (a) The closed-loop transfer function is

$$T(s) = \frac{P(s)}{R(s)} = \frac{G(s)/s}{1 + G(s)H(s)/s} = \frac{20}{s(s+40)} \ .$$

Therefore, the closed-loop system time constant is $\tau = 1/40$ sec.

(b) The transfer function from $T_d(s)$ to the output $P(s)$ is

$$\frac{P(s)}{T_d(s)} = \frac{-G(s)}{1 + G(s)H(s)/s} = \frac{-20}{s+40} \ .$$

The response to a unit step disturbance is

$$p(t) = -\frac{1}{2}(1 - e^{-40t}) \ .$$

At settling time, $p(t) = 0.98p_{ss} = -0.49$. Thus, solving for $t(= T_s)$ we determine that $T_s = 0.098$ sec.

P5.9 We need to track at the rate

$$\omega = \frac{v}{r} = \frac{16000}{2500} = 1.78 \times 10^{-3} \text{ radians/sec} \ .$$

The desired steady-state tracking error is

$$e_{ss} \leq \frac{1}{10} \text{ degree } = 0.1754 \times 10^{-2} \text{ rad} \ .$$

Therefore, with

$$e_{ss} = \frac{|\omega|}{K_v} \ ,$$

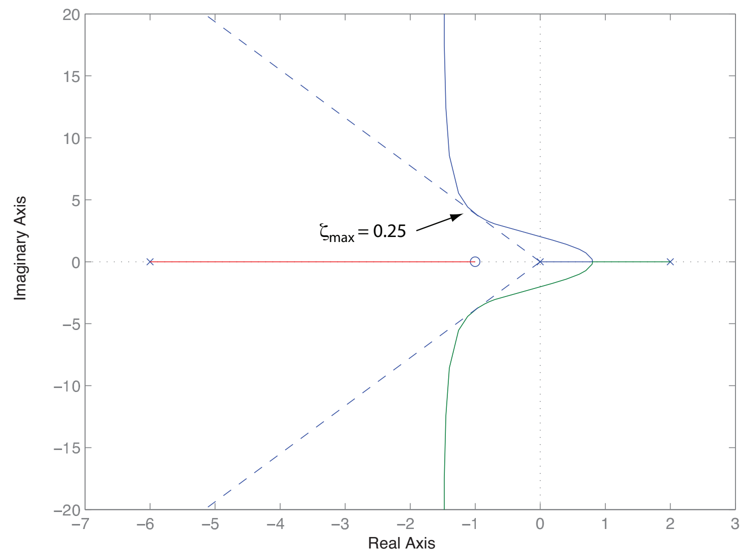


FIGURE E7.20
Root locus for $1 + \frac{K(s+1)}{s(s-2)(s+6)} = 0$.

E7.21 The gain is $K = 10.8$ when the complex roots have $\zeta = 0.66$.

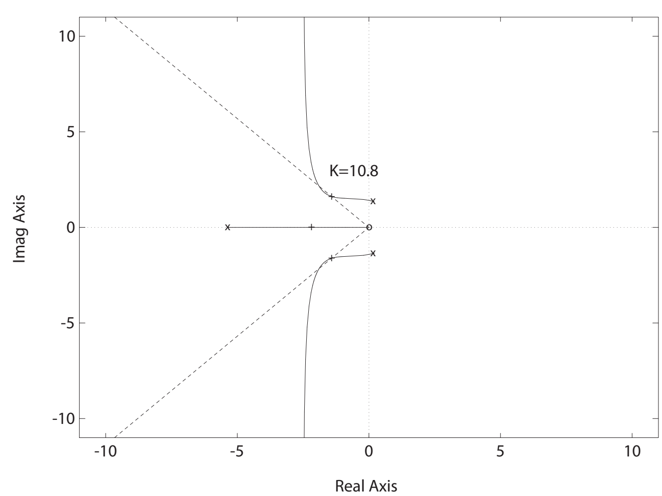


FIGURE E7.21
Root locus for $1 + \frac{Ks}{s^3+5s^2+10} = 0$.

(c) The transfer function is

$$G_c(s)G(s) = \frac{(s-8}{(s^2+6s+8)} \ .$$

The polar plot is shown in Figure P8.1c. A summary of the magnitude and phase angles for

$$\omega = 0,\ 1,\ 2,\ 3,\ 4,\ 5,\ 6,\ \infty$$

can be found in Table P8.1c.

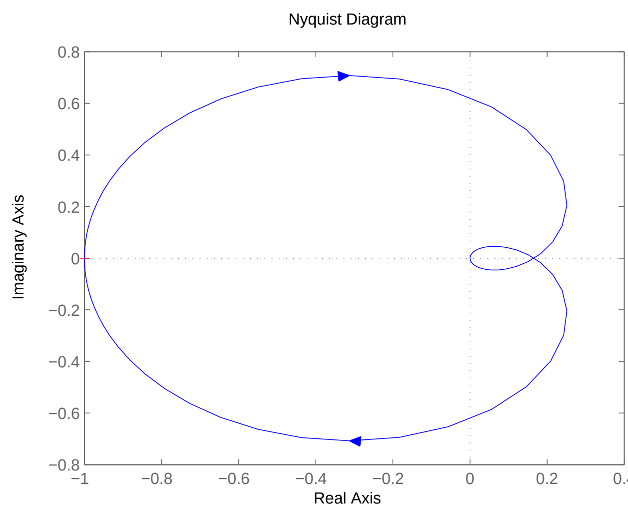


FIGURE P8.1
CONTINUED: (c) Polar plot for $G_c(s)G(s) = \frac{s-8}{s^2+6s+8}$.

ω	0	1	2	3	4	5	6	∞
$\lvert G_c(j\omega)G(j\omega)\rvert$ (dB)	1.00	0.87	0.65	0.47	0.35	0.27	0.22	0.00
ϕ (deg)	180.0	132.3	94.4	66.3	45.0	28.5	15.3	-90.0

TABLE P8.1 CONTINUED: (c) Magnitudes and phase angles for $G_c(s)G(s) = \frac{s-8}{s^2+6s+8}$.

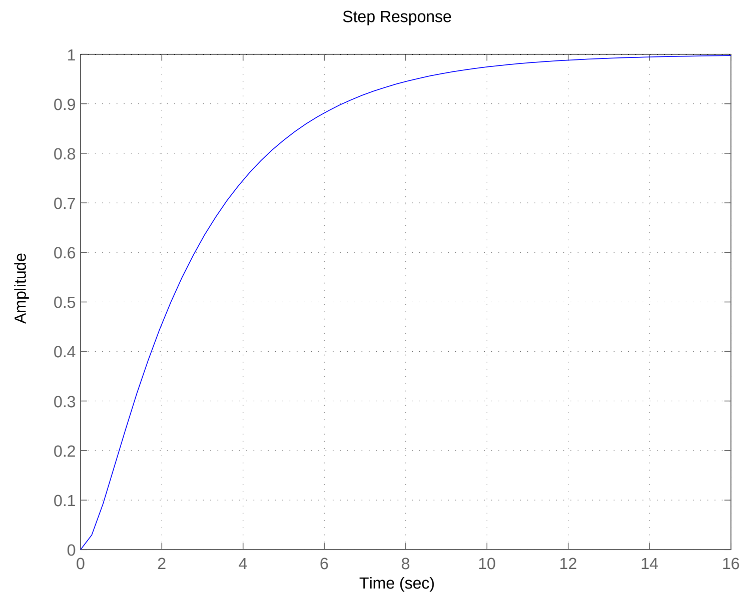


FIGURE AP9.10
Unit step response.

AP9.11 The phase margin versus time delay is shown in Figure AP9.11a.

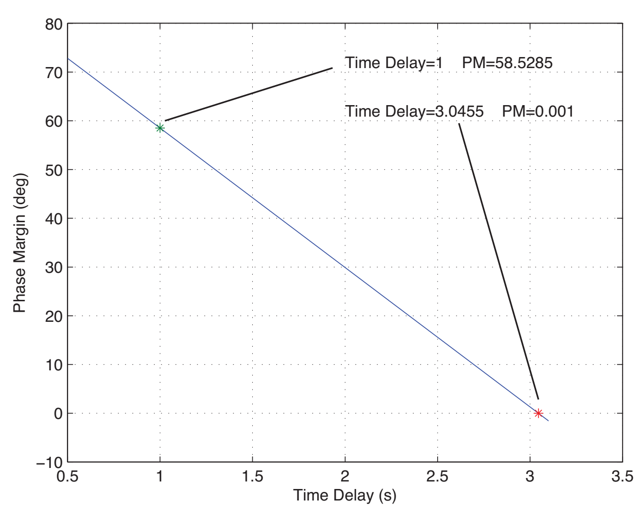


FIGURE AP9.11
Phase margin versus time delay.

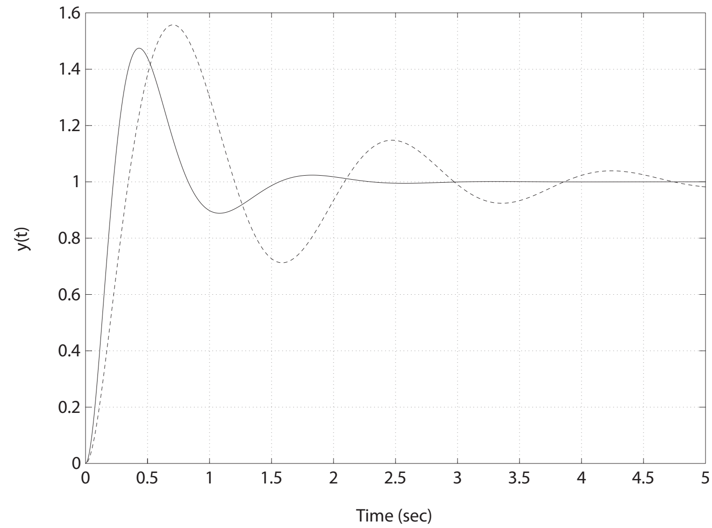


FIGURE DP12.3
CONTINUED: (b) Step response (without prefilters): PID with $K_3 = 90$ and $K_m = 1$ (solid line) and PID with $K_3 = 90$ and $K_m = 0.5$ (dashed line).

DP12.4 The nominal plant is

$$G(s) = \frac{17640}{s(s^2 + 59.4s + 1764)} ,$$

and the PID controller is

$$G_c(s) = \frac{K_I(\tau_1 s + 1)(\tau_2 s + 1)}{s} .$$

(a) Using ITAE methods, we determine that $\omega_n = 28.29$, $K_I = 36.28$, $\tau_1 + \tau_2 = 0.0954$ and $\tau_1\tau_2 = 0.00149$. So,

$$G_c(s) = \frac{36.28(0.00149s^2 + 0.0954s + 1)}{s} .$$

(b) The step response for the nominal plant and the PID controller is shown in Figure DP12.4a, with and without a prefilter.

(c) The disturbance response is shown in Figure DP12.4b.

(d) The off-nominal plant is

$$G(s) = \frac{16000}{s(s^2 + 40s + 1600)} .$$

The step response for the off-nominal plant is shown in Figure DP12.4a.