...ding a pole to the loop transfer function is to make the ...op system less stable, while decreasing the bandwidth. (T) (F)

15. For a minimum-phase loop transfer function $L(j\omega)$, if the phase margin is negative, then the closed-loop system is always unstable. (T) (F)

16. Phase-crossover frequency is the frequency at which the phase of $L(j\omega)$ is 0°. (T) (F)

17. Gain-crossover frequency is the frequency at which the gain of $L(j\omega)$ is 0 dB. (T) (F)

18. Gain margin is measured at the phase-crossover frequency. (T) (F)

19. Phase margin is measured at the gain-crossover frequency. (T) (F)

20. A closed-loop system with a pure time delay in the loop is usually less stable than one without a time delay. (T) (F)

21. The slope of the magnitude curve of the Bode plot of $L(j\omega)$ at the gain crossover usually gives indication on the relative stability of the closed-loop system. (T) (F)

22. Nichols chart can be used to find BW and M_r information of a closed-loop system. (T) (F)

23. Bode plot can be used for stability analysis for minimum- as well as nonminimum-phase transfer functions. (T) (F)

Answers to these true-and-false questions are found after the Problem section.

Answers to the Review Questions are found on the CD-ROM accompanying this text.

...RENCES

Nyquist Criterion of Continuous-Data Systems

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2. R. W. Brockett and J. L. Willems, "Frequency Domain Stability Criteria—Part I," *IEEE Trans. Automatic Control*, Vol. AC-10, pp. 255–261, July 1965.
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Sensitivity Function

6. A. Gelb, "Graphical Evaluation of the Sensitivity Function Using the Nichols Chart," *IRE Trans. Automatic Control*, Vol. AC-7, pp. 57–58, July 1962.

...MS

Most of the following problems may also be solved by using **freqtool** computer program that has been developed for this chapter. Some of the simpler problems should be solved analytically for a better understanding of the fundamental principles.

...utions of analytical ω_r, and

9-1. The forward-path transfer function of a unity-feedback control system is

$$G(s) = \frac{K}{s(s + 6.54)}$$

Analytically, find the resonance peak M_r, resonant frequency ω_r, and bandwidth BW of the closed-loop system for the following values of K: **(a)** $K = 5$. **(b)** $K = 21.39$. **(c)** $K = 100$. Use the formulas for the second-order prototype system given in the text.

...ions of

9-2. Use **ACSYS** to solve the following problems. Do not attempt to obtain the solutions analytically. The forward-path transfer functions of unity-feedback control systems are given in the following equations. Find the resonance peak M_r, resonant frequency ω_r, and bandwidth BW of the closed-loop systems. (Reminder: Make certain that the system is stable.)

(a) $G(s) = \dfrac{5}{s(1 + 0.5s)(1 + 0.1s)}$ (b) $G(s) = \dfrac{10}{s(1 + 0.5s)(1 + 0.1s)}$

(c) $G(s) = \dfrac{500}{(s + 1.2)(s + 4)(s + 10)}$ (d) $G(s) = \dfrac{10(s + 1)}{s(s + 2)(s + 10)}$

(e) $G(s) = \dfrac{0.5}{s(s^2 + s + 1)}$ (f) $G(s) = \dfrac{100e^{-s}}{s(s^2 + 10s + 50)}$

(g) $G(s) = \dfrac{100e^{-s}}{s(s^2 + 10s + 100)}$ (h) $G(s) = \dfrac{10(s + 5)}{s(s^2 + 5s + 5)}$

9-3. The specifications on a second-order unity-feedback control system with the closed-loop transfer function

$$M(s) = \frac{Y(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

are that the maximum overshoot must not exceed 10 percent, and the rise time must be less than 0.1 sec. Find the corresponding limiting values of M_r and BW analytically.

elation among um overshoot, rise M_r and BW

9-4. Repeat Problem 9-3 for maximum overshoot $\leq$ 20 percent, and $t_r \leq 0.2$ sec.

9-5. Repeat Problem 9-3 for maximum overshoot $\leq$ 30 percent, and $t_r \leq 0.2$ sec.

elation between ncy and time ses

9-6. The closed-loop frequency response $|M(j\omega)|$-versus-frequency of a second-order prototype system is shown in Fig. 9P-6. Sketch the corresponding unit-step response of the system; indicate the values of the maximum overshoot, peak time, and the steady-state error due to a unit-step input.

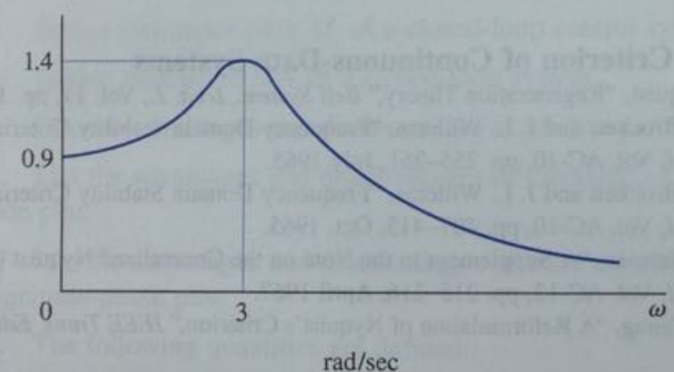

Figure 9P-6

M_r and BW

9-7. The forward-path transfer function of a unity-feedback control system is

$$G(s) = \frac{1 + Ts}{2s(s^2 + s + 1)}$$

Find the values of BW and M_r of the closed-loop system for $T = 0.05$, 1, 2, 3, 4, and 5. Use a computer program for solutions.

M_r and BW

9-8. The forward-path transfer function of a unity-feedback control system is

$$G(s) = \frac{1}{2s(s^2 + s + 1)(1 + Ts)}$$

Find the values of BW and M_r of the closed-loop system for $T = 0$, 0.5, 1, 2, 3, 4, and 5. Use a computer program for solutions.

ity analysis with criterion

9-9. The loop transfer functions $L(s)$ of single-feedback-loop systems are given below. Sketch the Nyquist plot of $L(j\omega)$ for $\omega = 0$ to $\omega = \infty$. Determine the stability of the closed-loop system. If the system is unstable, find the number of poles of the closed-loop transfer function that are in the right-half s-plane. Solve for the intersect of $L(j\omega)$ on the negative real axis of the $L(j\omega)$-plane analytically. You may construct the Nyquist plot of $L(j\omega)$ using any computer program.