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

(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.

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.

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.

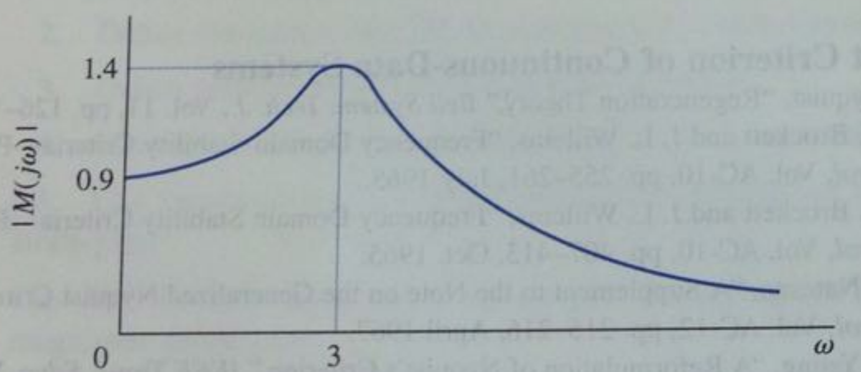


Figure 9P-6

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.

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.

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.

(a) $L(s) = \dfrac{20}{s(1 + 0.1s)(1 + 0.5s)}$ **(b)** $L(s) = \dfrac{10}{s(1 + 0.1s)(1 + 0.5s)}$

(c) $L(s) = \dfrac{100(1 + s)}{s(1 + 0.1s)(1 + 0.2s)(1 + 0.5s)}$ **(d)** $L(s) = \dfrac{10}{s^2(1 + 0.2s)(1 + 0.5s)}$

(e) $L(s) = \dfrac{3(s + 2)}{s(s^3 + 3s + 1)}$ **(f)** $L(s) = \dfrac{0.1}{s(s + 1)(s^2 + s + 1)}$

(g) $L(s) = \dfrac{100}{s(s + 1)(s^2 + 2)}$ **(h)** $L(s) = \dfrac{10(s + 10)}{s(s + 1)(s + 100)}$

Application of Nyquist
erion

9-10. The loop transfer functions of single-feedback-loop control systems are given in the following equations. Apply the Nyquist criterion and determine the values of K for the system to be stable. Sketch the Nyquist plot of $L(j\omega)$ with $K = 1$ for $\omega = 0$ to $\omega = \infty$. You may use a computer program to plot the Nyquist plots.

(a) $L(s) = \dfrac{K}{s(s + 2)(s + 10)}$ **(b)** $L(s) = \dfrac{K(s + 1)}{s(s + 2)(s + 5)(s + 15)}$

(c) $L(s) = \dfrac{K}{s^2(s + 2)(s + 10)}$

pplication of Nyquist
erion

9-11. The forward-path transfer function of a unity-feedback control system is

$$G(s) = \frac{K}{(s + 5)^n}$$

Determine by means of the Nyquist criterion, the range of K ($-\infty < K < \infty$) for the closed-loop system to be stable. Sketch the Nyquist plot of $G(j\omega)$ for $\omega = 0$ to $\omega = \infty$.

(a) $n = 2$. **(b)** $n = 3$. **(c)** $n = 4$.

plication of Nyquist
Routh-Hurwitz criteria

9-12. The characteristic equation of a linear control system is given in the following equation. Apply the Nyquist criterion to determine the values of K for system stability. Check the answers by means of the Routh-Hurwitz criterion.

$$s(s^3 + 2s^2 + s + 1) + K(s^2 + s + 1) = 0$$

ility of system with
ntroller

9-13. The forward-path transfer function of a unity-feedback control system with a PD (proportional-derivative) controller is

$$G(s) = \frac{10(K_P + K_D s)}{s^2}$$

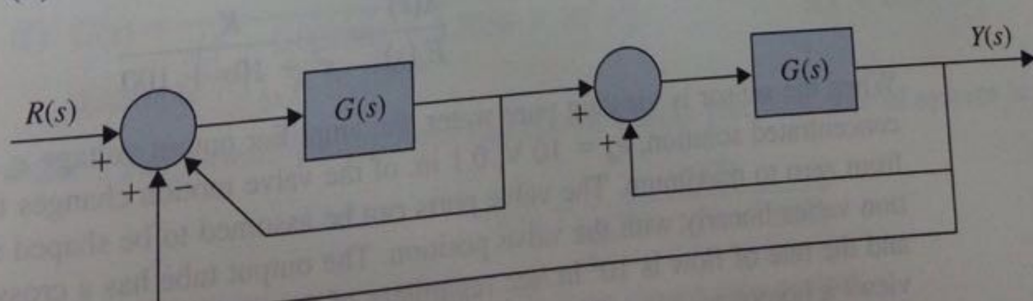
Select the value of K_P so that the parabolic-error constant K_a is 100. Find the equivalent forward-path transfer function $G_{eq}(s)$ for $\omega = 0$ to $\omega = \infty$. Determine the range of K_D for stability by the Nyquist criterion.

cation of SyQuest
th-Hurwitz

9-14. The block diagram of a feedback control system is shown in Fig. 9P-14.

(a) Apply the Nyquist criterion to determine the range of K for stability.

(b) Check the answer obtained in part (a) with the Routh-Hurwitz criterion.



$$G(s) = \frac{K}{(s + 4)(s + 5)}$$

ity study of liquid-
ntrol system by
criteraion

9-15. The forward-path transfer function of the liquid-level control system shown in Fig. 6P-13 is

$$G(s) = \frac{K_a K_i n K_I N}{s(R_a Js + K_i K_b)(As + K_o)}$$

The following system parameters are given: $K_a = 50$, $K_i = 10$, $K_I = 50$, $J = 0.006$, $K_b = 0.0706$, $n = 0.01$, and $R_a = 10$. the values of A, N, and K_o are variable.

(a) For $A = 50$ and $K_o = 100$, sketch the Nyquist plot of $G(j\omega)$ for $\omega = 0$ to ∞ with N as a variable parameter. Find the maximum integer value of N so that the closed-loop system is stable.

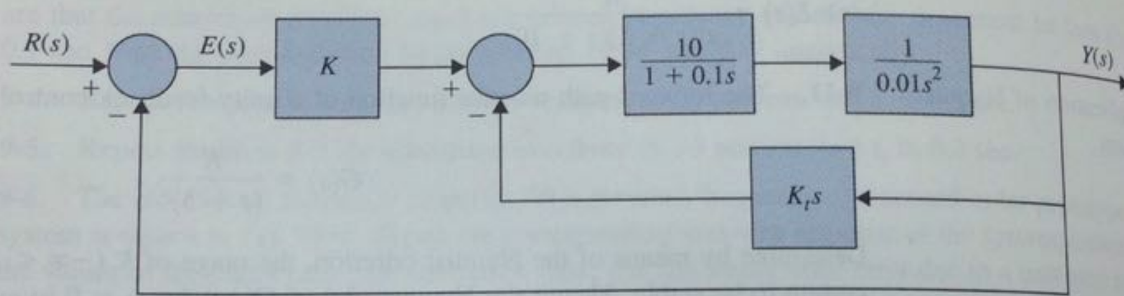
(b) Let $N = 10$ and $K_o = 100$. Sketch the Nyquist plot of an equivalent transfer function $G_{eq}(j\omega)$ that has A as a multiplying factor. Find the critical value of K_o for stability.

(c) For $A = 50$ and $N = 10$, sketch the Nyquist plot of an equivalent transfer function $G_{eq}(j\omega)$ that has K_o as a multiplying factor. Find the critical value of K_o for stability.

Figure 9P

study of dc-
trol system

9-16. The block diagram of a dc-motor control system is shown in Fig. 9P-16. Determine the range of K for stability using the Nyquist criterion when K_t has the following values:
(a) $K_t = 0$. **(b)** $K_t = 0.01$. **(c)** $K_t = 0.1$.



• Freq
analysi
system

9-17. For the system shown in Fig. 9P-16, let $K = 10$. Find the range of K_t for stability with the Nyquist criterion.

tudy of steel-
ol system

9-18. The steel-rolling control system shown in Fig. 4P-25 has the forward-path transfer function

$$G(s) = \frac{100Ke^{-T_d s}}{s(s^2 + 10s + 100)}$$

(a) When $K = 1$, determine the maximum time delay T_d in seconds for the closed-loop system to be stable.

(b) When the time delay T_d is 1 sec, find the maximum value of K for system stability.

udy of steel-
l system

9-19. Repeat Problem 9-18 with the following conditions.

(a) When $K = 0.1$, determine the maximum time delay T_d in seconds for the closed-loop system to be stable.

(b) When the time delay T_d is 0.1 sec, find the maximum value of K for system stability.

9-20. The system schematic shown in Fig. 9P-20 is devised to control the concentration of a chemical solution by mixing water and concentrated solution in appropriate proportions. The transfer function of the system components between the amplifier output e_a(V) and the valve position x (in.) is

$$\frac{X(s)}{E_a(s)} = \frac{K}{s^2 + 10s + 100}$$

When the sensor is viewing pure water, the amplifier output voltage e_a is zero; when it is viewing concentrated solution, $e_a = 10$ V; 0.1 in. of the valve motion changes the output concentration from zero to maximum. The valve ports can be assumed to be shaped so that the output concentration varies linearly with the valve position. The output tube has a cross-sectional area of 0.1 in.^{2}, and the rate of flow is 10^3 in./sec regardless of the valve position. To make sure that the sensor views a homogeneous solution, is it desirable to place it at some distance D in. from the valve.