For a first-order system with $V_o(s)/V_i(s) = 1/(\tau s + 1)$, the relationships are

$$t_r = 2.2\tau = \frac{2.2}{\omega_h} = \frac{0.35}{f_h} \tag{3.51}$$

$$P_0 = M_p = 1 \tag{3.52}$$

$$t_p = \infty \tag{3.53}$$

$$t_s = 4\tau \tag{3.54}$$

$$e_1 = \tau \tag{3.55}$$

$$\omega_p = 0 \tag{3.56}$$

For a second-order system with $V_o(s)/V_i(s) = 1/(s^2/\omega_n^2 + 2\zeta s/\omega_n + 1)$ and $\theta \triangleq \cos^{-1}\zeta$ (see Fig. 3.7) the relationships are

$$t_r \simeq \frac{2.2}{\omega_h} = \frac{0.35}{f_h} \tag{3.57}$$

$$P_0 = 1 + \exp\frac{-\pi\zeta}{\sqrt{1-\zeta^2}} = 1 + e^{-\pi/\tan\theta} \tag{3.58}$$

$$t_p = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}} = \frac{\pi}{\omega_n \sin\theta} \tag{3.59}$$

$$t_s \simeq \frac{4}{\zeta\omega_n} = \frac{4}{\omega_n \cos\theta} \tag{3.60}$$

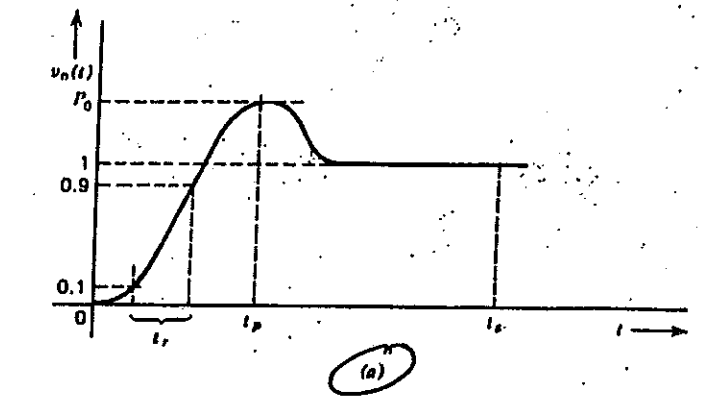
$$e_1 = \frac{2\zeta}{\omega_n} = \frac{2\cos\theta}{\omega_n} \tag{3.61}$$

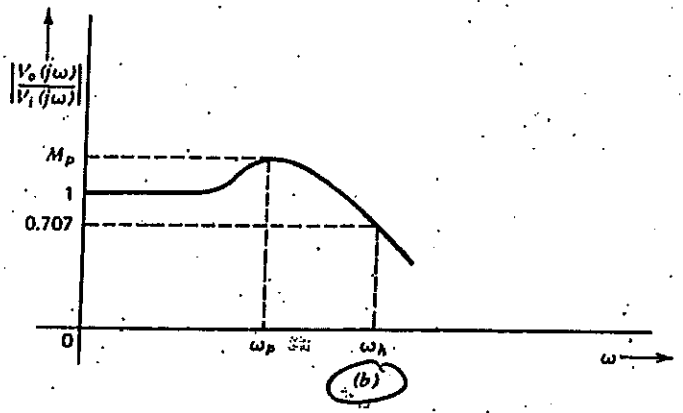
$$M_p = \frac{1}{2\zeta\sqrt{1-\zeta^2}} = \frac{1}{\sin 2\theta} \qquad \zeta < 0.707,\ \theta > 45° \tag{3.62}$$

$$\omega_p = \omega_n\sqrt{1-2\zeta^2} = \omega_n\sqrt{-\cos 2\theta} \qquad \zeta < 0.707,\ \theta > 45° \tag{3.63}$$

$$\omega_h = \omega_n\left(1 - 2\zeta^2 + \sqrt{2 - 4\zeta^2 + 4\zeta^4}\right)^{1/2} \tag{3.64}$$

If a system step response or frequency response is similar to that of an approximating system (see Figs. 3.6, 3.8, 3.11, and 3.12) measurements of t_r, P_0, and t_p permit estimation of ω_h, ω_p, and M_p or vice versa. The steady-state error in response to a unit ramp can be estimated from either set of measurements.





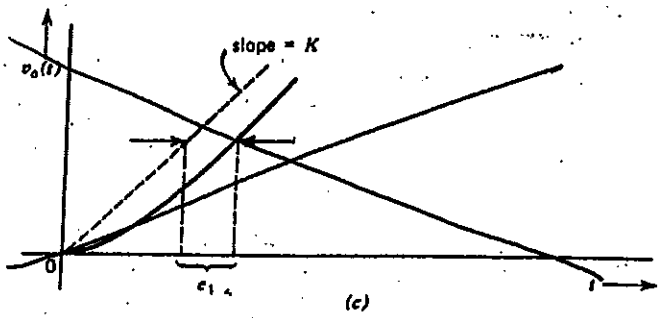


Figure 3.17 Parameters used to describe transient and frequency responses. (*a*) Unit-step response. (*b*) Frequency response. (*c*) Ramp response.

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