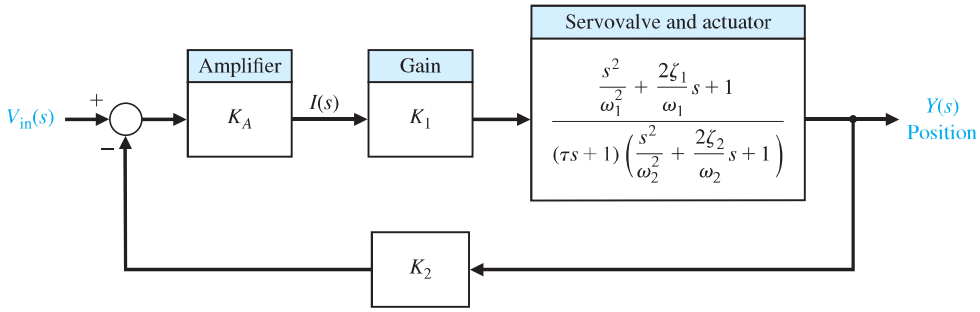
(a)



(b)

FIGURE P9.8
(a) A servovalve and actuator (courtesy of Moog Industrial Group). (b) Block diagram.

for reuse [19]. The shuttle used elevons at the trailing edge of the wing and a brake on the tail to control the flight during entry. The block diagram of a pitch rate control system is shown in Figure P9.9(b).

(a) Sketch the Bode plot of the system when $G_c(s) = 2$ and determine the stability margin. (b) Sketch the Bode plot of the system when

$$G_c(s) = K_P + K_I/s \quad \text{and} \quad K_I/K_P = 0.5.$$

The gain K_P should be selected so that the gain margin is 10 dB.

P9.10 Machine tools are often automatically controlled as shown in Figure P9.10. These automatic systems are often called numerical machine controls [9]. On each axis, the desired position of the machine tool is compared with the actual position and is used to actuate a solenoid coil and the shaft of a hydraulic actuator. The transfer function of the actuator is

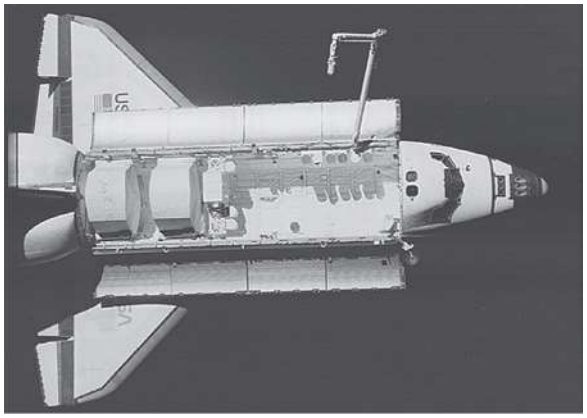
$$G_a(s) = \frac{X(s)}{Y(s)} = \frac{K_a}{s(\tau_a s + 1)},$$

where $K_a = 1$ and $\tau_a = 0.4$ s. The output voltage of the difference amplifier is

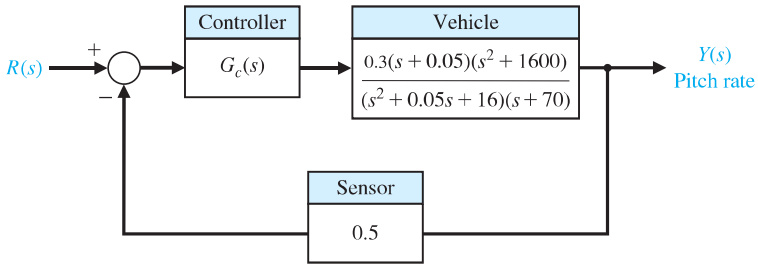
$$E_0(s) = K_1(X(s) - X_d(s)),$$

where $x_d(t)$ is the desired position input. The force on the shaft is proportional to the current $i(t)$, so that $F = K_2 i(t)$, where $K_2 = 3.0$. The spring constant K_s is equal to 1.5, $R = 0.1$, and $L = 0.2$.

(a) Determine the gain K_1 that results in a system with a phase margin of $P.M. = 30°$. (b) For the gain K_1 of part (a), determine $M_{p\omega}$, ω_r, and the closed-loop system bandwidth. (c) Estimate the percent overshoot of the transient response to a step input $X_d(s) = 1/s$, and the settling time (to within 2% of the final value).



(a)



(b)

FIGURE P9.9
(a) The Earth-orbiting space shuttle against the blackness of space. The remote manipulator robot is shown with the cargo bay doors open in this top view, taken by a satellite. (b) Pitch rate control system. (Courtesy of NASA.)

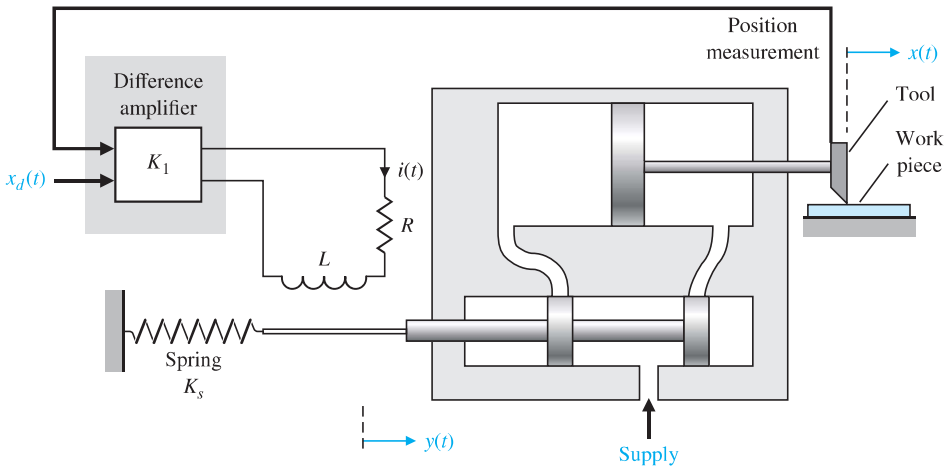


FIGURE P9.10
Machine tool control.

P9.11 A control system for a chemical concentration control system is shown in Figure P9.11. The system receives a granular feed of varying composition, and we want to maintain a constant composition of the output mixture by adjusting the feed-flow valve. The transport of the feed along the conveyor requires a transport (or delay) time, $T = 1.5$ s. (a) Sketch the Bode plot when $K_1 = K_2 = 1$, and investigate the stability of the system. (b) Sketch the Bode plot when $K_1 = 0.1$ and $K_2 = 0.04$, and investigate the stability