1-10. A thermal test chamber is illustrated in Figure P1-10a. This chamber, which is a large room, is used to test large devices under various thermal stresses. The chamber is heated with steam, which is controlled by an electrically activated valve. The temperature of the chamber is measured by a sensor based on a thermistor, which is a semiconductor resistor whose resistance varies with temperature. Opening the door into the chamber affects the chamber temperature and thus must be considered as a disturbance.

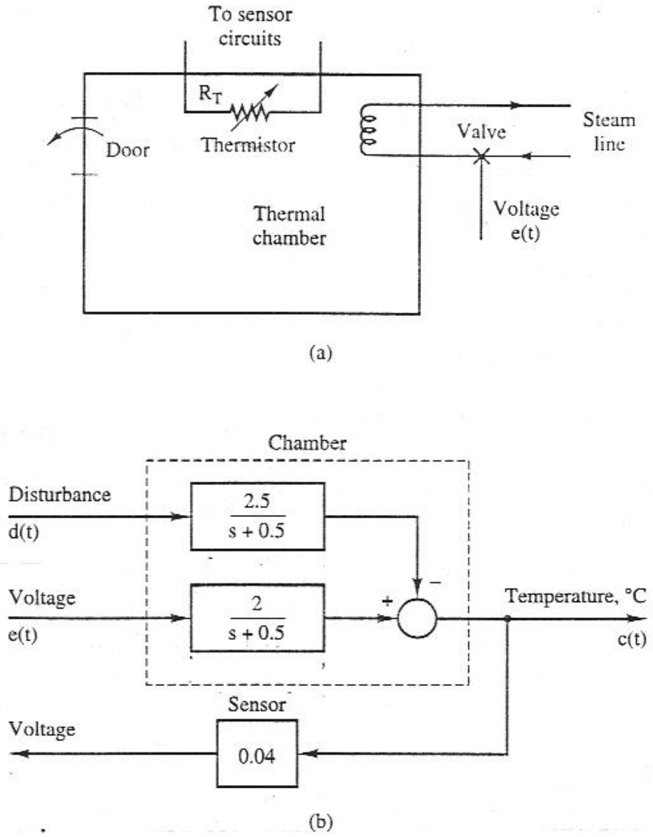


Figure P1-10 A thermal stress chamber.

A simplified model of the test chamber is shown in Figure P1-10b, with the units of time in minutes. The control input is the voltage $e(t)$, which controls the valve in the steam line, as shown. For the disturbance $d(t)$, a unit step function is used to model the opening of the door. With the door closed, $d(t) = 0$.

(a) Find the time constant of the chamber.

(b) With the controlling voltage $e(t) = 5u(t)$ and the chamber door closed, find and plot the chamber temperature $c(t)$. In addition, give the steady-state temperature.

(c) A tacit assumption in part (a) is an initial chamber temperature of zero degrees Celsius. Repeat part (b), assuming that the initial chamber temperature is $c(0) = 25°C$.

(d) Two minutes after the application of the voltage in part (c), the door is opened, and it remains open. Add the effects of this disturbance to the plot of part (c).

(e) The door in part (d) remains open for 12 min. and is then closed. Add the effects of this disturbance to the plot of part (d).

1-11. The thermal chamber transfer function $C(s)/E(s) = 2/(s + 0.5)$ of Problem 1-10 is based on the units of time being minutes.

(a) Modify this transfer function to yield the chamber temperature $c(t)$ based on seconds.

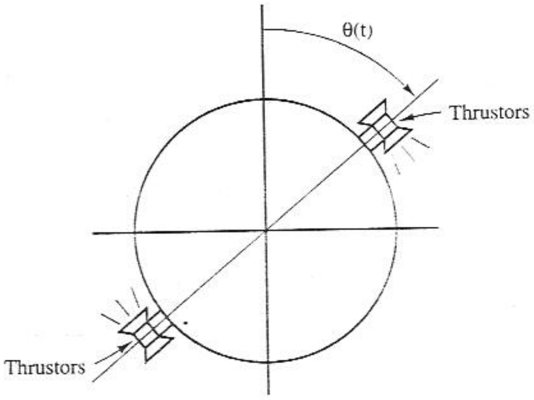
(b) Verify the result in part (a) by solving for $c(t)$ with the door closed and the input $e(t) = 5u(t)$ volts, **(i)** using the chamber transfer function found in part (a), and **(ii)** using the transfer function of Figure P1-10. Show that (i) and (ii) yield the same temperature at $t = 1$ min.

1-14. The input to the satellite system of Figure P1-12 is a step function $\theta_c(t) = 5u(t)$ in degrees. As a result, the satellite angle $\theta(t)$ varies sinusoidally at a frequency of 10 cycles per minute. Find the amplifier gain K and the moment of inertia J for the system, assuming that the units of time in the system differential equation are seconds.

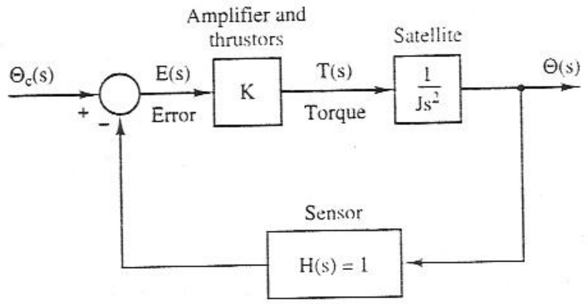
1-15. The satellite control system of Figure P1-12 is not usable, since the response to any excitation includes an undamped sinusoid. The usual compensation for this system involves measuring the angular velocity $d\theta(t)/dt$. The feedback signal is then a linear sum of the position signal $\theta(t)$ and the velocity signal $d\theta(t)/dt$. This system is depicted in Figure P1-15, and is said to have *rate feedback*.

(a) Derive the transfer function $\Theta(s)/\Theta_c(s)$ for this system.

(b) The state equations for the satellite are derived in Section 1.4. Modify these equations to model the closed-loop system of Figure P1-15.



(a)



(b)

Figure P1-12 Satellite control system.

(c) The state equations in part (b) can be expressed as

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\theta_c(t)$$

The system characteristic equation is

$$|s\mathbf{I} - \mathbf{A}| = 0$$

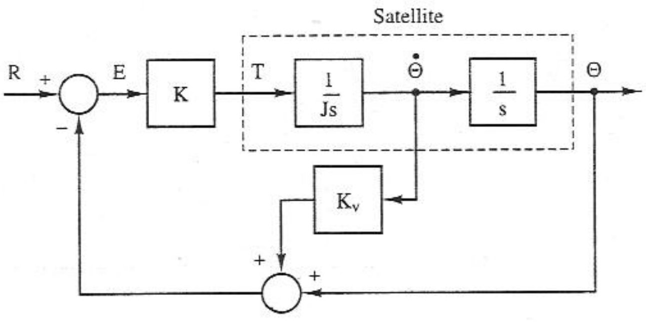


Figure P1-15 Satellite control system with rate feedback.