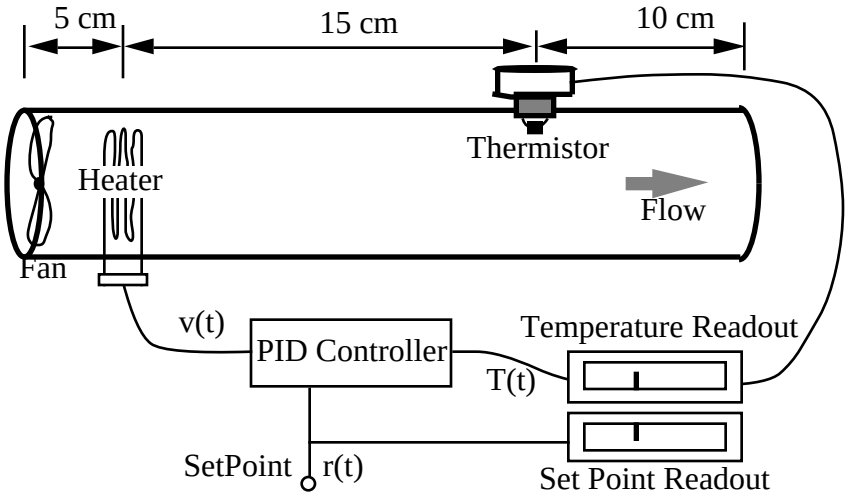
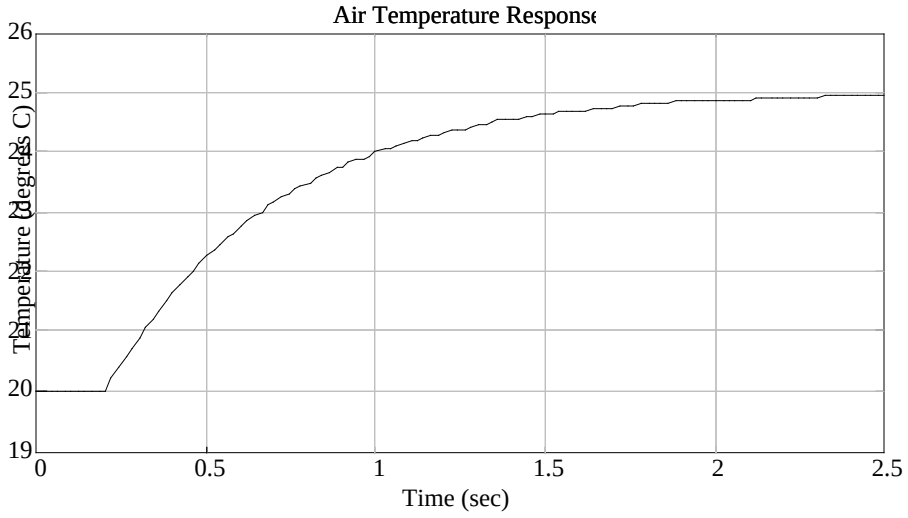
1. The apparatus shown below which is similar to the Air Temperature Control Laboratory. The system is composed of a tube 30 cm long with a fan at one end. Five (5) cm downstream of the fan is a heater and 15 cm further down the tube is a thermistor to measure temperature. Air flows down the tube from the fan and is heated by the heater. The PID controller is designed to control the temperature of the air in the tube. You measure the open-loop response of the plant to a 1 volt change in heater drive voltage and it takes the form of the graph shown below the schematic diagram.





(2 pt's) b) What is the open-loop system's process delay time? (Watch Units & Write result in the box)

Process Delay Time(sec)

(2 pt's) b) What is the air velocity in the tube? (Watch Units & Write result in the box)

Air Velocity (m/sec)

_____/4 pt's

(2 pt's) c) What is the system's time constant? (Watch Units & Write result in the box)

Time Constant (sec)

(2 pt's) d) What are the system's open-loop poles and zeros? (Write result in the box)

Pole(s) at s =

Open-Loop Pole(s)

(4 pt's) e) What is the open-loop plant's Drive voltage to Temperature transfer function, *T(s)/V(s)*? (Write result in the box)

$\frac{T(s)}{V(s)} =$

Drive Voltage to Temperature Transfer Function

(2 pt's) f) Is this open-loop system linear? (Check one Response Below)

☐ YES or ☐ NO or ☐ Can't Tell from Information Given

(2 pt's) g) To yield zero steady-state temperature error, what is the minimal set of gains in the PID controller must be made non-zero? (check the gains that apply)

☐ Proportional ☐ Integral

☐ Derivative ☐ None of them

_____/12 pt's

(4 points) 2. a) For the transfer function below, write the corresponding ordinary differential equation in the box provided for $X(s) = \mathcal{L}(x(t))$ and $U(s) = \mathcal{L}(u(t))$.

$$\frac{X(s)}{U(s)} = \frac{4}{s^2 + 0.5s + 9}$$

Differential Equation

(4 points) b) For the state-equations below, write the transfer function $X_2(s)/U(s)$ in the box provided. Simplify your result as much as possible and put it in the box provided.

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \end{bmatrix} = \begin{bmatrix} -1 & 0 \\ 1 & -2 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} 1 \\ 2 \end{bmatrix} u(t)$$

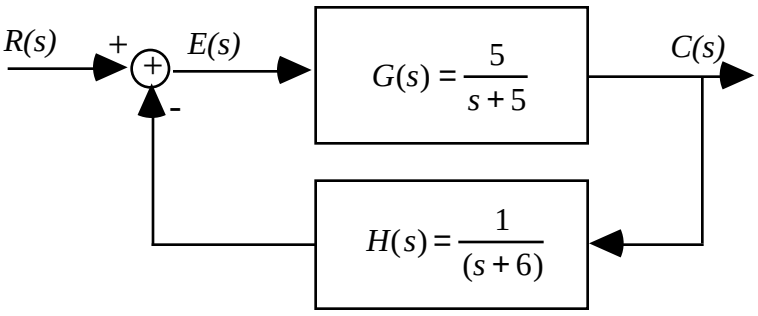
$$\frac{X_2(s)}{U(s)} =$$

Transfer Function

(4 points) c) For the block diagram below, what is the error transfer function $E(s)/R(s)$. Simplify your result as much as possible - no partial credit!

$$\frac{E(s)}{R(s)} =$$

Transfer Function



_____/12 pt's

3. An electric motor has the rotational differential equation for motor speed, $v(t)$ (rad/sec) versus input electric potential, $e(t)$ (volts) shown below.

$$\dot{v}(t) = -3v(t) + 2v(t)u(t) + 100u(t)$$

(2 points) a) Find the equilibrium value(s) of $u(t) = u_{equil}$ corresponding to an operating speed of $v(t) = 100$ rad/sec and enter it in the box below.

u_{equil} = volts

(2 points) b) Define a new set of variables about which a linear approximation for the above equation can be derived.

(4 points) c) Find the linearized ordinary differential equation(s) in state space form about the equilibrium point found in part a) and enter your result in the box below

Linearized State Equation(s)

_____/8 pt's

(3 points) 4) Is the equation below linear (obeys linear equation properties) for input u and output x ?

$$x = -3u + 5$$

☐ YES or ☐ NO or ☐ Can't Tell from Information Given

5) Answer the MatLab questions below and **enter answers in the boxes** supplied.

(3 points) a) Write the MatLab statement that defines the row vector, $a = \begin{bmatrix} 1 & 2 & 3 \end{bmatrix}$

(3 points) b) Write the MatLab statement that defines the column vector, $b = \begin{bmatrix} 4 \\ 5 \\ 6 \end{bmatrix}$

(3 points) c) Write the MatLab statement that plots the unit step response of the transfer function with numerator polynomial is stored in "A" and denominator polynomial stored in "B".

(3 points) d) Give the numerator polynomial in s that MatLab represents as "`num = [2 3 4]`".

_____/15 pt's

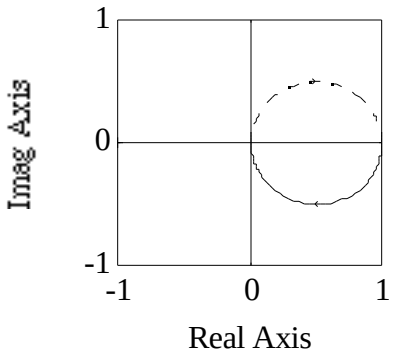
6. For each Nyquist diagram given below of the open-loop transfer function *KG(s)* with $K = 1$, state the gain and phase margins for the system, whether (yes/no) the system is stable for $K = 1$ and the range of positive stable gains, K for the system (state none if the closed-loop system is always unstable)

(8 points) a) Gain Margin = _____ Phase Margin = _____

Stable at $K = 1$? YES or NO (circle one)

Approximate Stable range for K _____

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

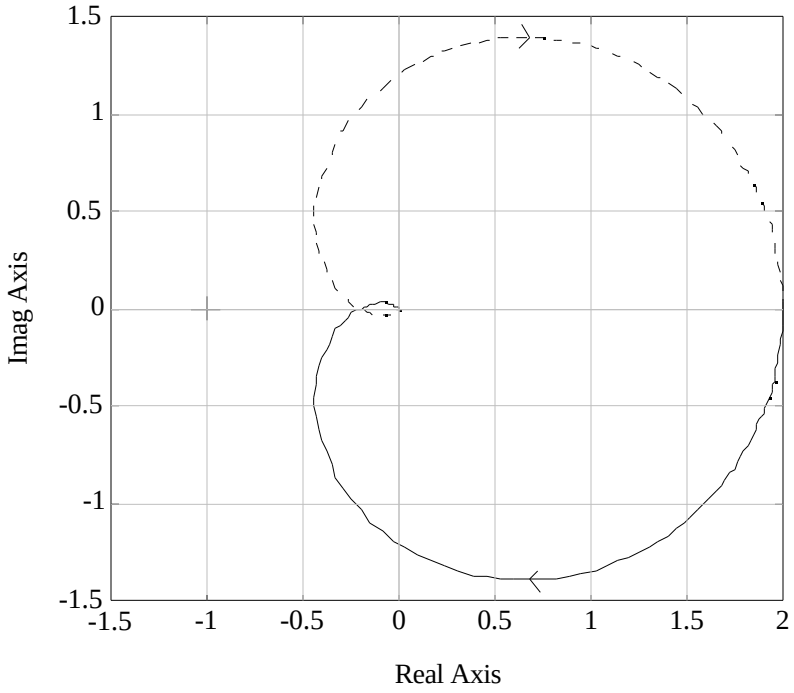


(8 points) b) Gain Margin = _____ Phase Margin = _____

Stable at $K = 1$? YES or NO (circle one)

Approximate Stable range for K _____

$$G(s) = \frac{12}{(s+3)(s+2)(s+1)}$$



_____/16 pt's

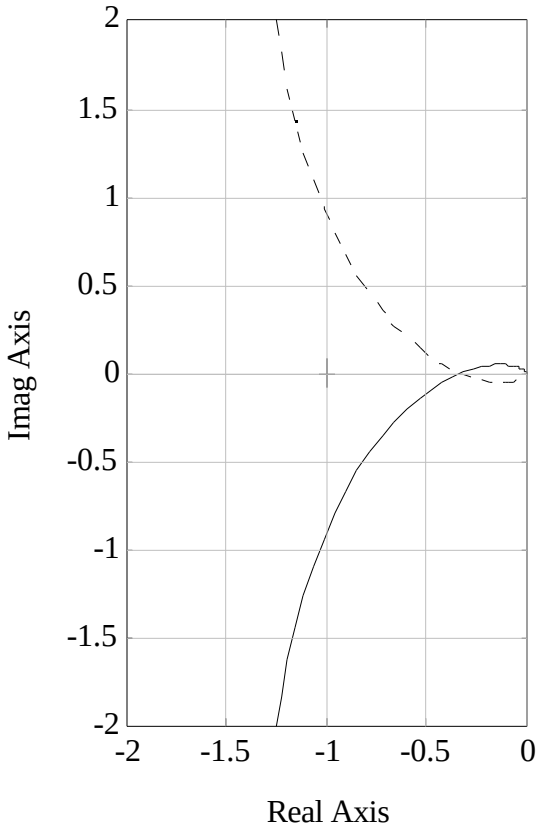
6 (cont.)

(8 points) c) Gain Margin = _____ Phase Margin = _____

Stable at $K = 1$? YES or NO (circle one)

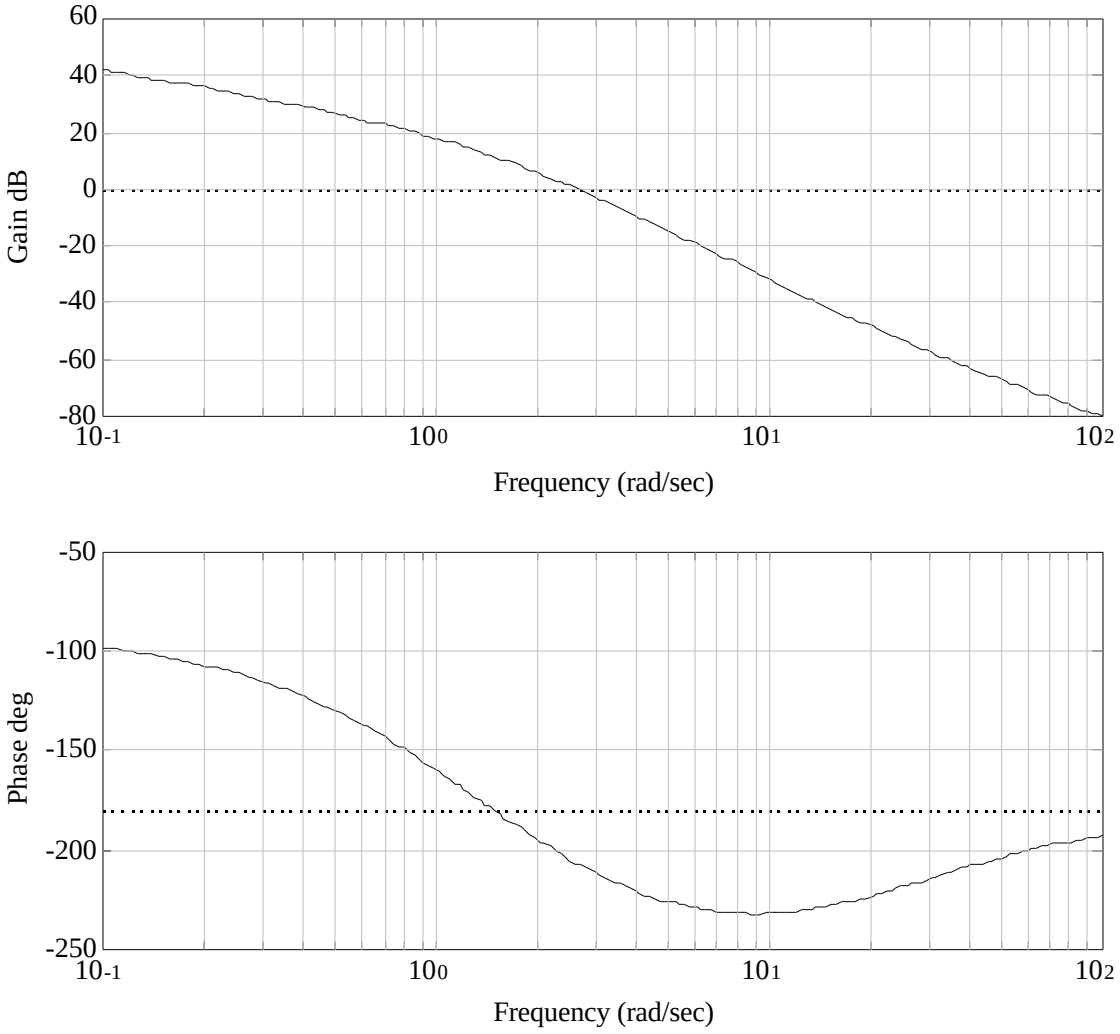
Approximate Stable range for K _____

$$G(s) = \frac{10}{s(s+2)(s+1)}$$



_____/8 pt's

(25 pt's) 7. For an open-loop system transfer function, $KG(s) = \dfrac{K(s+25)}{s(s+2)(s+1)}$, with $K = 1$, the Bode Diagram below was plotted.



(5 pts) a) Is the system stable at $K = 1$? YES or NO (circle one)

(5 pts) b) What is the Gain Margin? GM = _____ dB

(5 pts) c) What is the Phase Margin? PM = _____ deg

(5 pts) d) What is the maximum stable value of K? K_{max} = _____ dB

(5 pts) e) What value of K gives a phase margin of 45 degrees? K_{45} = _____ dB

_____/8 pt's