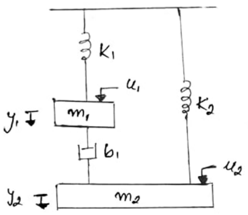
Tutorial 1: Introduction to Control Systems

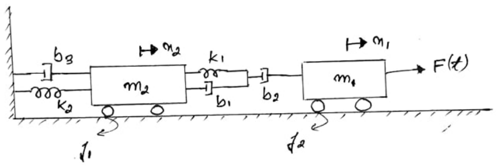
1. Write an essay on brief history of control system development. Include major historical developments in control engineering with its importance in modern society.
2. What is control system? Differentiate control system with their block diagram, advantages and disadvantages. Why closed loop control system are preferred in automation?
3. Describe a closed loop control system with an example. What is the importance of feedback on closed loop control system?
4. Explain the stages of control system design and analysis.
5. Describe typical sensors that can measure each of following:
   (a) Linear position
   (b) Velocity
   (c) Temperature
   (d) Pressure
   (e) Force
6. Describe the typical actuators that can convert the following:
   (a) Fluidic energy to mechanical energy
   (b) Electrical energy to mechanical energy

Tutorial 2: Mathematical Modelling

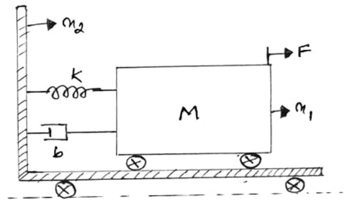
1. What is mathematical modelling? Explain the term accuracy vs complexity in mathematical modelling.
2. Describe the block diagram of the speed control system of a motorcycle with a human driver.
3. An automobile driver uses a control system to maintain the speed of the car at a prescribed level. Sketch a block diagram to illustrate this feed back system.
4. Obtain the systems of differential equation describing the dynamics of following mechanical system and find the respective transfer functions.
   (a) Find the transfer function $\frac{Y_1(s)}{U_2(s)}$ and $\frac{Y_2(s)}{U_1(s)}$ in system shown in figure 1.a
   (b) Find the transfer function $\frac{X_2(s)}{F(s)}$ and $\frac{X_1(s)}{F(s)}$ for system shown in figure 1.b.
   (c) Obtain the transfer function $\frac{X_1(s)}{X_2(s)}$ for the system 1.c
   (d) For the rotational system shown in figure 1.d, find the transfer function $\frac{\theta(s)}{\tau(s)}$.
   (e) Obtain the equivalent diagram with out gears in the system shown in figure 1.e and find the transfer function $\frac{\theta(s)}{\tau(s)}$
5. Obtain the systems of differential equation describing the dynamics of following electrical system and find the respective transfer functions.
   (a) Figure 2.a shows a typical differential circuit using op-amp. Obtain the transfer function $\frac{V_o(s)}{V_i(s)}$ of the system.
   (b) Figure 2.b shows a typical filter circuit used in ac circuits. Find the transfer function $\frac{V_{out}(s)}{V_{in}(s)}$ for the system.
   (c) Obtain the transfer function $\frac{V_{out}(s)}{V_{in}(s)}$ for typical op-amp circuit shown in figure 2.c.
   (d) Figure 2.d shows a RC ladder circuit. Find the transfer function $\frac{V_o(s)}{V_i(s)}$.
6. Discuss on the importance of analogous systems. Draw the F-V and F-I analogous circuit for the mechanical system shown in figure 1.a to 1.d.
7. What do you mean by non-linear system? Explain with examples. How would you approximate non-linear mathematical models into linear mathematical model around the equilibrium point? Why should we have to linearize?



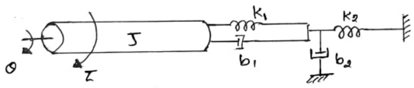
1.a



1.b



1.c



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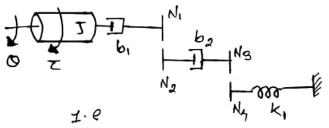
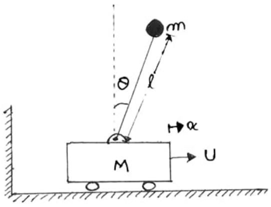
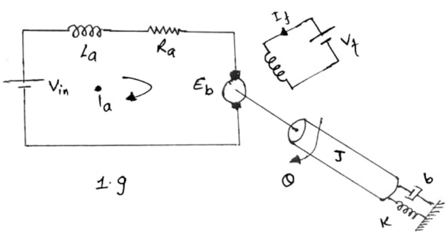


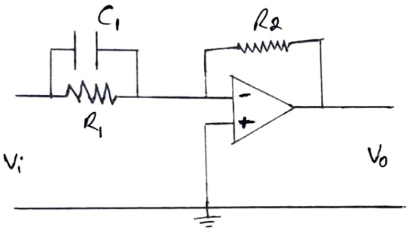
1.e



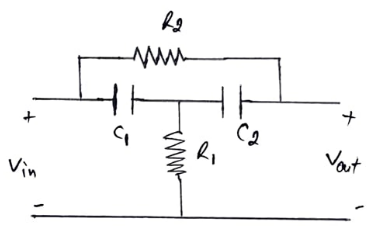
1.f



1.g



2.a



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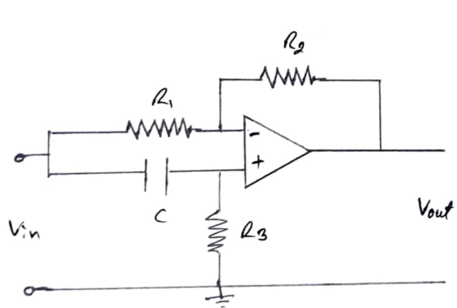

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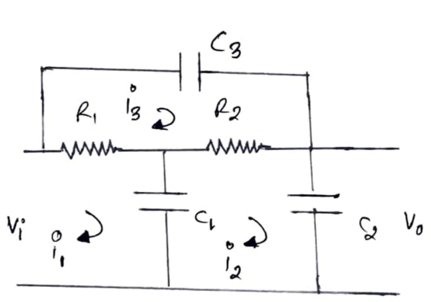

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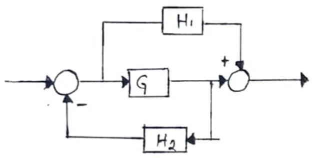
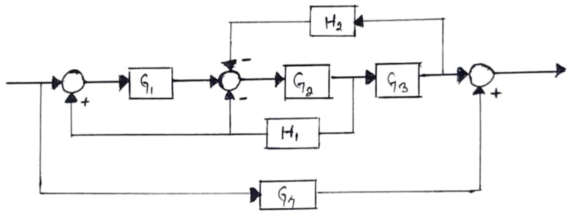
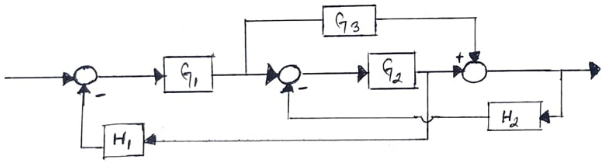


3.a



3.b



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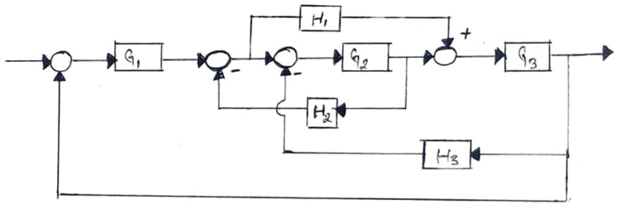

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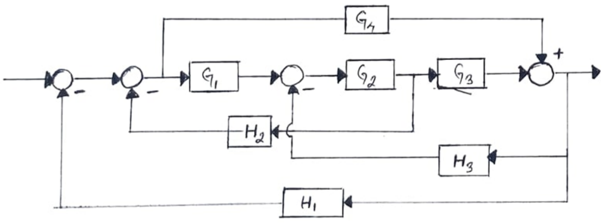
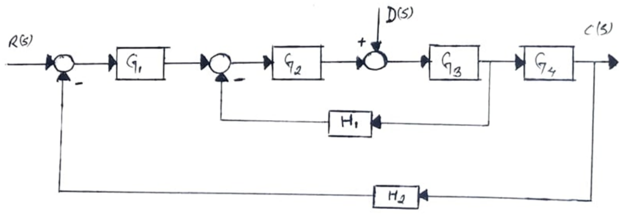


3.e



3.f

8. The mathematical model of the simple pendulum is given as:

$$\frac{d^2\theta}{dt^2} + \frac{g}{l} sin\theta = 0 \tag{1}$$

   How would you get the solution for θ. (you have to linearize before getting solution). Discuss on the topic.

9. Obtain the system of equation for the dynamics of inverted pendulum as shown in figure 1.f. Perform linearization around the point $\theta = 0$ (upright position) and obtain the transfer function $\frac{\theta(s)}{U(s)}$

10. Linearize the following non linear equation around the point $x = 2$

$$y = 0.1x^3 \tag{2}$$

11. Represent the armature controlled DC motor in block diagram and reduce to obtain the overall transfer function.

12. Perform block diagram reduction for the following problems using block diagram reduction algebra.

13. Represent the block diagrams shown above with signal flow graph and Obtain the transfer function between output and input using Mason Gain Formula.

Tutorial 3: Modelling in State Space

1. What is the difference between classical control engineering and modern control engineering? Mention the major advantages of modern control engineering.

2. Consider a system described by $\dddot{y} + 3\ddot{y} + 2\dot{y} = 4$. Represent the system in state space form.

3. Represent the translation mechanical system mentioned in problem 1.a and 3.1 in state space model.

4. Represent the permanent magnet dc motor mentioned in figure 1.g in state space form.

5. Represent the electrical system shown in figure 3.2 and 3.3 in state space model.

6. Represent the following transfer function in state space form.

(a) $\frac{Y(s)}{U(s)} = \frac{s+4}{s^2+4s+25}$

(b) $\frac{Y(s)}{U(s)} = \frac{s^2+2s+4}{s^3+3s^2+4s+4}$

(c) $\frac{Y(s)}{U(s)} = \frac{10}{s^2+s+4}$

7. Obtain the transfer function from following state space model.

   (a) $A = \begin{bmatrix} -2 & 1 \\ -3 & 0 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}, C = \begin{bmatrix} 1 & 0 \end{bmatrix}, D = 0$

   (b) $A = \begin{bmatrix} -5 & 10 & 0 \\ 0 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}, C = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}, D = 0$

   (c) $A = \begin{bmatrix} -1 & 1 & 0 \\ 0 & -1 & 1 \\ 0 & 0 & -2 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, C = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}, D = 0$

8. Obtain the state transition matrix for the state space system given in problem: 7a and 7b.

Tutorial 4: Stability Analysis

1. Define the term stability? How to check a system's stability using mathematical model equations.

2. What is the role of system pole in the dynamics of system. Explain with appropriate figures.

3. Using your calculator check the stability of following systems.

4. What is R-H criterion. Use R-H criterion to obtain the stability for the system having characteristics equation given below:

   (a) $s^4 + 2s^3 + 3s^2 + 4s + 5 = 0$

   (b) $s^5 + 2s^4 + 24s^3 + 48s^2 - 25s - 50 = 0$

5. Determine the range of K for stability of a unity feedback control system whose open loop transfer function is $G(s) = \frac{K}{s(s+1)(s+2)}$

6. Determine the range of K for stability of a unity feedback control system shown in figure 3.9.

7. Consider the following characteristics equation:

$$s^4 + 2s^3 + (4 + K)s^2 + 9s + 25 = 0$$

   Use the RH criterion and determine the range of K for stability. At what value if K the system is under damped, overdamped and critically damped.

Tutorial 5: Root Locus Analysis

1. What is root locus? Explain the significance of root locus in control system design and analysis.

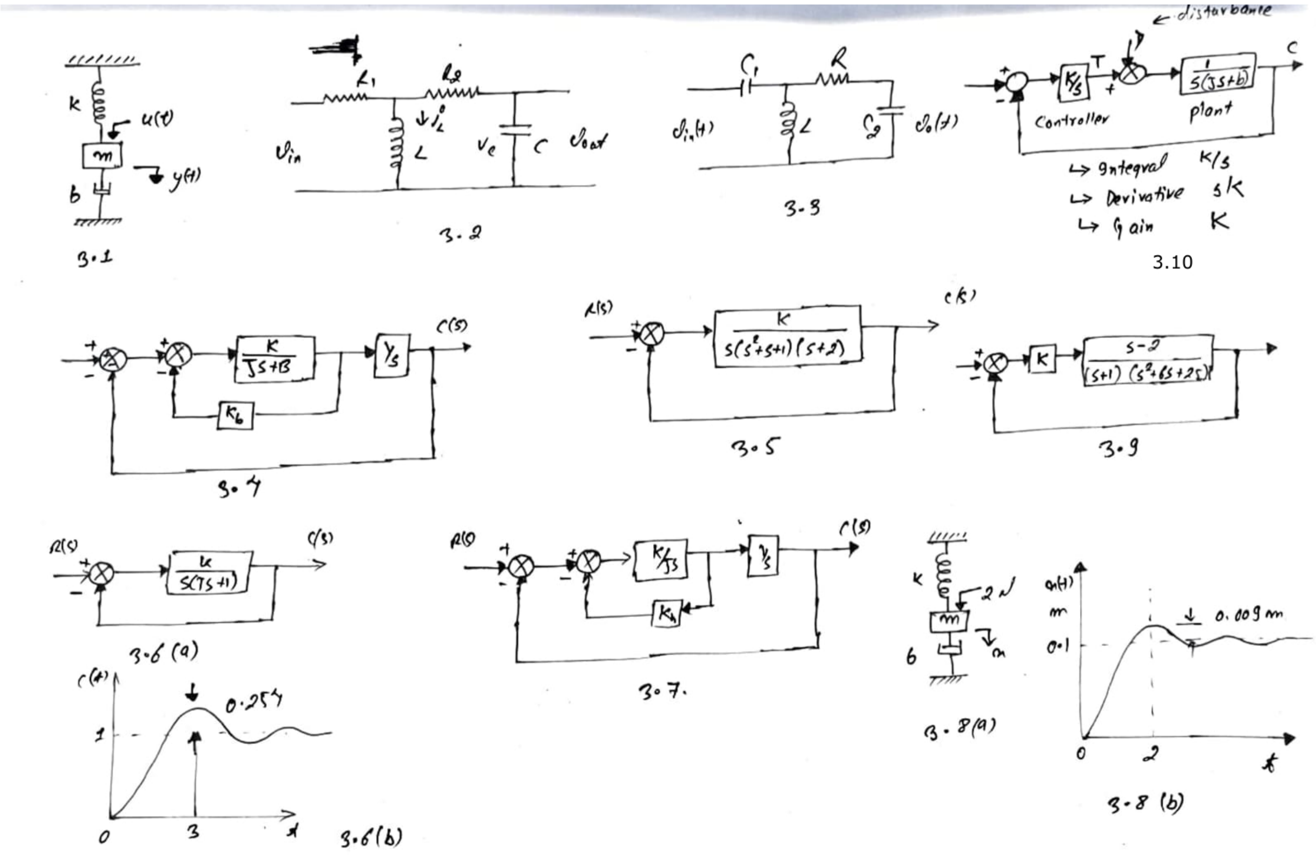
2. Sketch the root locus for the feedback system shown in figure 3.5 and 3.9.

3. A unity feedback control system has an open loop transfer function $G(s) = \frac{K(s+9)}{s(s^2+4s+11)}$. Sketch the root locus and determine i) range of K for system to be stable ii) Undamped natural frequency of oscillation

4. A unity feedback control system has and open loop transfer function $G(s) = \frac{s^2+2s+10}{s(s^2+4s+20)}$. Sketch the root locus for the system.

5. The open loop transfer function of a control system is given by:

$$G(s)H(s) = K\frac{s^2 - 2s + 5}{s^2 + 1.5s - 1}$$



Tutorial 6: Frequency Response Analysis

1. What is frequency response analysis? What is the significane of frequency response technique in control system design and analysis.
2. Sketch the Bode plot for following system and obtain the gain and phase margin.
   (a) $G(s) = \frac{20(s+1)}{s(s+5)(s^2+2s+10)}$ (Ans: GM: 10, PM: 103)
   (b) $G(s) = \frac{25}{s(s+1)(s+10)}$ (Ans: GM: 13, PM:27)
3. What is polar plot? How do you obtain the phase and gain margin from polar plot of a system.
4. Sketch the polar and nyquist plot for the system having following open loop gain (G(s)H(s)):
   (a) $\frac{10}{2s+4}$
   (b) $\frac{40}{s(5s+1)}$
   (c) $\frac{20}{s(2s+4)(5s+2}$
5. Explain Nyquist stability criterion?
6. The open loop transfer function of a control system is:

$$G(s)H(s) = \frac{(4s+1)}{s^2(s+1)(2s+1)}$$

   Using Nyquist stability criterion, determine the open loop and closed loop stability of the given system.

Tutorial 7: Control System Design

1. Obtain the time constant of the system and plot the approximate graph for the step response for the system $\frac{C(s)}{R(s)} = \frac{20}{10s+1}$.
2. Obtain the rise time, peak time, maximum overshoot and settling time in the unit step response of a closed loop system given by: $\frac{C(s)}{R(s)} = \frac{36}{s^2+2s+36}$ Plot the approximate response with appropriate labelling.

3. Referring figure 3.4 obtain the damping ratio of the system without the feedback term k_h and with k_h. What is the difference. If the values of J and b are 1 and 2 respectively, find the values of K and k_h for the system for closed loop damping ratio of 0.7 and undamped natural frequency of 4 rad/sec.

4. Consider a control sytem shown in figure 3.7. If the value of K/J is 4, for what value of K_h will yield the damping ratio of 0.6.

5. The figure 3.8(a) shwos a mechanical vibratory system. When 2 N force (step input) is applied to the system, the mass oscillates as shown in figure 3.8(b). Determine the value of m,b and k of the system from the response diagram. The displacemnt x is measured from equilibrium position.

6. When the system shown in figure 3.6 (a) is subjected to a unit stpe input, the system output responds as shown in figure 3.6 (b). Determine the values of K and T from the response curve.

7. Determine the values of K and k_h of the closed loop system shown in figure 3.7 so that the maximum overshoot in unit step response is 25 % and the peak time is 2 sec. Assume that J = 1 kgm^2.

8. From the figure 3.10 find the steady state error for integral controller, derivative controller and gain controller for unit disturbance input in the system.

9. The open loop transfer function of a unity feedback system is given by:

$$G(s) = \frac{108}{s^2(s+4)(s^2+2s+12)}$$

   Find the steady state error coefficents and steady state error of the system when subjected to an input given by $r(t) = 2 + 5t + 8t^2$

10. Consider a unity feedback control sytem with closed loop transfer function:

$$\frac{C(s)}{R(s)} = \frac{Ks+b}{s^2+as+b}$$

   Determine the open loop transfer function. Show that the steady state error in the unit ramp input response is given by: $e_{ss} = \frac{a-k}{b}$

11. Design a lead compensator for a unity feedback system with its feedforward transfer function as $G(s) = \frac{4}{s(s+2)}$ such that its settling time would be 2 sec but without change in maximum percentage overshoo of its unit step response. Also velocity error constant should not be less than 2.5 per sec.

12. Consider a system having feedforward transfer function given as $G(s) = \frac{K}{s(s+4)(s+5)}$. Design an appropriate controller such that the velocity error coefficient is at least 5 and damping ratio is 0.707.

13. Design a suitable compensator for a unity feedback system with open loop transfer function $G(s) = \frac{4}{s(s+2)}$ such that the settling time will become 2 seconds without change in overshoot and velocity time constant will be 2 s^{-1}

14. Design a suitable lead compensator for a system having open loop transfer function $G(s) = \frac{K}{s(1+0.1s)(1+0.001s)}$ such that the compensated system should have phase margin of at least 45 degrees and static velocity error constant of at least 1000 per second.

15. Design a compensator using Bode plot for a unity feedback system having open loop transfer function $G(s) = \frac{K}{s(s+2)(s+20)}$ to meet the specifications: $35^o \leq PM$, $20s^{-1} \leq K_v$ such that the bandwidth of the resultant system decreases. (lag compensator decreases the system overall bandwidth)