Gebze Technical University
Department of Mechanical Engineering

ME 332 - Control Systems Theory

Spring 2024, Mid-term exam
03 April 2024

Time Allowed: 150 min
Attention!

- Please read carefully before you start answering the questions.
- Books or notes are not allowed. You can use calculators.
- Show all the details of your answer. You will be penalized for unsystematic or unclear solutions.

Full name	Student No.	Q1	Q2	Q3	Q4	Q5	Total

Good luck, Saeed Lotfan

Formulae you may need:

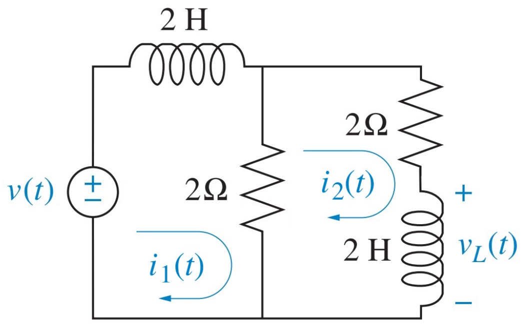
- $\mathscr{L}[t^n u(t)] = \dfrac{n!}{s^{n+1}}$
- $\mathscr{L}[e^{-at} f(t)] = F(s+a)$
- $T_p = \dfrac{\pi}{\omega_n \sqrt{(1-\zeta^2)}}$
- $\%OS = e^{-\zeta\pi/\sqrt{(1-\zeta^2)}} \times 100$
- $v_R(t) = Ri(t)$
- $v_L(t) = L\dfrac{\mathrm{d}i(t)}{\mathrm{d}t}$
- $T_s = \dfrac{4}{\zeta\omega_n}$

Question 1: (10%)
A bread toaster machine can be calibrated to a desired heating time by the user via a potentiometer. After starting the toaster by setting a specific time, the heating unit starts working and toasts the bread to the desired quality. Finally, as the time comes, the machine is switched off automatically.
a. Specify the type of the control system (Open-loop or Closed-loop).
b. Draw a functional block diagram for the system identifying the input and output transducers, the controller, the plant, and the feedback (if any).
Solution 1:

Question 2: (20%)
An electrical system's network including a voltage source, two resistors, and two inductors is shown below.

a. By using impedance method and mesh analysis show that the transfer function relating the output v_L to the input v is in the following form.

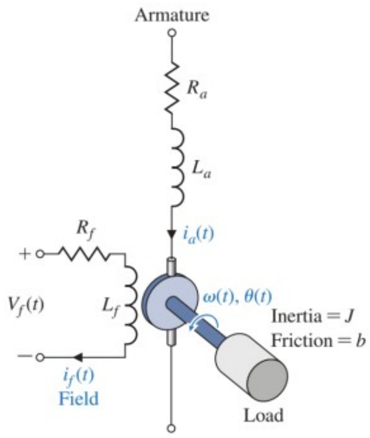
$$G(s) = \frac{V_L(s)}{V(s)} = \frac{s}{s^2 + 3s + 1}$$



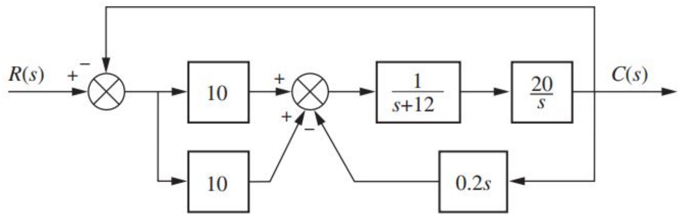
b. By using partial fraction expansion and inverse Laplace relations find the output $v_l(t)$ response to a unit step input.

Solution 2:

Question 3: (20%)
For the DC motor with variable field below,
a. Sketch the block diagram of the system with v_f being input, and θ as output. Use I_f, T_L, and ω as internal parameters, where T_L is load torque with $T_L = K_m I_f$.
b. With ω being the controlled variable, and considering $R_f = 1\,\Omega$, $L_f = 1\,\mathrm{H}$, and $K_m = 1\,\mathrm{N.m/A}$, find the condition(s) for J and b such that the system response to a unit step voltage of v_f is critically damped.
Solution 3:



Question 4: (30%)
For the block diagram shown below,
a. Find the equivalent single block that represents the transfer function, $T(s) = C(s)/R(s)$.
b. Find the damping ratio, natural frequency, percent overshoot, settling time, peak time, and damped frequency of oscillation.
c. Plot the unit step response of the system, based on the data in **b**.
d. Draw the s-plane for the system, and mention the options of the designer to decrease the peak time by keeping the over shoot constant.
Solution 4:



Question 5: (20%)
For a negative unit feedback system with an open-loop transfer function as below,

$$G(s) = \frac{s+3}{s^2+9s+21}$$

Represent the system in state-space forms including phase-variable and parallel. (You must draw the signal flow graphs and provide the equations)
Solution 5:

Gebze Technical University

Department of Mechanical Engineering

ME 332 - Control Systems Theory

Spring 2024, Final exam

12 June 2024

Time Allowed: 180 min

Attention!

- Please read carefully before you start answering the questions.
- Books or notes are not allowed. You can use calculators.
- Show all the details of your answer. You will be penalized for unsystematic or unclear solutions.

Full name	Student No.	Q1	Q2	Q3	Q4	Total

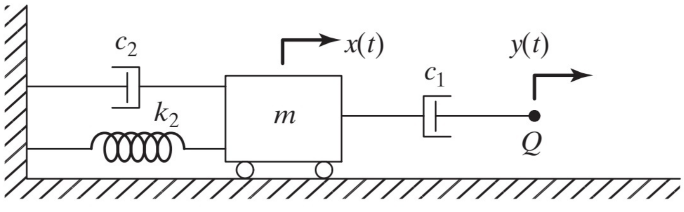
Good luck, Saeed Lotfan

Formulae you may need:

- $T_p = \dfrac{\pi}{\omega_n\sqrt{(1-\zeta^2)}}$
- $T_s = \dfrac{4}{\zeta\omega_n}$
- $\%OS = e^{-\zeta\pi/\sqrt{(1-\zeta^2)}} \times 100$

Question 1: (25%)

For the system shown below, x and y denote, respectively, the absolute displacements of the mass m and the end point Q of the dashpot c_1. Assuming x as output, y as input, and zero initial conditions, express the governing equations of the system in time domain (state-space) and frequency domain (s-domain), respectively.



Question 2: (25%)
For a negative unit feedback system with gain k, open-loop poles at -2, -4, -5, and no zeros,

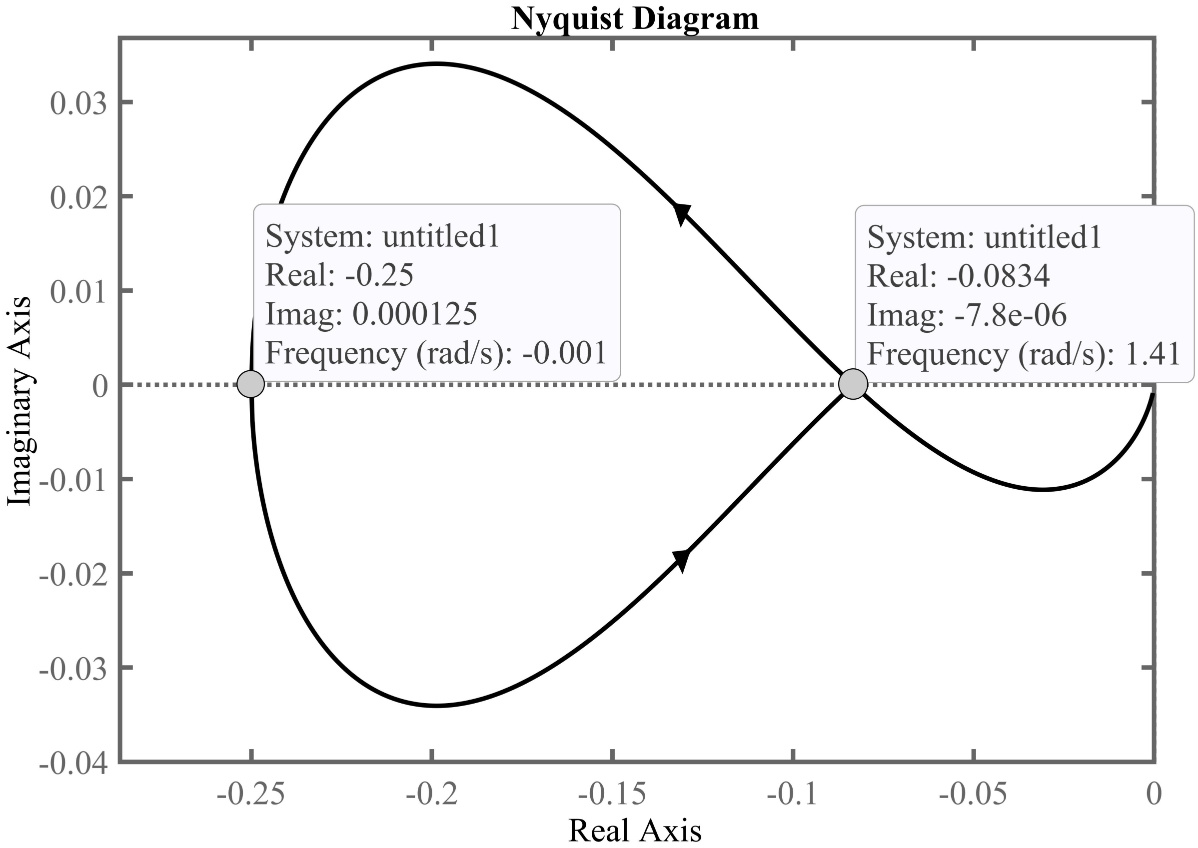
a. Plot asymptotic approximation of Bode diagrams for unit value of gain. Please make sure to point out the important values on magnitude, phase, and frequency axes, and the slopes between each breaking frequencies.

b. For which value of gain, phase margin would happen at frequency of 5 rad/s.

Question 3: (25%)
For a negative unit feedback system with open-loop transfer function given below, the Nyquist diagram is plotted by mapping the rhp plane via $G(s)H(s)$ function.

$$G(s) = \frac{K}{(s^2 + 2s - 2)(s + 2)}$$

a. According to the Nyquist criterion, explain the stability regions of the system for different gain values. What are the gain values for marginal stability and radian frequencies of oscillation?
b. Based on the Nyquist criterion how many poles will be on rhp in the unstable regimes?



Question 4: (25%)
For the unity feedback system with open-loop tranfer function, the system is working with $\zeta = 0.707$:

$$G(s) = \frac{K}{(s+1)(s+3)} \tag{1}$$

using root-locus technique design a PID controller that will yield a peak time of 1.122 seconds and a zero steady-state error for a unit step input. Give step-by-step details (approximate root-locus diagrams) and complete the table below.

Property	Uncompensated system.	System with PD	System with PID
$G(s)$	$K/(s+1)(s+3)$	$K(s+8.96)/(s+1)(s+3)$	
Dom. Poles		$-2.57 \pm 2.57j$	
K		1.14	
ζ	0.707	0.707	
ω_n(rad/s)			
$\%, OS$	%4.31	%4.31	
T_p(s)		1.22	
K_p			
e_{ss}			
Other Poles	—-	—-	-0.0077
Zeros	—-	-8.96	-0.01, -8.96
Approx. OK?	—-		

For solutions:

Gebze Technical University
Department of Mechanical Engineering

ME 332 - Control Systems Theory

Summer 2023, Midterm exam
08 August 2023

Time Allowed: 120 min
Attention!

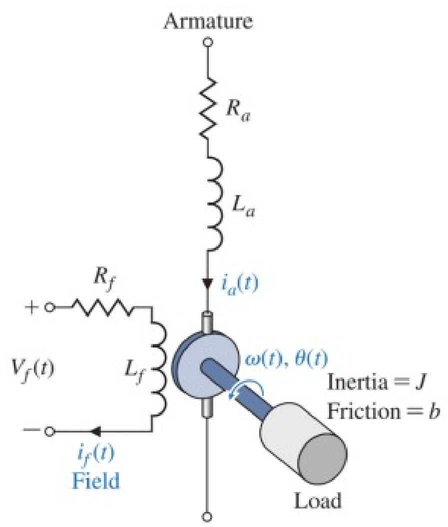
- Please read carefully before you start answering the questions.
- Books or notes are not allowed. You can use calculators.
- Show all the details of your answer. You will be penalized for unsystematic or unclear solutions.

Full name	Student No.	A	B	C	D	Total

Good luck, Saeed Lotfan

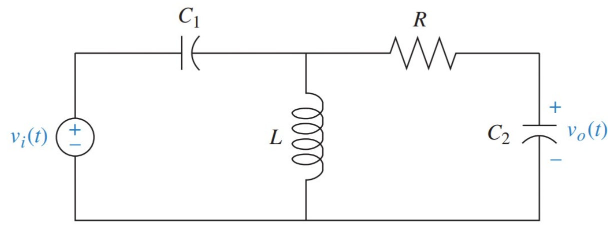
Part A: (20%)

For the DC motor with variable field below,
A.1. Sketch the block diagram of the system with v_f being input, and θ as output. Use I_f, T_L, and ω as internal parameters, where T_L is load torque.
A.2. With ω being the controlled variable, and considering $R_f = 1\,\Omega$, $L_f = 1\,\mathrm{H}$, and $K_m = 1\,\mathrm{N.m/A}$, find the condition(s) for J and b such that the system response to a unit step voltage of v_f is critically damped.

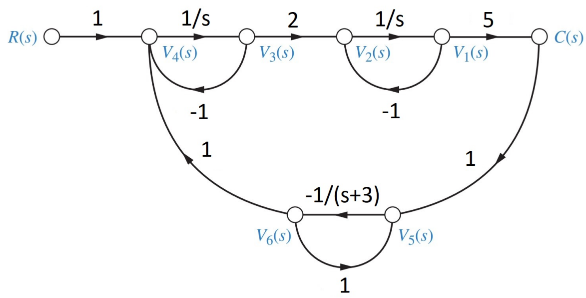


Part B: (40% points)
For the electrical network shown below,

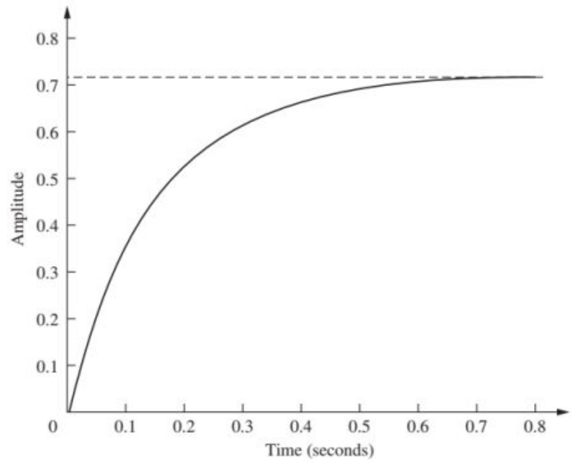
B.1. Represent the system in state-space, with v_o being the output.
B.2. Draw the signal flow graph.
B.3. If $C_1 = C_2 = L = R = 1$, find the transfer function and represent it in phase-variable form.



Part C: (30% points)
For the signal flow graph shown below:
C.1. What is the possible approach to approximate the system with a second-order one?
C.2. Find the approximate values for the overshoot and settling time.



Part D: (10% points)
For the experimental response of a system to a unit step input, shown below, find the transfer function.



For solutions:

Gebze Technical University
Department of Mechanical Engineering

ME 332/ELEC 322 - Control Systems Theory

Summer 2023, Final exam
8 September 2023

Attention!

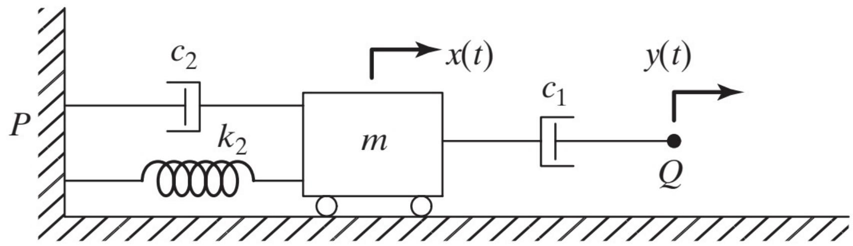
- Time allowed is 120 min.
- Make sure you have already read the instructions for this exam before starting.

Full name	Student No.	A	B	C	D	Total

Good luck, Saeed Lotfan

Part A: (20%: Final solutions with valid details: 16%, and details: 4%)

For the system shown below, x and y denote, respectively, the absolute displacements of the mass m and the end Q of the dashpot c_1. Find m, c_1, c_2, and steady-state error to yield 40% overshoot, a settling time of 4 seconds, and a final value of 0.1 for a step input of $y(t)$. Consider $k_2 = 10$ N/m.



Part B: (25% points)
For a negative unit feedback system with open-loop poles at -2, -4, -5, and no open-loop zeros,

B.1. Plot asymptotic approximation of Bode diagrams for unit final value (15%: Final plots with valid details: 13%, and details: 2%)

B.2. Find the ultimate gain value based on gain margin definition. (10%: Final solution with valid details: 5%, and details: 5%)

Part C: (20% points)
For a negative unit feedback system with open-loop transfer function given below:

$$G(s) = \frac{K}{(s^2+2s+2)(s^2+s+2)} \tag{1}$$

C.1. Draw the Nyquist diagram for $+j\omega$-axis. (10%: Final diagram with valid details: 8%, and details: 2%)

C.2. What is the gain value for marginal stability and radian frequency of oscillation based on the Nyquist criterion. (5%: Final solutions with valid details: 5%)

C.3. Based on the Nyquist criterion how many poles will be on rhp in the unstable regime? (5%: Final solutions with valid details: 5%)

Part D: (35% points)
For the unity feedback system with open-loop tranfer function, the system is working with $\zeta = 0.707$:

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

using root-locus technique design a PID controller that will yield a peak time of 1.122 seconds and a zero error for a step input. Give step-by-step details and complete the table below.

Property	Uncompensated system.	System with PD	System with PID
$G(s)$			
Dom. Poles			
K			
ζ			
ω_n			
$\%, OS$			
T_p			
K_p			
e_{ss}			
Other Poles			
Zeros			
Approx. OK?			

For solutions:

Gebze Technical University

Department of Mechanical Engineering

ME 332 - Control Systems Theory

Spring 2023, Mid-term exam

4 May 2023

Attention!

- Make sure you have already read the instructions for this exam before starting.

Full name	Student No.	A.1	A.2	B.1	B.2	Total

Good luck, Saeed Lotfan

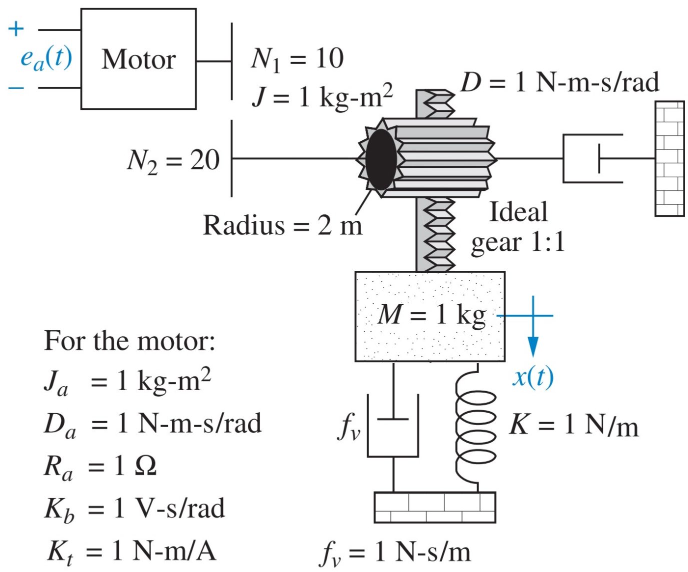
Part A: (50%) - Time allowed is 60 mins.

A fixed-field DC motor is meant to derive a mass-spring-damper system via a small gear-box as shown below. The motor's armchair includes an inertia J_a, a torsional damper D_a, and a negligible stiffness, (*i.e.* $K_a = 0$). The electrical network of the armchair has a negligible inductance, (*i.e.* $L_a = 0$) and a resistance of R_a. Moreover, the torque, T_m, imposed by the rotor is proportional to the armchair network's current, I_a, with proportionality constant K_t, and its back emf, v_b, is proportional to rotor's angular velocity, ω_m, with proportionality constant K_b.

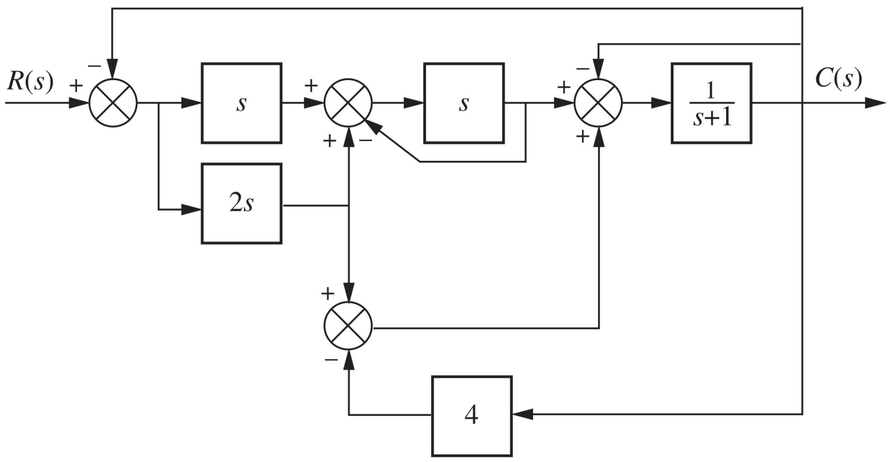
The gear-box includes two gears with teeth N_1 and N_2 without inertia, however, in the rack-pinion part which is an ideal gear, the pinion has an inertia of J. For this electromechanical system:

A.1. Find the transfer function of the system with $x(t)$ being the controlled parameter and $e_a(t)$ being the system input (40%).

A.2. What is the type of the system in case of underdamped, overdamped, undamped, or critically damped (10%).



Part B: (50%) - Time allowed is 45 mins.
For the block diagram shown below,
B.1. Reduce the block diagram to a single block (25%).
B.2. Draw the signal flow graph of the system in the form of a combination of parallel and phase-variable state-space representations (25%). (Hint: the transfer function of the system, $T(s)$, has nominator and denominator of the same order. Therefore, your must first divide $N(s)$ by $D(s)$ and find $T(s)$ in the form of $G_1 + G_2$, such that G_1 and G_2 are parallel and G_2 can be represented as phase-variable form)



Gebze Technical University

Department of Mechanical Engineering

ME 332 - Control Systems Theory

Spring 2023, Final exam (Online)
15 June 2023

Attention!

- Make sure you have already read the instructions for this exam before starting.

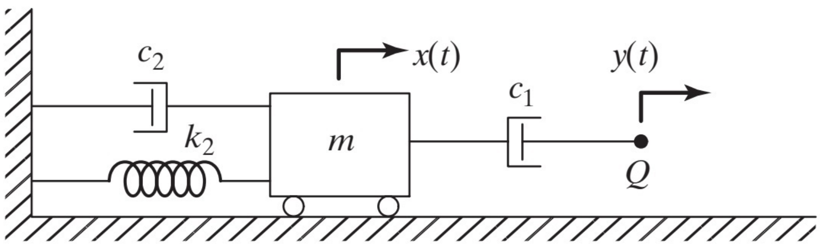
Full name	Student No.	A	B	C	D	Total

Good luck, Saeed Lotfan

Part A: (20%: Final solutions with valid details: 15%, and details: 5%)
Time allowed is 20 mins.

For the system shown below, x and y denote, respectively, the absolute displacements of the mass m and the end Q of the dashpot c_1. Find m, c_1 and c_2 to yield 20% overshoot, a settling time of 2 seconds, and a steady-state error of 0.1 for a step input of $y(t)$.

Use three ending digits of your student number as k_2, for example: for a student number 823456789012, $k_2 = 012 = 12$ N/m.



Part B: (35%) - Time allowed is 40 mins.
For a negative unit feedback system with open-loop poles at -2, -4, -10, and no open-loop zeros, the system is working with a damping ratio ζ.

Use two ending digits of your student number as $100 \times \zeta$**, for example: for a student number 823456789412,** $\zeta = 0.12$.

B.1. Using root locus technique find the gain value and settling time for this working condition? (10%: Final solutions with valid details: 8%, and details: 2%)

B.2. Find the ultimate gain value for the system via Routh-Hurwitz criterion. (10%: Final solution with valid details: 8%, and details: 2%)

B.3. Using Ziegler–Nichols tuning method based on closed-loop concepts, design a PID controller for the system, how does the settling time change for the same overshoot? (15%: Final solution with valid details: 12%, and details: 3%)

If you want to use MATLAB, you can get help from tf, rlocus, and sgrid commands.

Part C: (20%) - Time allowed is 20 mins.
For a negative unit feedback system with open-loop transfer function belwo:

$$G(s) = \frac{K}{(s^2+2s+2)(s+b)} \tag{1}$$

Use the ending digit of your student number as b**, for example: for a student number 823456789412,** $b = 2$.

C.1. Draw the Nyquist diagram for the system. (10%: Final diagram with valid details: 8%, and details: 2%)

C.2. What is the gain value for marginal stability and radian frequency of oscillation based on the Nyquist criterion. (10%: Final solutions with valid details: 8%, and details: 2%)

Part D: (25%) - Time allowed is 20 mins.
For the state-space representation of a control system below,

$$\dot{\mathbf{x}} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -4 & -2 & -6 \end{bmatrix} \mathbf{x} + \begin{Bmatrix} 0 \\ 0 \\ 1 \end{Bmatrix} r \tag{2}$$

$$y = \begin{bmatrix} 1 & 1 & 0 \end{bmatrix} \mathbf{x} \tag{3}$$

D.1. Draw the signal flow diagram. (10%: Final diagram)

D.2. What is the transfer function of the system. (5%: Final value)

D.3. Redraw the signal flow diagram by adding bs^2 to the numerator of the transfer function. (10%: Final diagram)

Use two ending digits of your student number as b, **for example: for a student number 823456789412,** $b = 12$.

Gebze Technical University
Department of Mechanical Engineering

ME 332 - Control Systems Theory

Spring 2022, Mid-term exam #1
31 March 2022

Time Allowed: 90 minutes
Attention!

- Please read carefully before you start answering the questions.
- Books or notes are not allowed. You can use calculators.
- Show all the details of your answer. You will be penalized for unsystematic or unclear solutions.

Full name	Student No.	Q1	Q2	Q3	Total

Good luck, Saeed Lotfan

Formulae you may need:

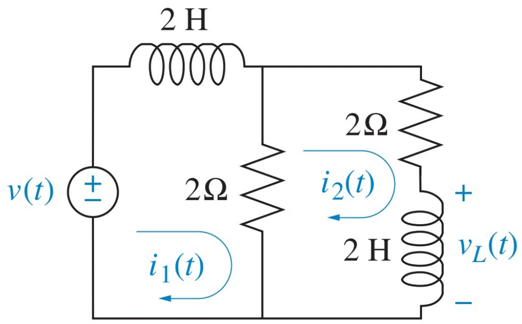
- $\mathscr{L}[t^n u(t)] = \dfrac{n!}{s^{n+1}}$
- $\mathscr{L}[e^{-at} f(t)] = F(s+a)$
- $v_R(t) = Ri(t)$
- $v_L(t) = L\dfrac{\mathrm{d}i(t)}{\mathrm{d}t}$

Question 1: (25%)
A bread toaster machine can be calibrated to a desired heating time by the user via a potentiometer. After starting the toaster by setting a specific time, the heating unit starts working and toasts the bread to the desired quality. Finally, as the time comes, the machine is switched off automatically.
a. Specify the type of the control system (Open-loop or Closed-loop).
b. Draw a functional block diagram for the system identifying the input and output transducers, the controller, the plant, and the feedback (if any).
Solution 1:

Question 2: (35%)
An electrical system's network including a voltage source, two resistors, and two inductors is shown below.

a. By using impedance method and mesh analysis show that the transfer function relating the output v_L to the input v is in the following form.

$$G(s) = \frac{V_L(s)}{V(s)} = \frac{s}{s^2 + 3s + 1}$$



b. By using partial fraction expansion and inverse Laplace relations find the output $v_l(t)$ response to a unit step input.

Solution 2:

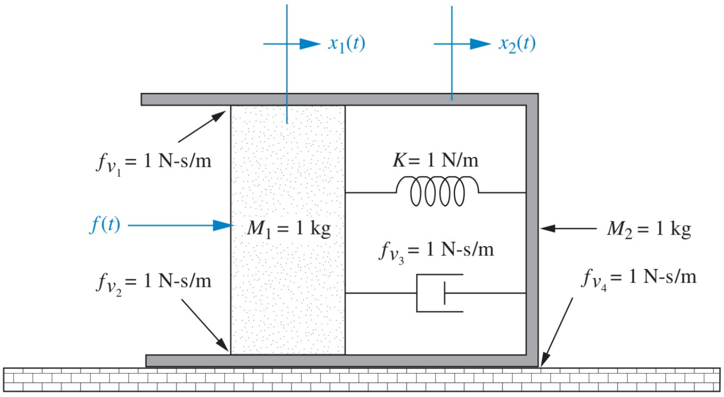
Question 3: (40%)

For the translational mechanical system below,

a. Determine the governing equations in the frequency domain based on the impedance method.

b. Transfer the governing equations in part **a** to the time domain.

c. Represent the system in state space, where $x_2(t)$ is the output.



Solution 3:

Gebze Technical University
Department of Mechanical Engineering

ME 332 - Control Systems Theory

Spring 2022, Mid-term exam #2
28 April 2022

Time Allowed: 120 minutes

Attention!

- Please read carefully before you start answering the questions.
- Books or notes are not allowed. You can use calculators.
- You are not allowed to leave the exam for any reason, before handing in the exam sheet.
- Show all the details of your answer. You will be penalized for unsystematic or unclear solutions.

Full name	Student No.	Q1	Q2	Q3	Total

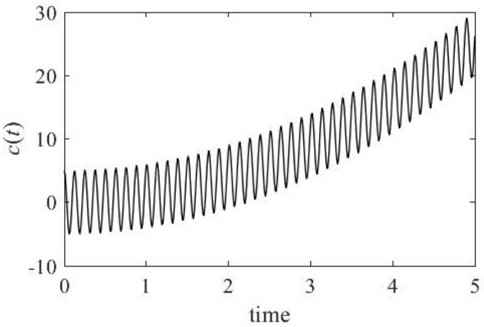
Good luck, Saeed Lotfan

Formulae you may need:

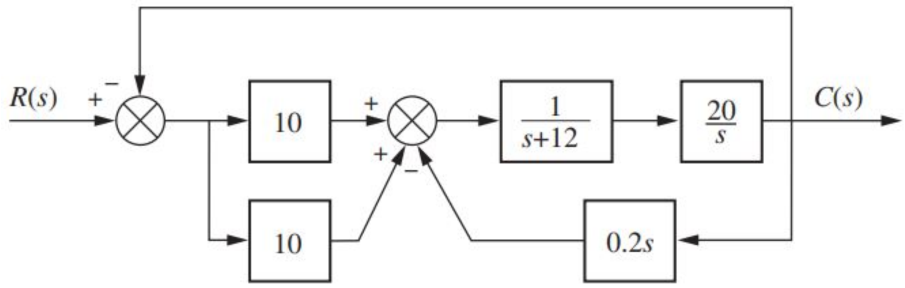
- $T_p = \dfrac{\pi}{\omega_n\sqrt{(1-\zeta^2)}}$
- $T_s = \dfrac{4}{\zeta\omega_n}$
- $\%OS = e^{-\zeta\pi/\sqrt{(1-\zeta^2)}} \times 100$

Question 1: (10%)
Response of a control system to a parabola input for $0 \leq t \leq 5$ sec, is shown in the figure below. Discuss the stability of the system.

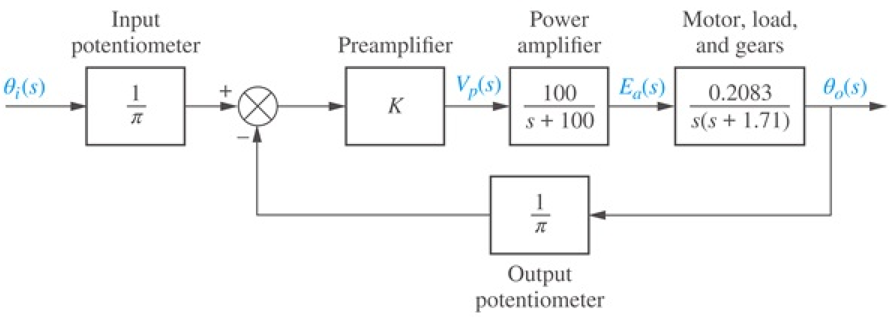
Solution 1:

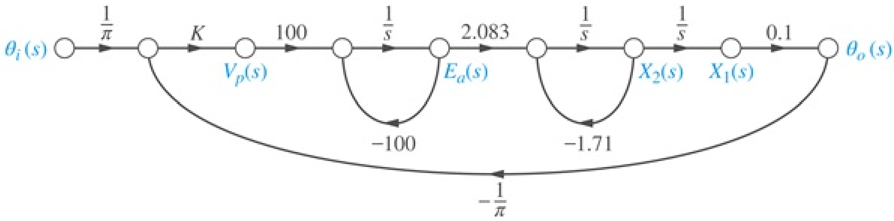


Question 2: (40%)
For the block diagram shown below,
a. Find the equivalent single block that represents the transfer function, $T(s) = C(s)/R(s)$.
b. Find the damping ratio, natural frequency, percent overshoot, settling time, peak time, and damped frequency of oscillation.
c. Plot the unit step response of the system, based on the data in **b**.
d. Draw the s-plane for the system, and mention the options of the designer to decrease the peak time by keeping the over shoot constant.
Solution 2:



Question 3: (50%)
For the antenna azimuth position control system the block diagram and signal-flow graph based on cascade idea are shown below,
a. Represent the system in state space by using 3 state variables including $x_1(t)$, $x_2(t)$, and $e_a(t)$.
b. Give the controller canonical form of the representation in part **a**, and draw the corresponding signal-flow graph.
c. Apply the Routh-Hurwitz criterion to the controller canonical form, and discuss the range of K to have a stable system.
d. Use Mason's rule to derive the transfer function based on the given signal-flow graph.
Solution 3:





For Solutions:

Gebze Technical University
Department of Mechanical Engineering

ME 332 - Control Systems Theory

Spring 2022, Final exam
16 June 2022

Time Allowed: 120 minutes

Attention!

- Please read carefully before you start answering the questions.
- Books or notes are not allowed. You can use calculators.
- You are not allowed to leave the exam for any reason, before handing in the exam sheet.
- Show all the details of your answer. You will be penalized for unsystematic or unclear solutions.

Full name	Student No.	Q1	Q2	Q3	Q4	Total

Good luck, Saeed Lotfan

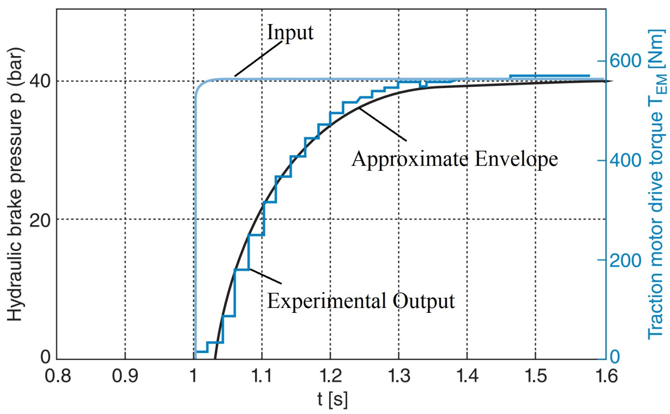
Formulae you may need:

- $T_p = \dfrac{\pi}{\omega_n\sqrt{(1-\zeta^2)}}$
- $T_s = \dfrac{4}{\zeta\omega_n}$
- $\%OS = e^{-\zeta\pi/\sqrt{(1-\zeta^2)}} \times 100$

Question 1: (15%)

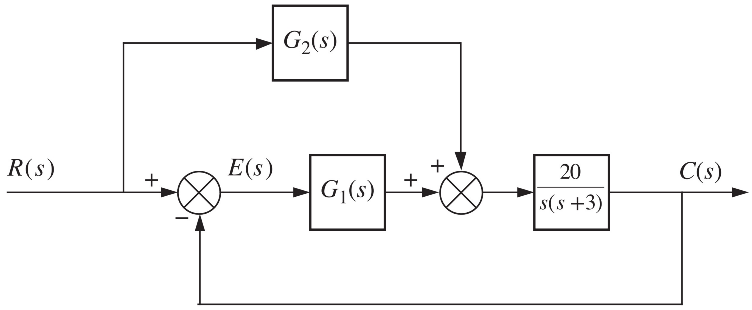
Figure below shows the step response of an electric vehicle's mechanical brakes when the input is the drive torque and the output is the hydraulic brake pressure. Find the transfer function of the system.

Solution 1:



Step response of an electric vehicle's mechanical brake

Question 2: (15%)
For the block diagram shown below,
a. Find the expression for $E(s)$ as a function of input and system transfer functions,
b. What are the restrictions on the type of feedforward transfer function $G_2(s)$ to obtain zero steady-state error for step inputs if $G_1(s)$ is a Type 2 transfer function?
Solution 2:



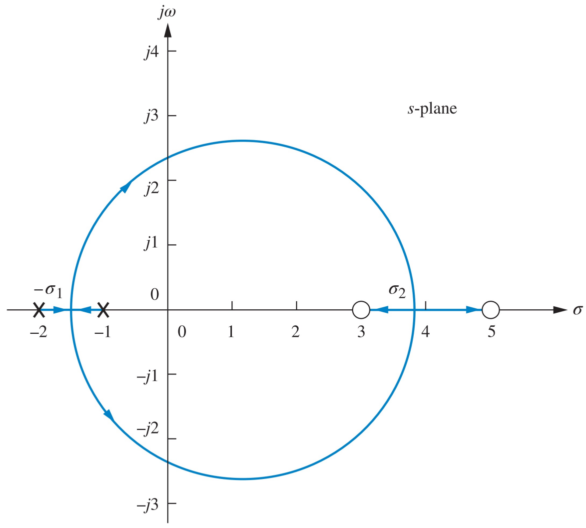
Question 3: (30%)

For a unit feedback system the root locus diagram is shown below,

a. Find the breakaway and break-in points for the root locus based on differentiation method.

b. Find the range of the gain for the system to be stable.

Solution 3:



Question 4: (40%)
For the feedback control system shown below design an ideal derivative compensator to yield a 16% overshoot, with a threefold reduction in settling time.
Solution 4: