Final Examination: Regulation and Control

Course: Regulation and Control

Total Time: 180 Minutes

Total Marks: 100

Instructions:

- Answer all questions in the provided answer booklet.
- This exam contains three sections. Please ensure you attempt all sections.
- Where calculations are required, show all your working. A correct answer with no working may not receive full marks.
- Assume reasonable values for any missing parameters and state your assumptions clearly.

Section A: Fundamental Concepts & Multiple Choice

Total: 25 Marks

A1. Multiple Choice (10 Questions × 1 Mark = 10 Marks)

Circle the single best answer.

1. The primary purpose of a **sensor** in a control system is to:

   a) Calculate the error signal.

   b) Execute the physical action on the process.

   c) Measure the current value of the output variable.

   d) Provide the desired target value.

2. A system where the output has no influence on the control action is called a(n):

   a) Robust system

   b) Closed-loop system

   c) Unstable system

   d) Open-loop system

3. In a second-order system, the parameter that primarily determines the overshoot of the step response is the:

   a) Natural Frequency (ω_n)

   b) Damping Ratio (ζ)

   c) System Gain (K)

   d) Time Constant (τ)

4. According to the Routh-Hurwitz criterion, a system is stable if:

   a) All coefficients of the characteristic equation are positive.

   b) There are no zeros in the transfer function.

   c) All poles have negative real parts.

   d) There are no sign changes in the first column of the Routh array.

5. The Phase Margin of a system is defined as:

   a) The additional gain required to make the system marginally stable.

   b) The frequency at which the phase shift is -180 degrees.

c) The additional phase lag required to make the system marginally stable, measured at the gain crossover frequency.

d) The difference between the setpoint and the process variable.

6. The primary purpose of a Lead Compensator is to:

a) Reduce steady-state error.

b) Improve steady-state accuracy and slow down the response.

c) Increase the phase margin and speed up the transient response.

d) Attenuate high-frequency noise.

7. On a Bode plot, the **Gain Crossover Frequency** (ω_{gc}) is defined as the frequency where:

a) The phase plot crosses -180 degrees.

b) The magnitude plot is at its maximum peak.

c) The magnitude plot crosses 0 dB.

d) The phase margin is measured.

8. According to the Root Locus construction rules, the locus starts at the:

a) Closed-loop zeros.

b) Closed-loop poles.

c) Open-loop zeros.

d) Open-loop poles.

9. The **Integral (I)** term in a PID controller is used primarily to:

a) Reduce overshoot and damp oscillations.

b) Provide a control action proportional to the current error.

c) Eliminate steady-state error.

d) Amplify high-frequency noise.

10. A point on the real axis is part of the Root Locus if:

a) The number of poles and zeros to its right is even.

b) The number of poles and zeros to its left is odd.

c) The number of poles and zeros to its right is odd.

d) It is exactly midway between two poles.

A2. Short Answer Questions (3 Questions × 5 Marks = 15 Marks)

Provide concise answers.

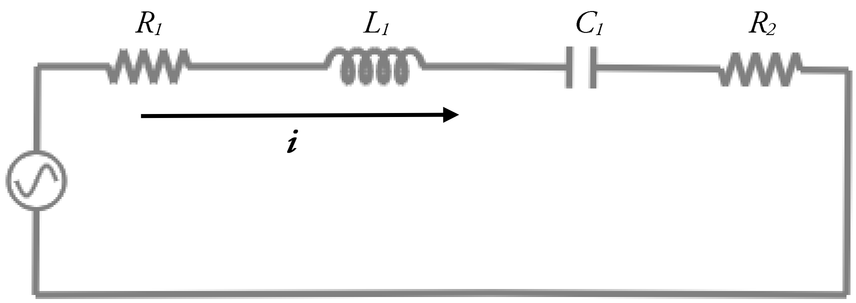
1. Define "Regulation" and "Control" in the context of automatic systems. Provide a simple example of each.
2. Explain, in one sentence each, the practical effects of having too much and too little Phase Margin on a system's time-domain response.
3. State the **Angle Condition** for a point ss to lie on the Root Locus.

Section B: Analytical Problems

Total: 50 Marks

B1. Mathematical Modeling & Transfer Function (10 Marks)

For an electrical circuit with input voltage $v_i(t)$ and output voltage across a capacitor $v_c(t)$:



a) Using Kirchhoff's Voltage Law (KVL), derive the differential equation governing the system dynamics.

b) Find the transfer function $G(s) = \frac{V_c(s)}{V_i(s)}$ (Assume zero initial conditions)

B2. Time Domain Analysis (10 Marks)

A second-order system has the transfer function:

$$G(s) = \frac{25}{s^2 + 4s + 25}$$

a) Determine the natural frequency (ω_n), damping ratio (ζ), and damped natural frequency (ω_d).

b) Calculate the peak time (T_p), percent overshoot (%OS), and 2% settling time (T_s).

c) Sketch the expected step response, labeling key features from part (b).

B3. Stability Analysis (10 Marks)

The characteristic equation of a unity feedback system is:

$$s^4 + 6s^3 + 11s^2 + 6s + K = 0$$

a) Construct the Routh array for this system.

b) Determine the range of gain K for which the system is stable.

B4. Bode Plot & Stability Analysis (10 Marks)

A system has the open-loop transfer function:

$$G(s) = \frac{50}{(s+1)(s+5)}$$

a) Calculate the **Phase Margin (PM)** and **Gain Margin (GM)** analytically.

b) Is the closed-loop system stable? Justify your answer.

c) The gain 50 is replaced by a variable gain K. What is the range of K for closed-loop stability?

B5. Root Locus Construction (10 Marks)

For the open-loop system:

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

a) Sketch the Root Locus by hand, showing poles, zeros, real-axis segments, asymptotes, and breakaway points.

b) Determine the value of K where the root locus crosses the imaginary axis. What does this value represent?

Section C: Design & Synthesis

Total: 25 Marks

C1. Compensator Design (12 Marks)

Consider a unity feedback system with plant:

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

Design specifications:

- Velocity Error Constant $K_v \geq 10$
- Phase Margin $PM \geq 45^0$

a) Design a **Lag Compensator** Gc(s)to meet these specifications. Show all steps.

b) Sketch the expected Bode plot for both uncompensated and compensated systems, indicating improvements.

C2. Controller Selection & Real-World Application (13 Marks)

You are a control engineer presented with three systems:

- **System A**: DC motor for a conveyor belt requiring precise speed control under varying load.
- **System B**: Pitch control for a naturally unstable drone.
- **System C**: Liquid level control in a chemical plant where maintaining level between limits is sufficient.

For each system:

1. Recommend a suitable controller type (e.g., P, PI, PID, Lead, Lag).
2. Justify your choice based on the system's specific needs.
3. Discuss one primary **trade-off** or practical challenge when implementing your chosen controller.