GAZiANTEP UNIVERSITY

Department of Electrical and Electronics Engineering

EEE 352 Automatic Control Systems Lab

Comprehensive Study Guide

This guide covers the fundamental theories, control strategies, and hardware-specific configurations used in the laboratory experiments. Students are expected to understand the practical applications of these concepts, not just their mathematical definitions.

1. Basic Control System Terminology

To analyze any control system, you must first understand its foundational definitions:

- **Open-Loop Control:** A system where the actuating signal is generated independently of the system's output. The system cannot correct for errors.
- **Closed-Loop (Feedback) Control:** A system where the output is measured and fed back to be compared with the reference input. The actuating signal is driven by this difference (the error).
- **Feedback:** The operation performed to reduce the difference between a prescribed reference value and the actual system output.
- **Disturbance:** An unwanted signal that adversely affects the output of the system. Closed-loop systems are designed to reject disturbances.

2. Transducers and Lab Hardware

A **transducer** is a device that converts information from one physical energy system into another (e.g., converting mechanical motion into an electrical voltage).

- **Tachogenerator:** Acts as an **output transducer** in speed control systems. It couples physically to the motor shaft and outputs a DC voltage proportional to the rotational speed.
- **Servopotentiometer:** Acts as a feedback transducer for position control. The standard servopotentiometers in our lab set allow for continuous 360° mechanical measurement.
- **System Gain Configuration:** The total mathematical gain of an amplifier block in the lab is calculated by multiplying the dials:

$$\text{Total Gain} = \text{Gain Coarse} \times \text{Gain Fine}$$

- **Current Measurement Safety (1 Ω Resistor):** Oscilloscopes measure voltage, not current. To safely observe fast transient motor currents without breaking the circuit, a 1 Ω sense resistor is placed in series with the DC motor. According to Ohm's Law ($V = I \times R$), since $R = 1$, the voltage drop measured across this resistor is numerically equal to the current ($V = I$).

3. The Comparator (Open-Loop Operational Amplifiers)

A comparator is one of the most critical elements in control circuitry. It is essentially an operational amplifier running in an **open-loop** configuration (without any negative feedback).

How it works:

The comparator looks at the voltage difference between its non-inverting input (V_+) and its inverting input (V_-). The output is defined by the formula:

$$V_{out} = A_{OL} \times (V_+ - V_-)$$

Where A_{OL} is the op-amp's open-loop gain (which is practically infinite, often $> 100,000$).

Saturation States:

Because the gain is massive, any slight difference between the inputs will mathematically result in an impossibly high voltage. Since the op-amp is physically limited by its power supply (e.g., $+15V$ and $-15V$), it instantly "maxes out."

- **Positive Saturation:** Occurs when the non-inverting input (V_+) is strictly greater than the inverting input (V_-). The output slams to the positive power rail.
- **Negative Saturation:** Occurs when the inverting input (V_-) is strictly greater than the non-inverting input (V_+). The output slams to the negative power rail.

Example: If $+6V$ is applied to the inverting input and $+4V$ is applied to the non-inverting input, the inverting side "wins," and the output immediately goes to negative saturation. It does *not* output a simple subtraction of $-2V$.

4. Control Strategies and PID Theory

On-Off (Bang-Bang) Control

A simple control method that uses a comparator to switch a system fully ON or fully OFF based on saturation limits (like a thermostat).

- It is generally inexpensive but is **not** a highly accurate method due to constant oscillation around the target.
- **Dead-zone:** A defined voltage band where the controller takes no action, leaving the system inactive.
- **Hysteresis:** A built-in threshold gap used to prevent the system relays from chattering rapidly when the error is hovering near zero.

PID Control Parameters

A PID controller balances speed, overshoot, and steady-state error. You must know exactly how changing each parameter affects the closed-loop step response.

- **1. Proportional Control (P):** Provides a control signal proportional to the current error.
  - *Effect of increasing K_p:* Rise time decreases (system gets faster), overshoot increases (system gets more aggressive), and steady-state error decreases (but is never completely eliminated).
- **2. Integral Control (I):** Accumulates past errors over time.
  - *Purpose:* The primary function of the Integral term is to completely **eliminate steady-state error**.
  - *Time Constant (T_i):* A smaller time constant means the integrator reacts faster to loads. For example, a 50 ms setting will recover target speed much faster than a 10 s setting.
  - *Integrator Windup:* If the system saturates, the integrator's internal capacitor overcharges. If it is not discharged (using the hardware "Reset" button), the system suffers from a sluggish, delayed recovery when the error changes sign.

- **3. Derivative Control (D):** Predicts future error based on the current rate of change.
  - *Purpose:* Adds damping to the system, which directly reduces overshoot and stabilizes oscillatory behavior.
  - *Hardware Note:* Derivative op-amp circuits naturally invert the signal. An "Inverter" block is required in the feedback path to correct the phase and maintain proper negative feedback.

Controller Selection Guide:

- **P-only:** Fast response, but leaves a steady-state error.
- **PI:** Eliminates steady-state error, but can increase overshoot and settling time.
- **PD:** Reduces overshoot and settles quickly, but does not fix steady-state error.
- **PID:** The ultimate balance—fast response, controlled overshoot, and zero steady-state error.

5. System Damping Responses

When evaluating a system's transient response, it will fall into one of three distinct damping categories:

1. **Underdamped:** The system shoots past the target and oscillates before settling.
2. **Critically Damped:** The system reaches the target as fast as physically possible *without* oscillating or overshooting.
3. **Overdamped:** The system is slow and sluggish, taking a long time to gradually reach the target without any oscillation.

6. Active Op-Amp Circuits

Recognizing basic op-amp configurations is essential for understanding the analog controller blocks:

- **Active Low-Pass Filter (Lag Compensator):** Features a resistor and capacitor in parallel in the feedback loop.
- **Ideal Integrator:** Features only a capacitor in the feedback loop.
- **Ideal Differentiator:** Features a capacitor on the input line and a resistor in the feedback loop.