UNIVERSITY OF ENERGY AND NATURAL RESOURCES

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ELNG 305: Classical control systems

LECTURE-1: INTRODUCTION TO CLASSICAL CONTROL SYSTEMS

LECTURER

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Overview of Control Systems

Control systems are all over, forming an integral part of modern society. This includes the use of controllers for;

- Firing a rocket
- Lifting the space shuttle to Earth orbit
- Splashing water
- Regulating the fuel flow in an automobile

Within our bodies are numerous control systems, such as the pancreas, which regulates our blood sugar. In time of ''fight or flight,'' our adrenaline increases along with our heart rate, causing more oxygen to be delivered to our cells. Our eyes follow a moving object to keep it in view; our hands grasp the object and place it precisely at a predetermined location.

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Introduction to control systems

A control system is anything that consists of subsystems and processes (or plants) assembled to obtain a desired output with desired performance, given a specified input.

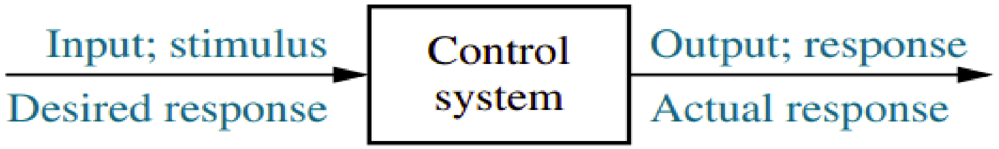


FIGURE 1.1 Simplified description of a control system

For example, consider an elevator. When the fourth-floor button is pressed on the first floor, the elevator rises to the fourth floor with speed and floor-leveling accuracy designed for passenger comfort. The push of the fourth-floor button is an input that represents our desired output when the elevator starts to move, that is the output or response, where it stops is the actual response

Introduction to control systems

Two major measures of performance are apparent:

(1) the transient response

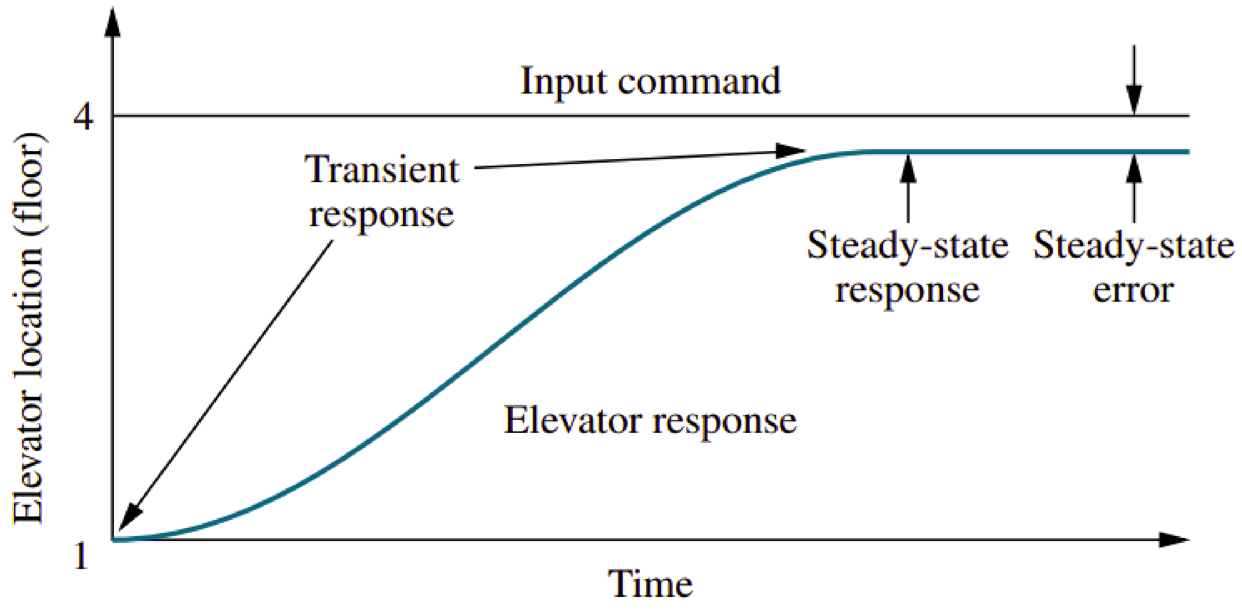
(2) the steady-state error.

In our example, passenger comfort and passenger patience are dependent upon the transient response.

- If this response is too fast, passenger comfort is sacrificed
- if too slow, passenger patience is sacrificed.

The steady-state error is another important performance specification since passenger safety and convenience would be sacrificed if the elevator did not properly level.

Introduction to control systems



Advantages of Control Systems

We build control systems for four primary reasons:

1. Power amplification: A control system can produce the needed power amplification, or power gain to a system requiring high input power.
2. Remote control: Control systems can be used in remote or dangerous locations. For example, a remote-controlled robot arm can be used to pick up material in a radioactive environment.
3. Convenience of input form: Control systems can also be used to provide convenience by changing the form of the input. For example, in a temperature control system, the input is a position on a thermostat. The output is heat. Thus, a convenient position input yields the desired thermal output

Advantages of Control Systems

4. Compensation for disturbances: Another advantage of a control system is the ability to compensate for disturbances. Typically, we control such variables as temperature in thermal systems, position and velocity in mechanical systems, and voltage, current, or frequency in electrical systems. The system must be able to yield the correct output even with a disturbance.

System Configurations

In this section, we discuss two major configurations of control systems which are:

- open loop system
- closed loop system

Open loop system

- An open loop system starts with a subsystem called an input transducer, which converts the form of the input to that used by the controller.
- The controller drives a process or a plant.
- The input is sometimes called the reference, while the output can be called the controlled variable.
- Other signals, such as disturbances, are shown added to the controller and process outputs via summing junctions, which yield the algebraic sum of their input signals using associated signs.
- For example, the plant can be a furnace or air conditioning system, where the output variable is temperature. The controller in a heating system consists of fuel valves and the electrical system that operates the valves.

Open loop system

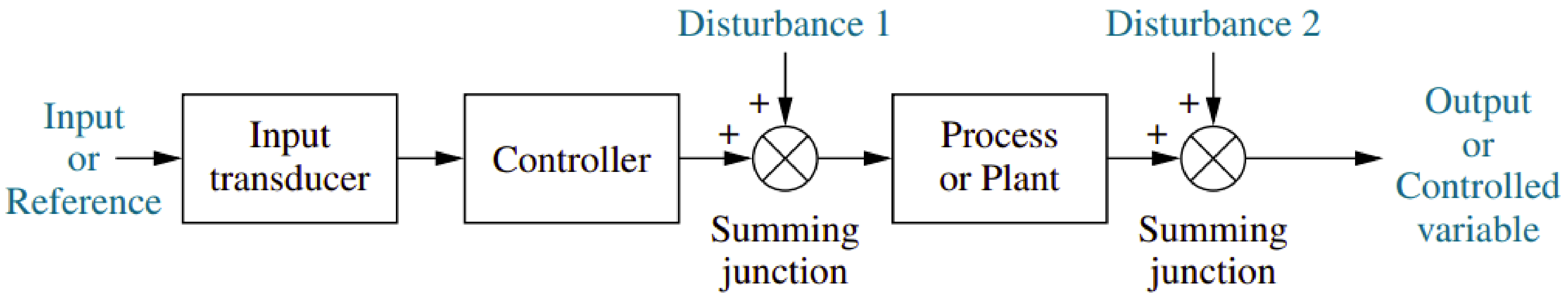


Fig.2: Open loop system

- Open-loop systems do not correct for disturbances and are simply commanded by the input.

For example, assuming that you calculate the amount of time you need to study for an examination that covers three chapters to get an A. If the lecturer decides to add a fourth chapter, this can be said to be a disturbance and you become an open-loop system if you do not detect the disturbance and add study time to that previously calculated time. The result of this oversight would be a lower grade than you expected

Open loop system

Another example of an open loop system a is toaster. Anyone with burnt toast can attest. The controlled variable (output) of a toaster is the color of the toast. The device is designed with the assumption that the toast will be darker the longer it is subjected to heat. The toaster does not measure the color of the toast; it does not correct for the fact that the toast is rye, white, or sourdough, nor does it correct for the fact that toast comes in different thicknesses.

Closed-Loop (Feedback Control) Systems

systems that perform the previously described measurement and correction are called closed-loop, or feedback control, systems. Systems that do not have this property of measurement and correction are called open-loop systems

- The disadvantages of open-loop systems, namely sensitivity to disturbances and inability to correct for these disturbances, may be overcome in closed-loop systems.

In a close-loop system;

- The input transducer converts the form of the input to the form used by the controller.
- An output transducer, or sensor, measures the output response and converts it into the form used by the controller.

The closed-loop system compensates for disturbances by;

- measuring the output response, feeding that measurement back through a feedback path, and comparing that response to the input at the summing junction.

Closed-Loop (Feedback Control) Systems

- If there is any difference between the two responses, the system drives the plant, via the actuating signal, to correct it.
- If there is no difference, the system does not drive the plant, since the plant's response is already the desired response

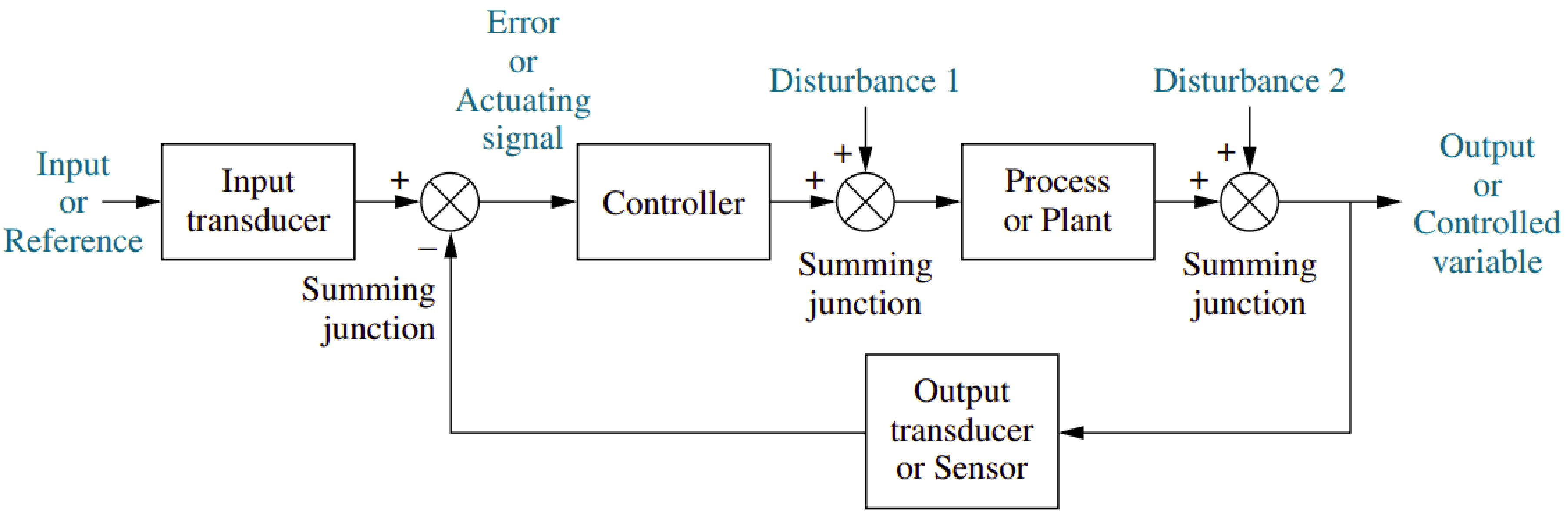


Fig.3: Close loop system

Closed-Loop (Feedback Control) Systems

- Closed-loop systems have the advantage of greater accuracy than open-loop systems.
- They are less sensitive to noise, disturbances, and changes in the environment.
- Transient response and steady-state error can be controlled more conveniently and with greater flexibility in closed-loop systems, often by a simple adjustment of gain (amplification) in the loop and sometimes by redesigning the controller.
- Closed-loop systems are more complex and expensive than open-loop systems. Thus, the control systems engineer must consider the trade-off between the simplicity and low cost of an open-loop system and the accuracy and higher cost of a closed-loop system

Analysis and Design Objectives

In Section 1.1 we briefly alluded to some control system performance specifications, such as transient response and steady-state error. We now expand upon the topic of performance and place it in perspective as we define our analysis and design objectives

- **Analysis**: Analysis is the process by which a system's performance is determined. For example, we evaluate its transient response and steady-state error to determine if they meet the desired specifications
- **Design** : Design is the process by which a system's performance is created or changed. For example, if a system's transient response and steady-state error are analyzed and found not to meet the specifications, then we change parameters or add additional components to meet the specifications.
- **A control system is dynamic**: It responds to an input by undergoing a transient response before reaching a steady-state response that generally resembles the input.

Analysis and Design Objectives

Three major objectives of systems analysis and design:

- Producing the desired transient response
- Reducing steady-state error: We define steady-state error as the difference between the input and the output after the transients have effectively disappeared
- Achieving stability

Total response = Natural response + Forced response

- For a control system to be useful, the natural response must;(1) eventually approach zero, thus leaving only the forced response, or (2) oscillate.
- In some systems, however, the natural response grows without bound rather than diminish to zero or oscillate. Eventually, the natural response is so much greater than the forced response that the system is no longer controlled.
- This condition is called instability and could lead to self-destruction of the physical device if limit stops are not part of the design

Analysis and Design Objectives

For example, the elevator would crash through the floor or exit through the ceiling; an aircraft would go into an uncontrollable roll without limit stops in their control system design.

- A time plot of an unstable system would show a transient response that grows without bound and without any evidence of a steady-state response.
- Control systems must be designed to be stable. That is, their natural response must decay to zero as time approaches infinity, or oscillate.

Aside from the three main objectives of control system analysis and design, other important considerations include;

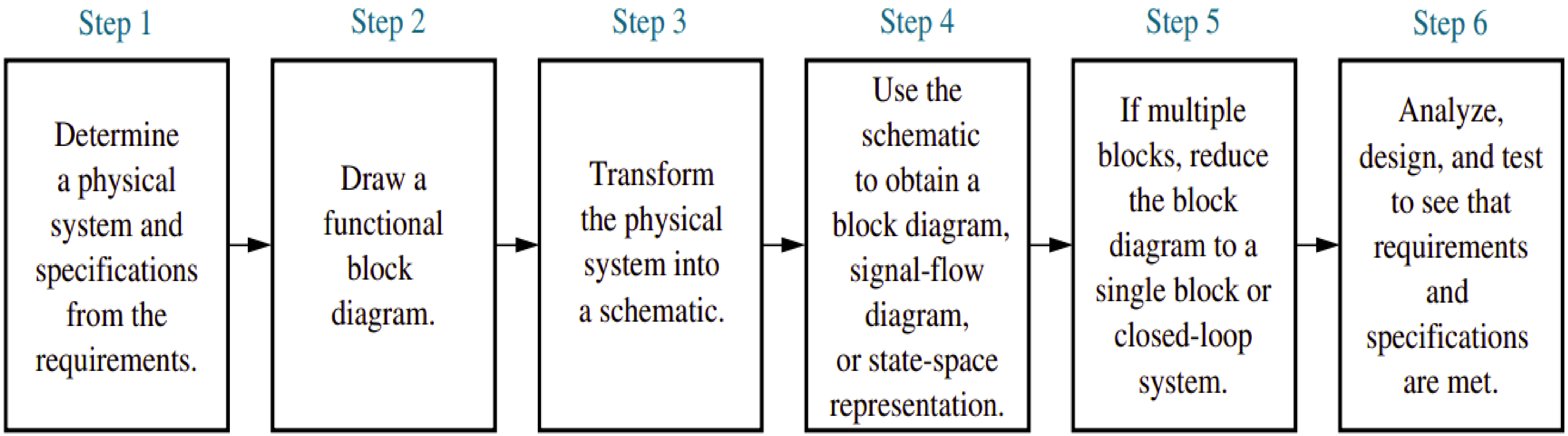
- Finances are another consideration: Control system designers cannot create designs without considering their economic impact. Such considerations as budget allocations and competitive pricing must guide the engineer

Analysis and Design Objectives

- Another consideration is robust design. System parameters considered constant during the design for transient response, steady-state errors, and stability change over time when the actual system is built. Thus, the performance of the system also changes over time and will not be consistent with your design
- Factors affecting hardware selection, such as motor sizing to fulfill power requirements and choice of sensors for accuracy, must be considered early in the design
- In summary, then, our design objectives and the system’s performance revolve around the transient response, the steady-state error, and stability.

Design Process

- In order to design a control system, some steps must be followed. The steps are summarized below.
- **NB:** Students are to read and understand each of the processes.

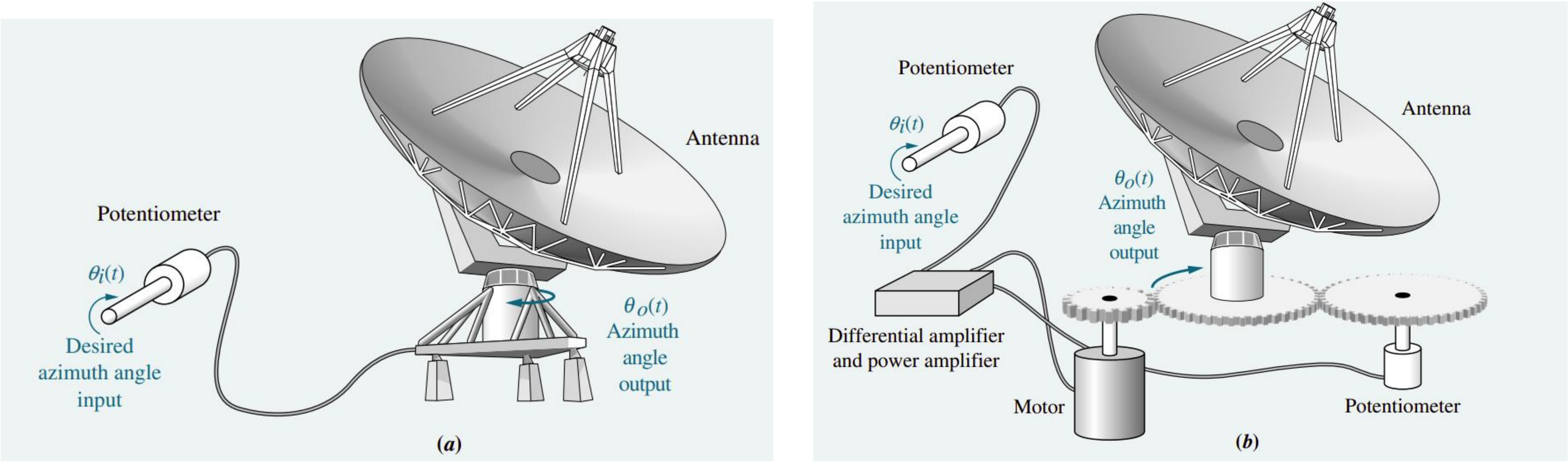


Position control system

A position control system converts a position input command to a position output response. Position control systems find widespread applications in antennas, robot arms, and computer disk drives.

- In this section, we will look in detail at an antenna azimuth position control system that could be used to position radio telescope antenna. We will see how the system works and how we can effect changes in its performance.
- For example. Lets consider an antennae control system. An antenna azimuth position control system is shown in Figure 1.9(a), with a more detailed layout and schematic in Figures 1.9(b) and 1.9(c), respectively. Figure 1.9(d) shows a functional block diagram of the system.

Position control system

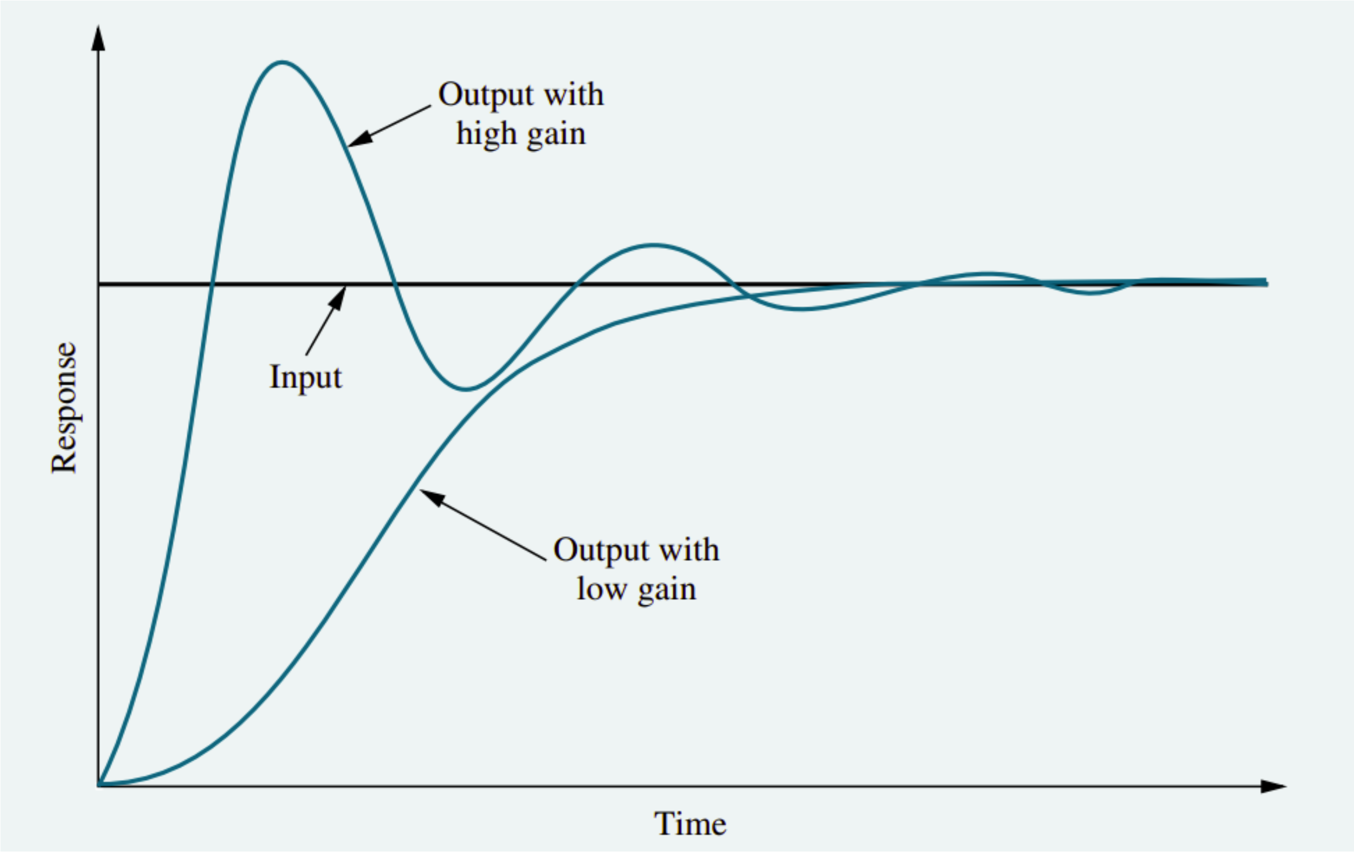


- The potentiometer converts the angular displacement into a voltage.
- Similarly, the output angular displacement is converted to a voltage by the potentiometer in the feedback path.
- The signal and power amplifiers boost the difference between the input and output voltages.
- This amplified actuating signal drives the plant

Position control system

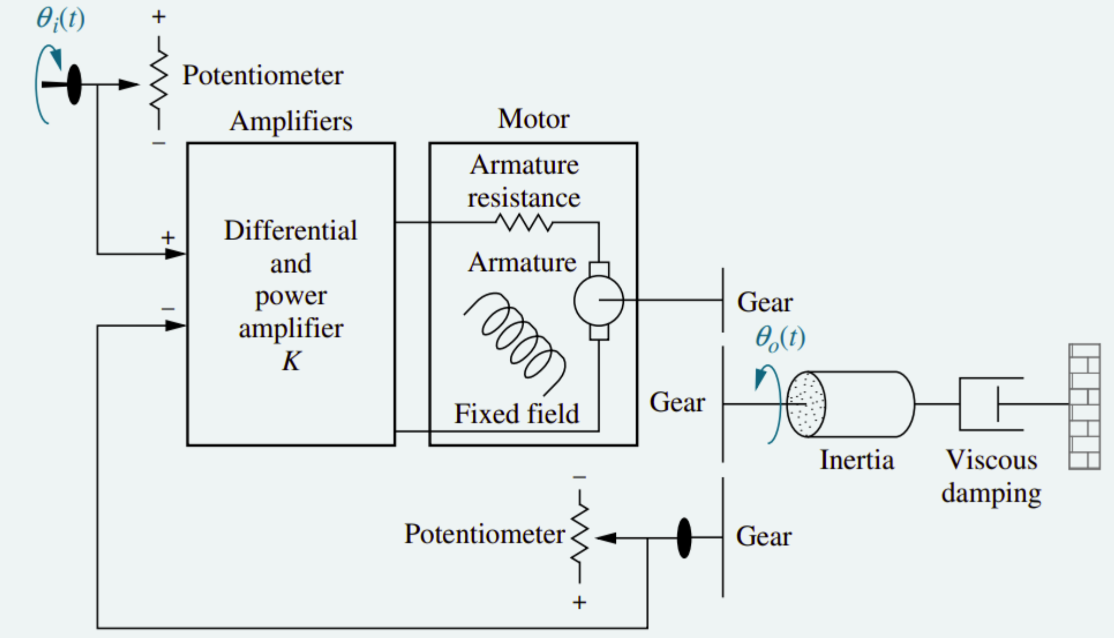
- The system normally operates to drive the error to zero.
- When the input and output match, the error will be zero, and the motor will not turn. Thus, the motor is driven only when the output and the input do not match.
- The greater the difference between the input and the output, the larger the motor input voltage, and the faster the motor will turn.
- If the gain is increased, then for a given actuating signal, the motor will be driven harder.
- However, the motor will still stop when the actuating signal reaches zero, that is, when the output matches the input.
- The difference in the response, however, will be in the transients. Since the motor is driven harder, it turns faster toward its final position.
- Also, because of the increased speed, increased momentum could cause the motor to overshoot the final value and be forced by the system to return to the commanded position

Position control system

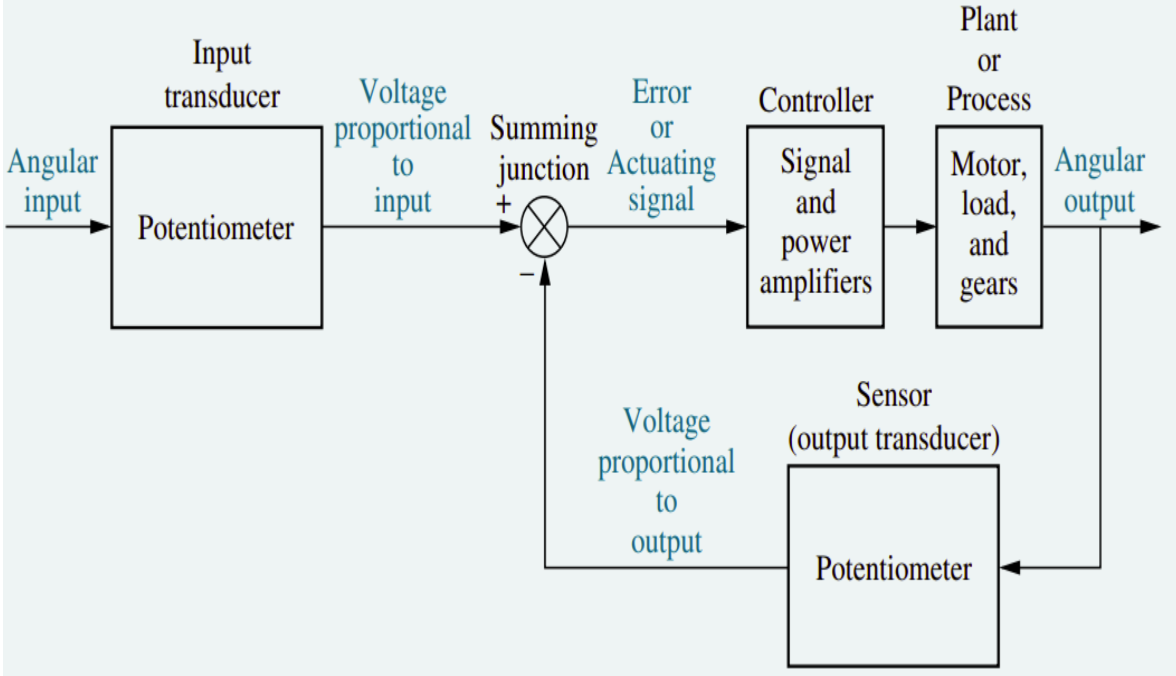


The responses for low gain and high gain

Position control system



(c)



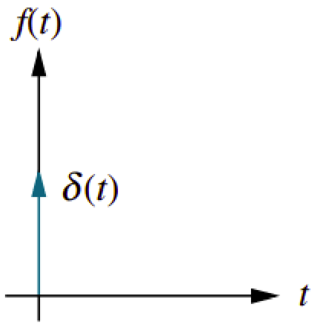
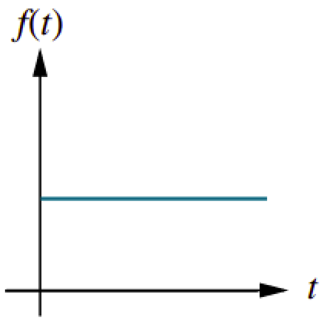
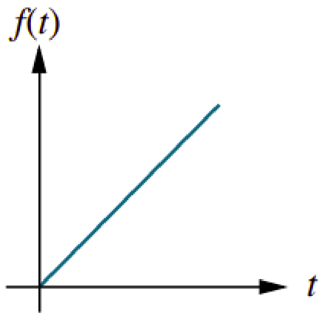
(d)

System analysis and design

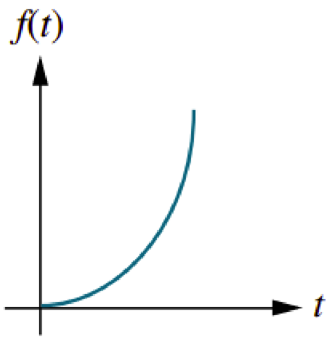
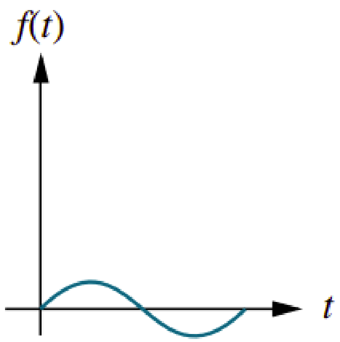
In this phase, the engineer analyzes the system to see if the response specifications and performance requirements can be met by simple adjustments of system parameters. If specifications cannot be met, the designer then designs additional hardware to effect a desired performance.

- Test input signals are used, both analytically and during testing, to verify the design.
- It is neither necessarily practical nor illuminating to choose complicated input signals to analyze a system's performance. Thus, the engineer usually selects standard test inputs.
- These inputs are impulses, steps, ramps, parabolas, and sinusoids

System analysis and design

Input	Function	Description	Sketch	Use
Impulse	$\delta(t)$	$\delta(t) = \infty$ for $0- < t < 0+$ $= 0$ elsewhere $\int_{0-}^{0+} \delta(t)dt = 1$		Transient response Modeling
Step	$u(t)$	$u(t) = 1$ for $t > 0$ $= 0$ for $t < 0$		Transient response Steady-state error
Ramp	$tu(t)$	$tu(t) = t$ for $t \geq 0$ $= 0$ elsewhere		Steady-state error

System analysis and design

Input	Function	Description	Sketch	Use
Parabola	$\frac{1}{2}t^2u(t)$	$\frac{1}{2}t^2u(t) = \frac{1}{2}t^2$ for $t \geq 0$ $= 0$ elsewhere		Steady-state error
Sinusoid	$\sin \omega t$			Transient response Modeling Steady-state error