Feedback Control Principle

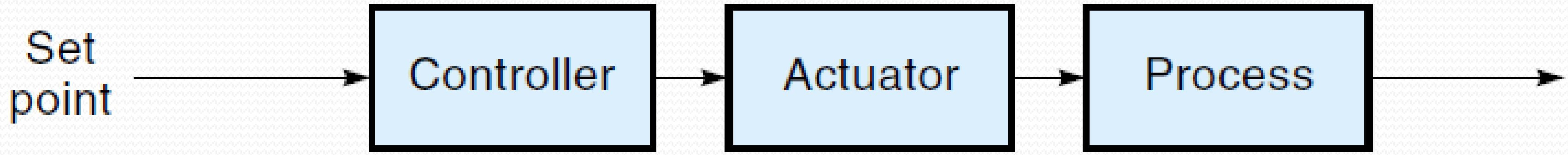
CEG3H3

Randy E. Saputra, ST. MT.

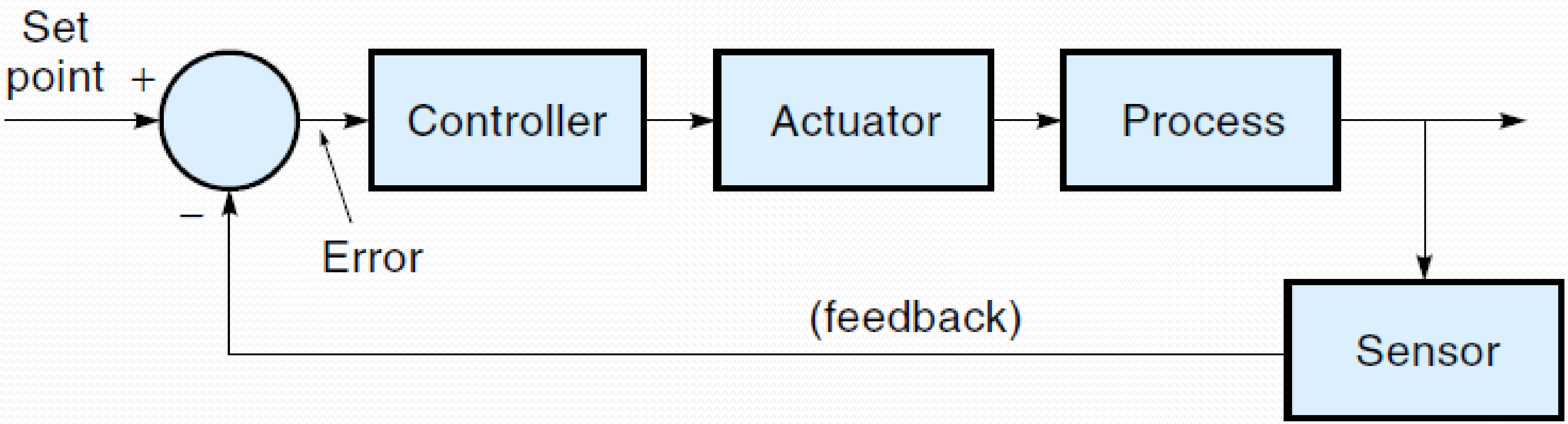
Objectives

- Understand the terms and operation of a closed-loop control-system block diagram
- Describe the basic operation of on-off control systems
- Understand the concept and operation of a proportional control system (including bias) and calculate the error and controller output, given the system gain and inputs
- Understand the concept of dead band and calculate the dead-band range for a proportional control system

Control System

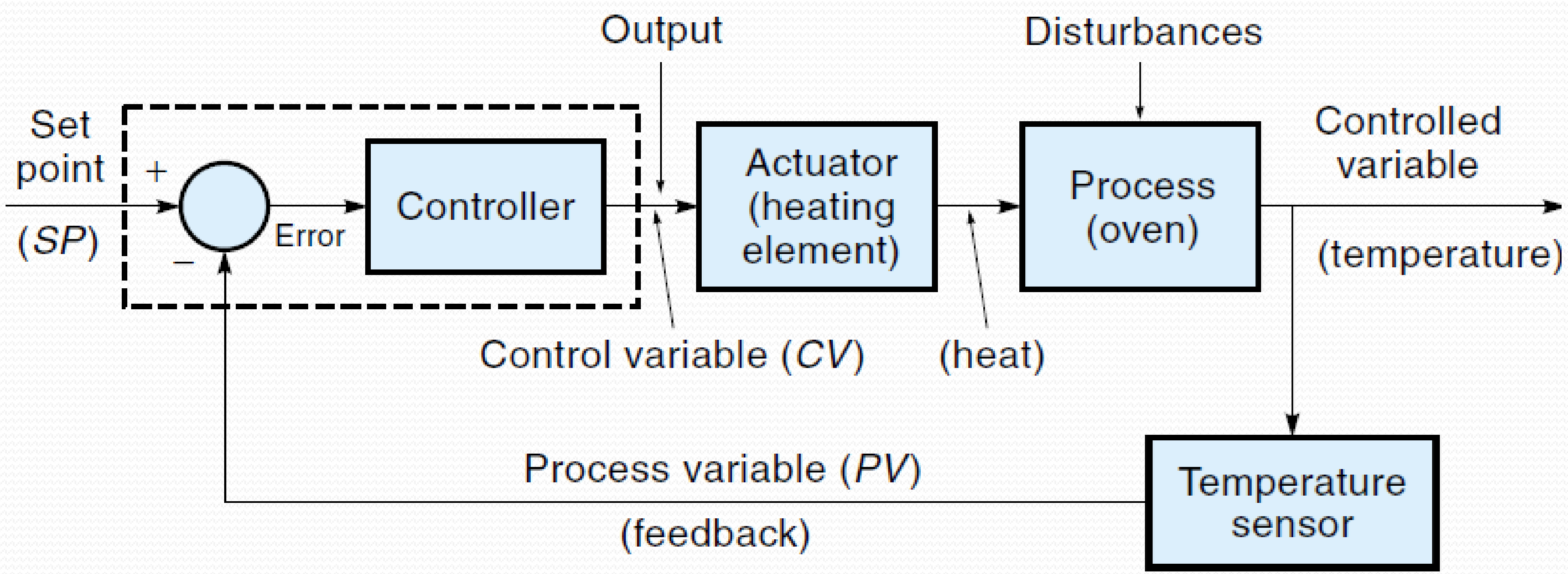


(a) Open-loop control system



(b) Closed-loop control system

Closed-loop Control System



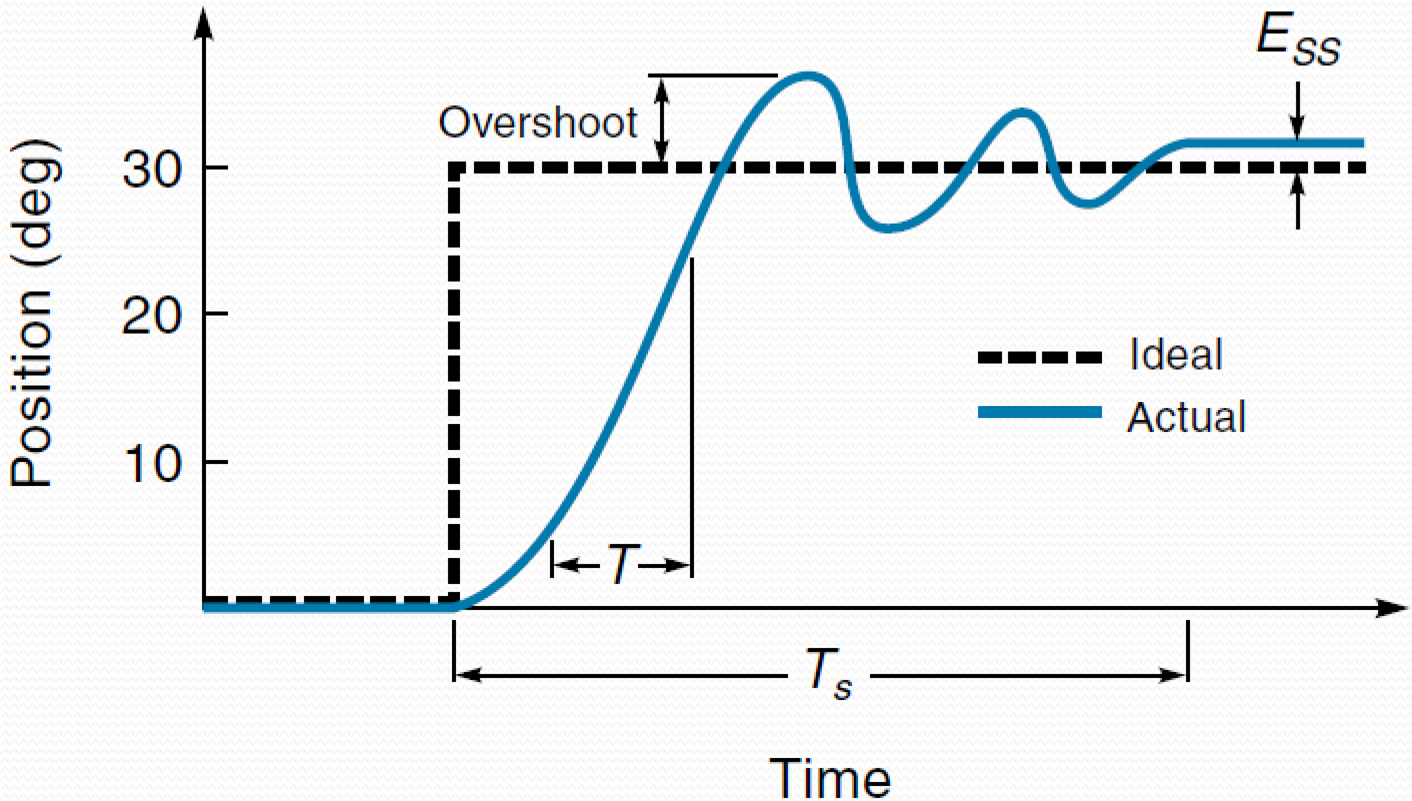
Closed-loop Control System

- **Controller** is an analog or digital circuit that accepts data from the sensors, makes a decision, and sends the appropriate commands to the actuator

- Controller keeps the **controlled variable** (such as temperature, liquid level, position, or velocity) at a certain value called the **set point** (*SP*)

- **Error** (*E*) is the difference between where the controlled variable is and where it should be

Performance Criteria



Performance Criteria

- **Transient response** is the exact path the controlled variable takes when go from one position to the next

- **Rise time** (T) is usually defined as the time it takes for the controlled variable to go from 10 to 90% of the way to its new position

- **Settling time** (T_s) refers to the time it takes for the response to settle down to within some small percentage (typically 2-5%) of its final value

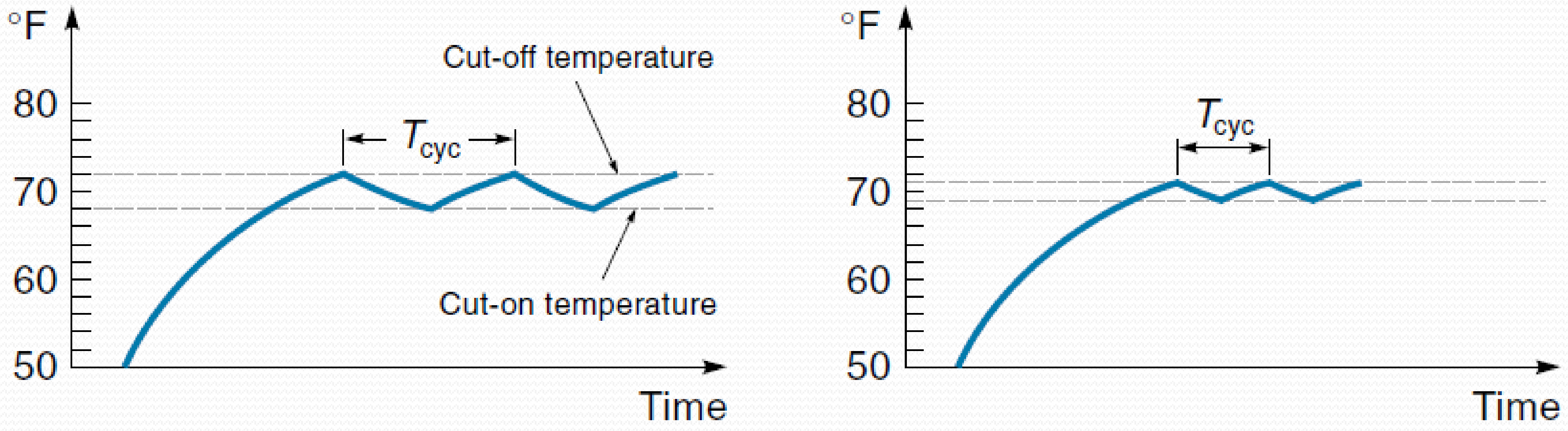
Performance Criteria

- **Overshoot** happen when object's momentum keep it going right on past where it was supposed to stop

- **Steady-state error** (E_{SS}) of the system is simply the final position error, which is the difference between where the controlled variable is and where it should be

Two-position Control

- Example : Heating system

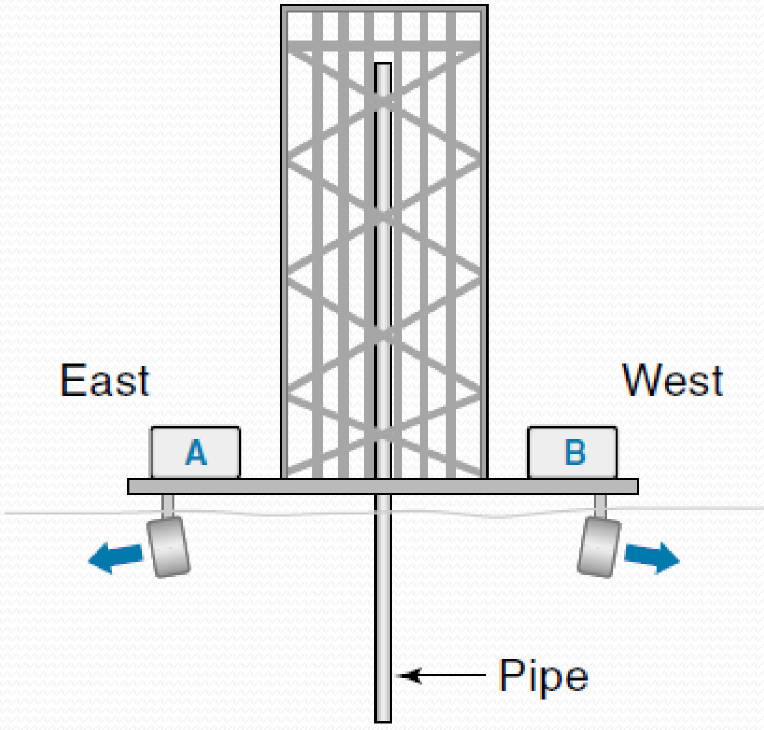


(a) Cut-on = 68°; cut-off = 72°

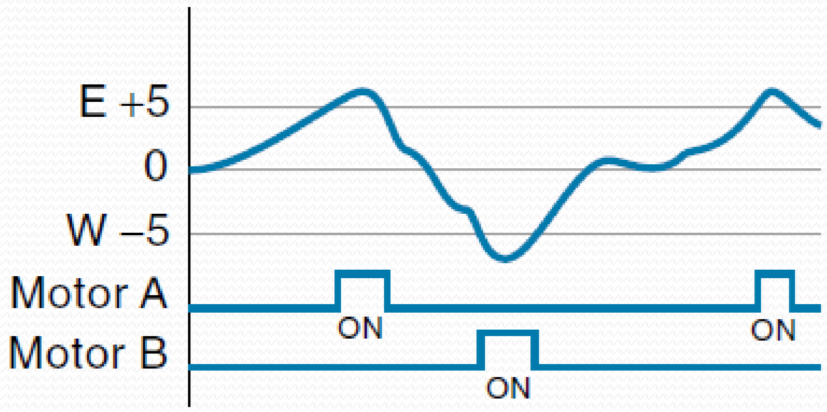
(b) Cut-on = 69°; cut-off = 71°

Three-position Control

- Example : Floating oil-drilling platform



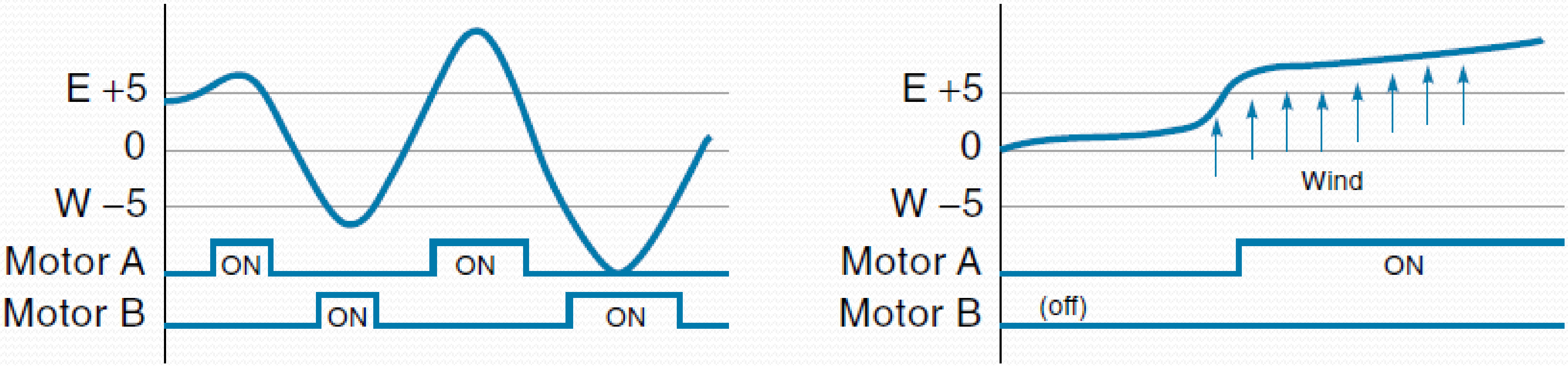
(a) Floating platform



(b) Typical operation

Three-position Control

- Example : Floating oil-drilling platform



(c) Dead calm (motor too strong)

(d) High wind (motor too weak)

Proportional Control

- Proportional control is the application of a corrective force that is proportional to the amount of error :

$$\text{Output}_P = K_P E$$

where

Output_P = controller output of proportional control

K_P = proportional constant for the system called **gain**

E = error

Proportional Control

- Feedback signal is called the **process variable** (PV) and **error** (E) is the difference between PV and SP :

$$E = SP - PV$$

where

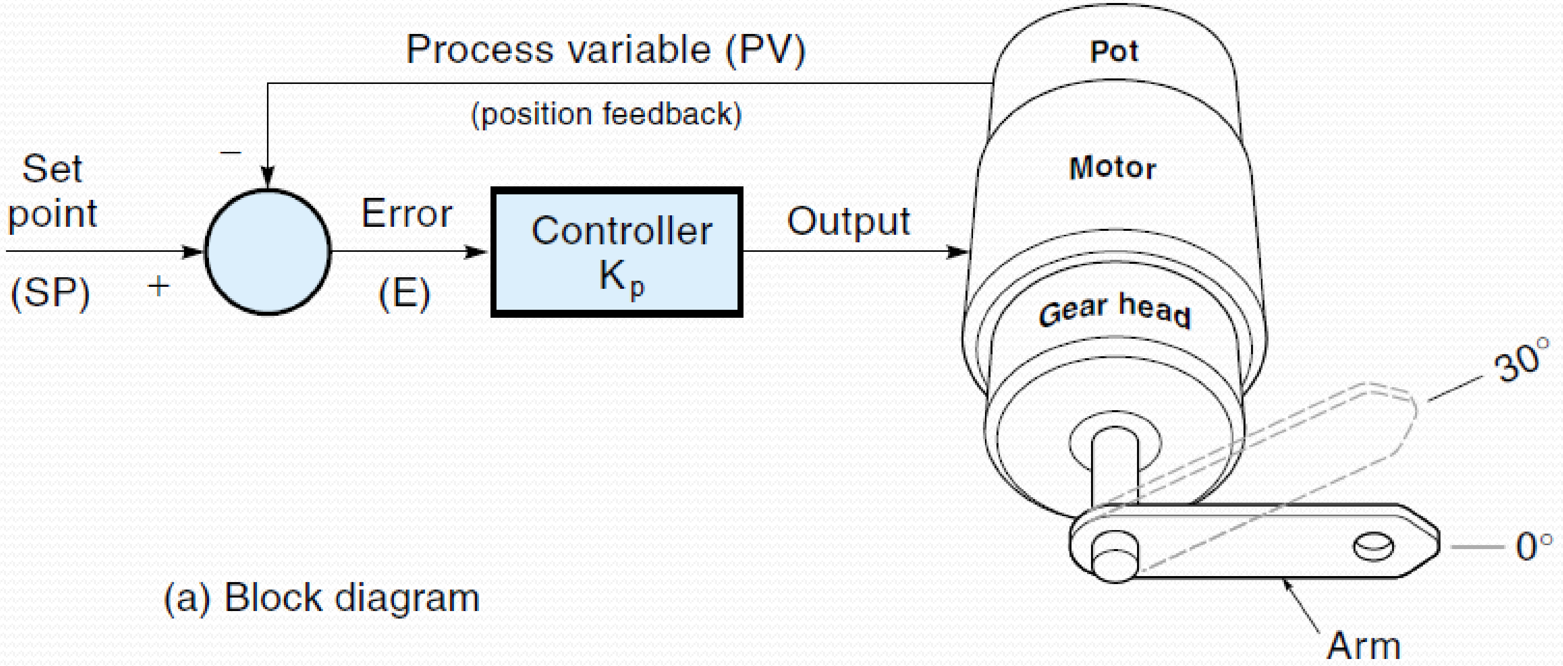
E = error

SP = set point, desired value of the controlled variable

PV = process variable, actual value of the controlled variable

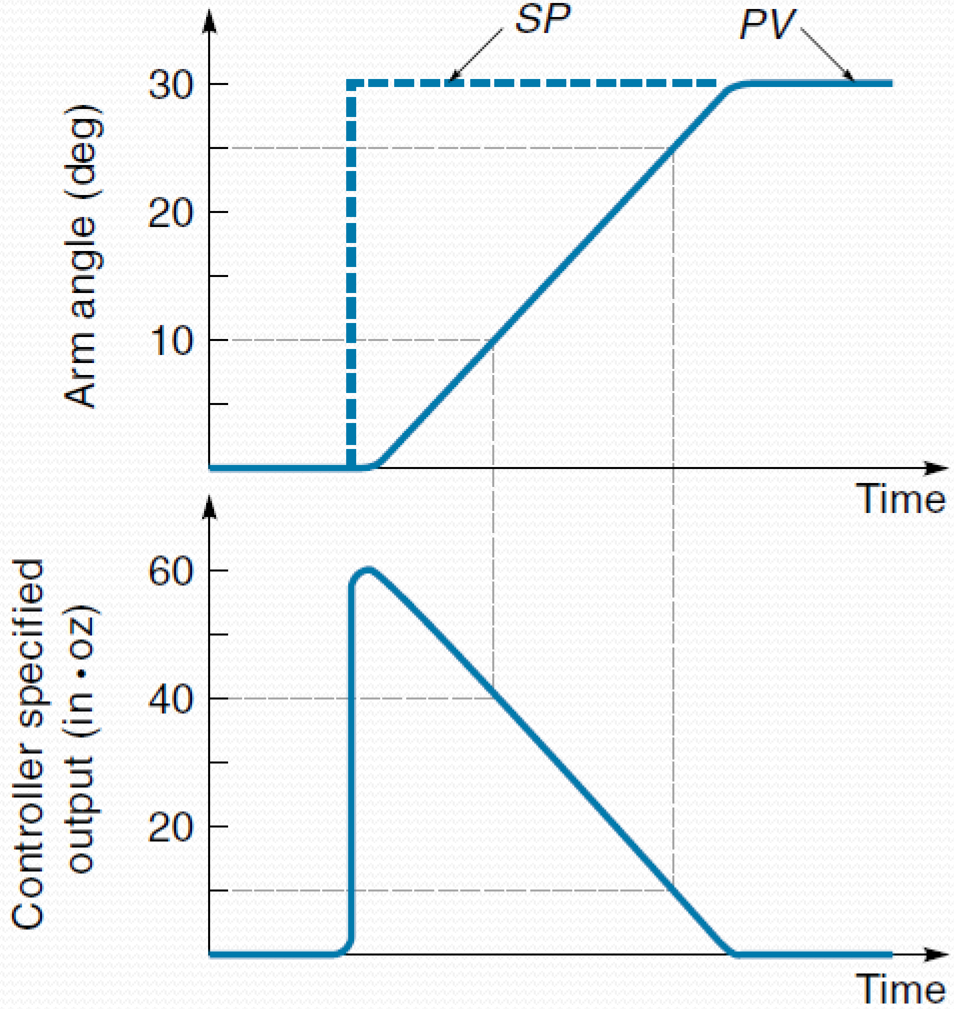
Example

- Assume that a motor driven arm was originally at 0° and then was directed to move to a new position at 30°. The gain of the system is KP = 2 inch · oz/deg. Describe how the controller responds to this situation.



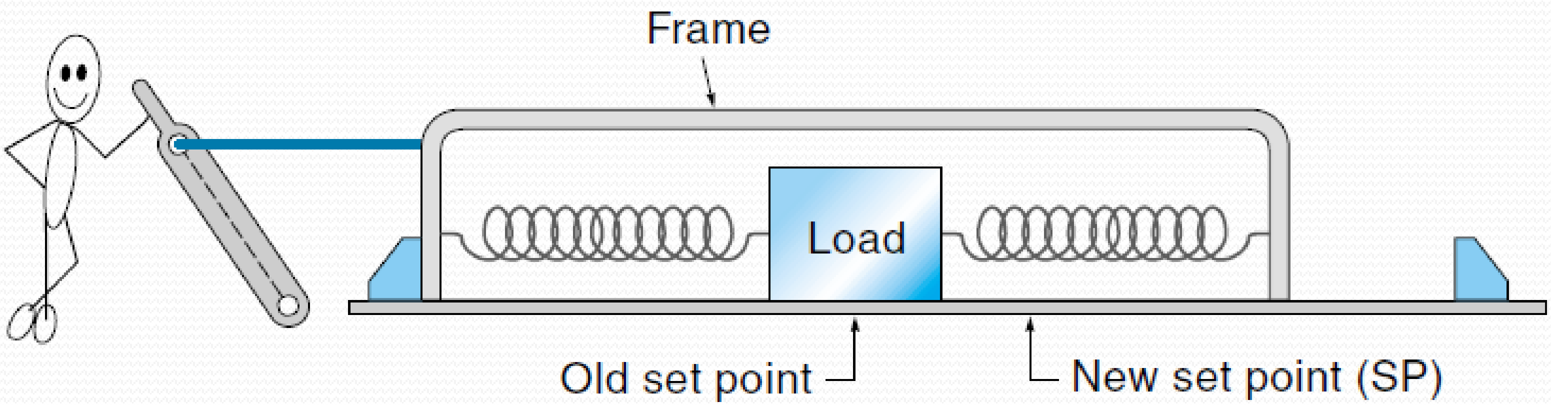
(a) Block diagram

Example

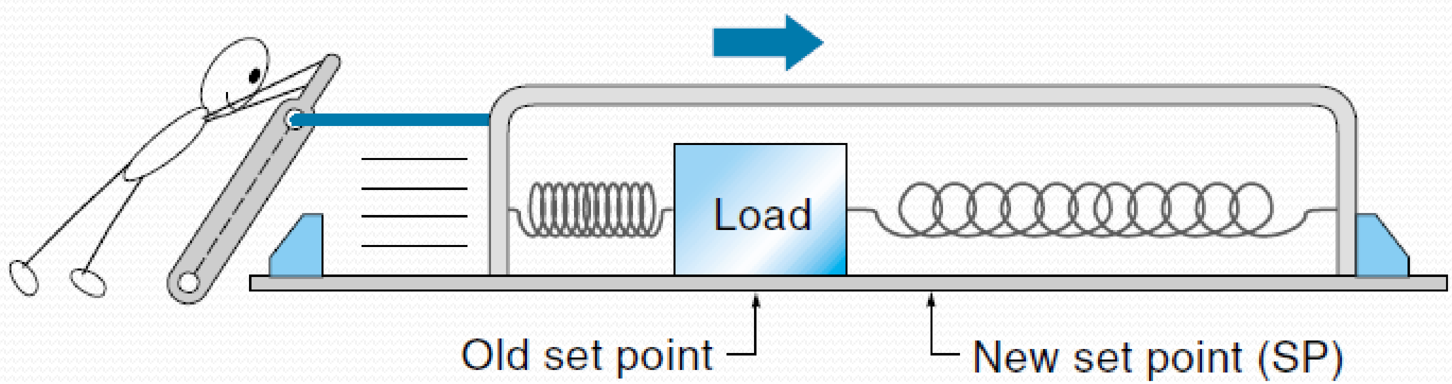


(b) Graphs showing response to change in set point

Steady-State-Error Problem

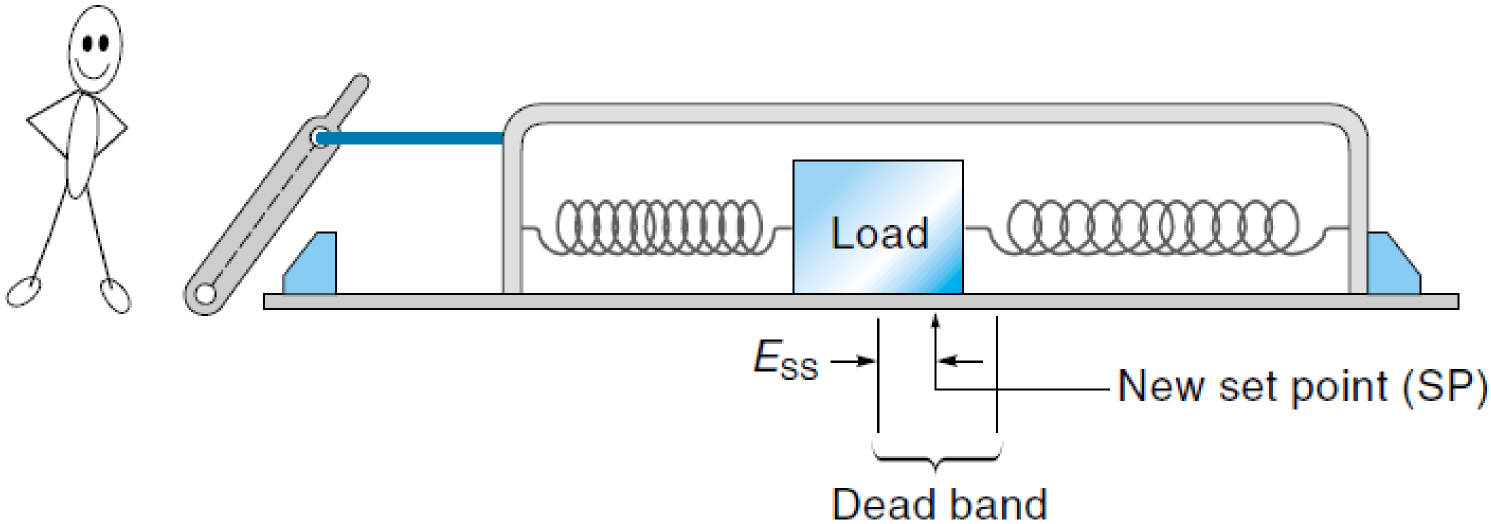


(a) Load is centered



(b) Load is commanded to new position by moving frame

Steady-State-Error Problem



(c) Load is at rest in new position; friction keeps load from being centered

- The region on either side of the set point, where the restoring force is incapable of precisely locating the controlled variable, is called the dead band/dead zone

Example

- A position control system has a gain KP of 2 inch · oz/deg and works against a constant friction torque of 6 inch · oz. What is the size of the dead band?

Solution

To overcome the friction, the system must cause the motor to output 6 inch · oz. Because the input to the controller is the error signal, we need to find the value of error that results in a controller output of 6 inch · oz

Example

Starting with the basic proportional equation :

$$\text{Output}_P = K_P E$$

Rearranging to solve for error :

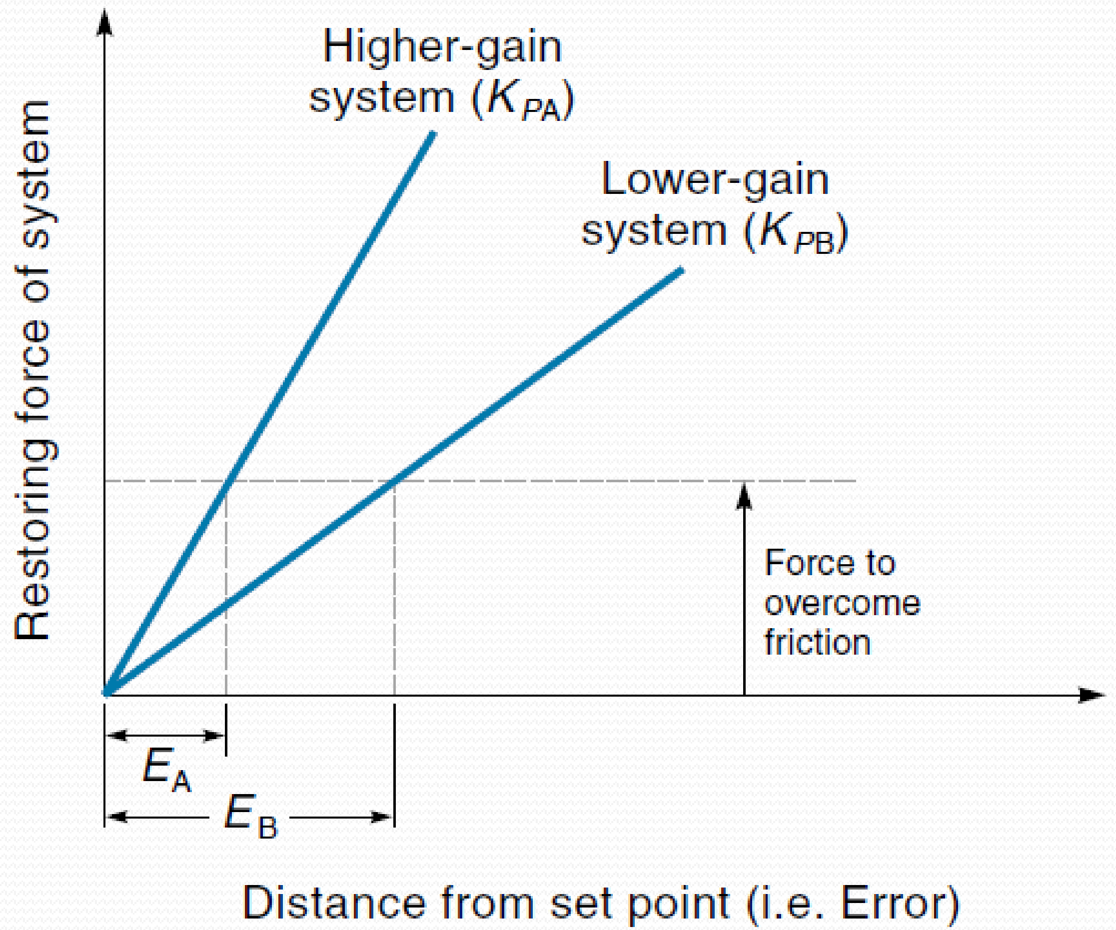
$$E = \frac{\text{Output}_P}{\text{K}_P} = \frac{6\ \text{inch} \cdot \text{oz}}{2\ \text{inch} \cdot \text{oz/deg}} = 3°$$

With 3° error on each side of the set point, then dead band = 6°

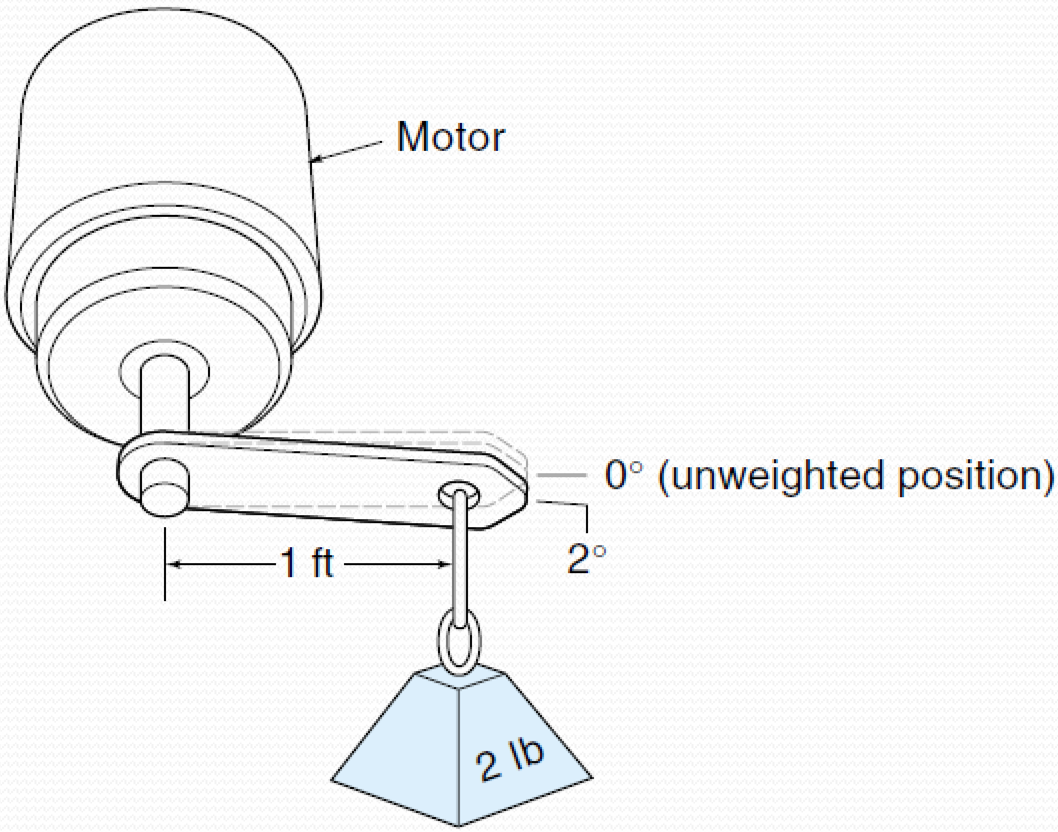
Steady-State-Error Problem

- One way to decrease the steady-state error due to friction is to increase the system gain (K_P)
- It might seem reasonable to make the gain of every system very high, however, high K_P can lead to instability problems (oscillations)

Steady-State-Error Problem



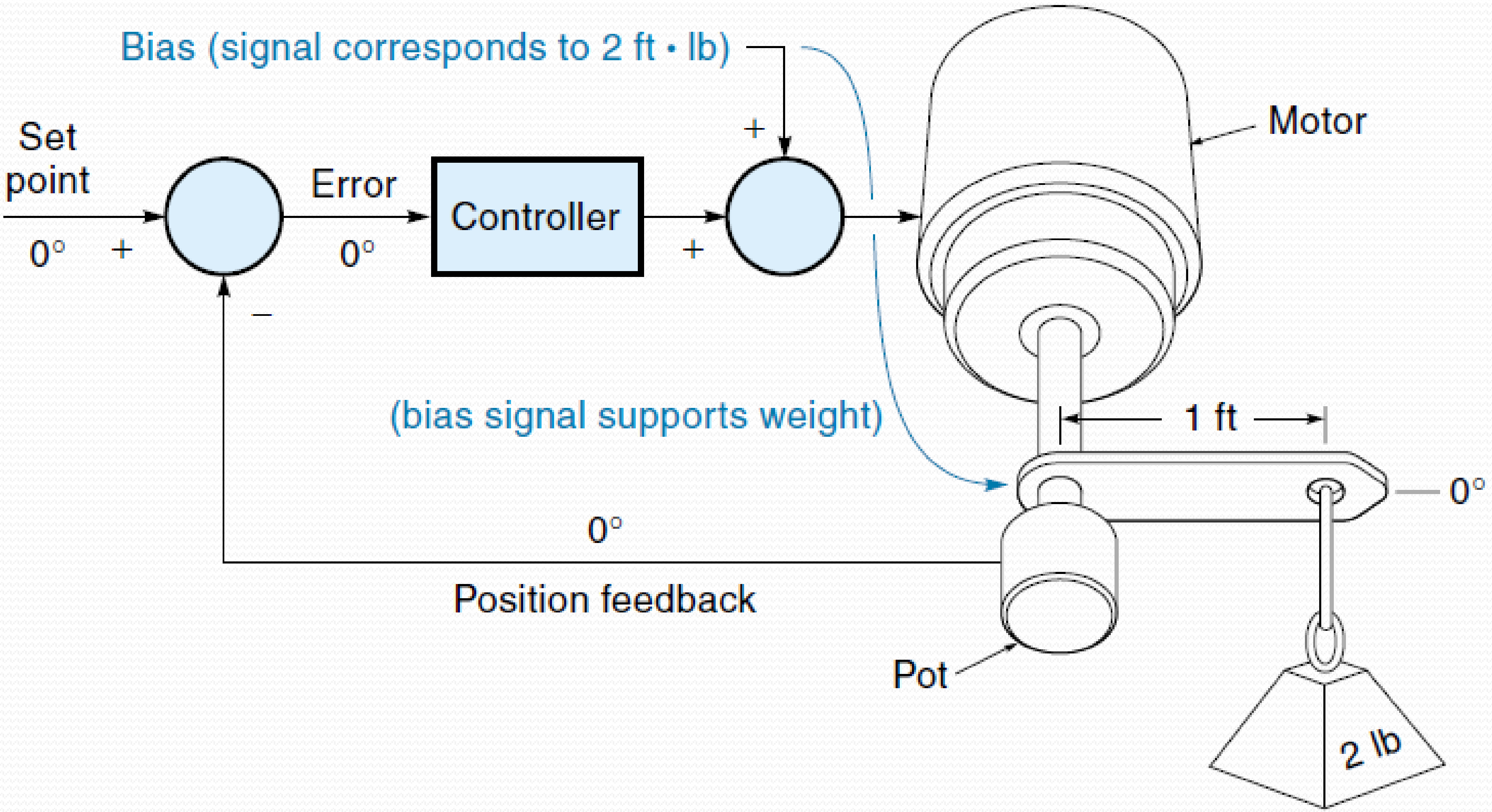
Gravity Problem



Gravity Problem

- For the system to support the weight, there must be an error
- It happens because the proportional system only produces a restoring force when there is an error and the weight requires a constant force to support it

Bias



Bias (signal corresponds to 2 ft • lb)
Set point
0°
+
Error
0°
Controller
+
+
Motor
–
(bias signal supports weight)
1 ft
0°
0°
Position feedback
Pot
2 lb

Bias

- One way to deal with the gravity problem is to have the controller add in a constant value (to its output) that is just sufficient to support the weight, called **bias**
- Equation for a proportional control system with bias :

$$\text{Output}_P = K_P E + \text{bias}$$

Objectives Completed

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