Feedback Control Principle (2)

CEG3H3

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Objectives

- Understand the concept and characteristics of integral control
- Understand the concept and characteristics of derivative control

Integral Control

- Integral control in a control system can reduce the steady-state error to zero
- It creates a restoring force that is proportional to the sum of all past errors multiplied by time

Integral Control

- Integral control is expressed in :

$$\text{Output}_I = K_I K_P \Sigma(E\Delta t)$$

where
Output_I = controller output of integral control
K_I = integral gain constant (sometimes written $1/T_I$)
K_P = proportional gain constant
$\Sigma(E\Delta t)$ = sum of all past error multiplied by the time

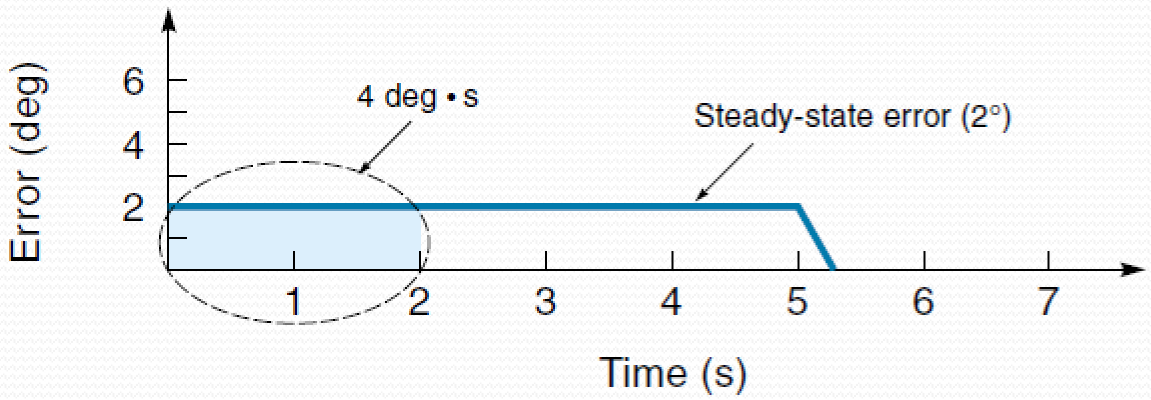
Integral Control

- For a constant value of error, the value of $\Sigma(E\Delta t)$ will increase with time, causing the restoring force to get larger and larger
- Eventually, the restoring force will get large enough to overcome friction and move the controlled variable in a direction to eliminate the error

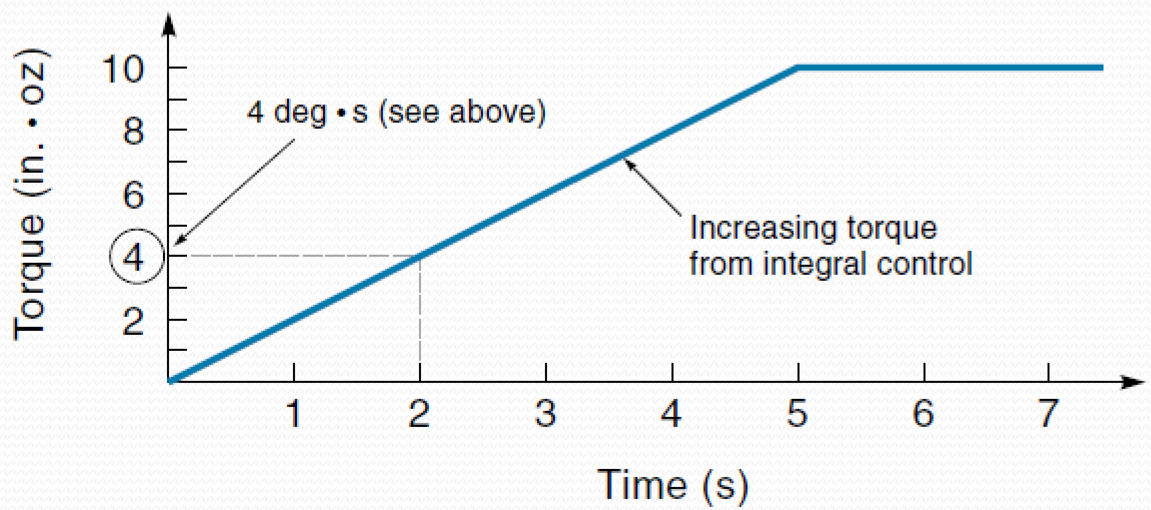
Example

- A robot arm has a steady-state error position of 2° due to friction. Assuming that $K_P = 1 \text{ inch} \cdot \text{oz/deg}$ and $K_I = 1/\text{s}$, then $K_P K_I = 1 \text{ inch} \cdot \text{oz/deg} \cdot \text{s}$. The graph shows how the restoring torque due to integral control increases with time. The magnitude of the restoring torque at any point in time is proportional to the area under the error curve. The last point remains at the elevated level of $10 \text{ inch} \cdot \text{oz}$ is important because it allows the gravity problem to be overcome.

Example



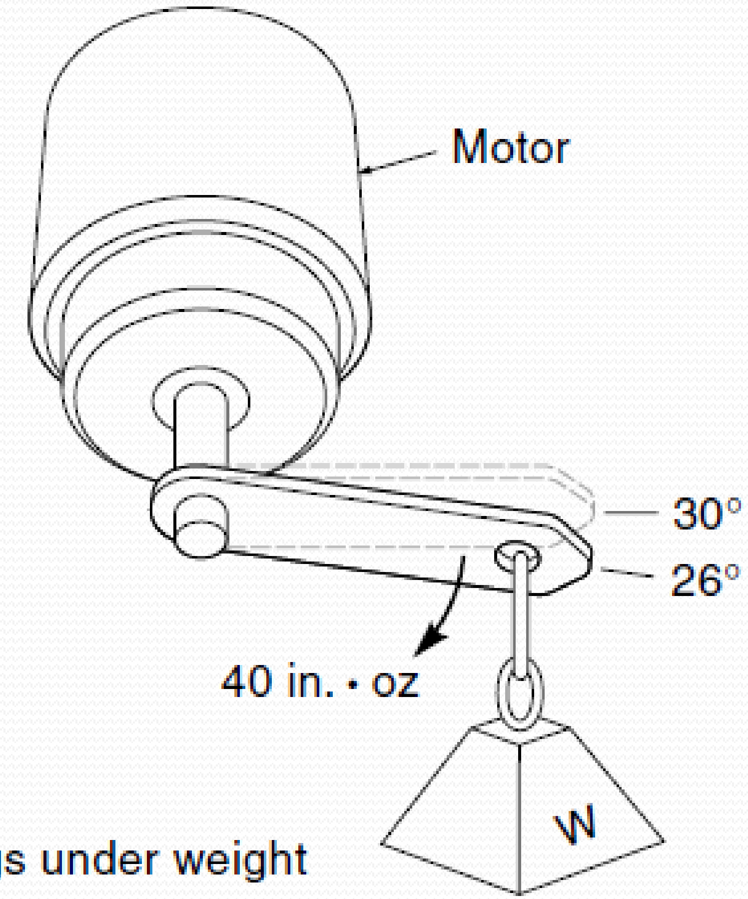
(a) Steady-state error is being reduced to zero



Example

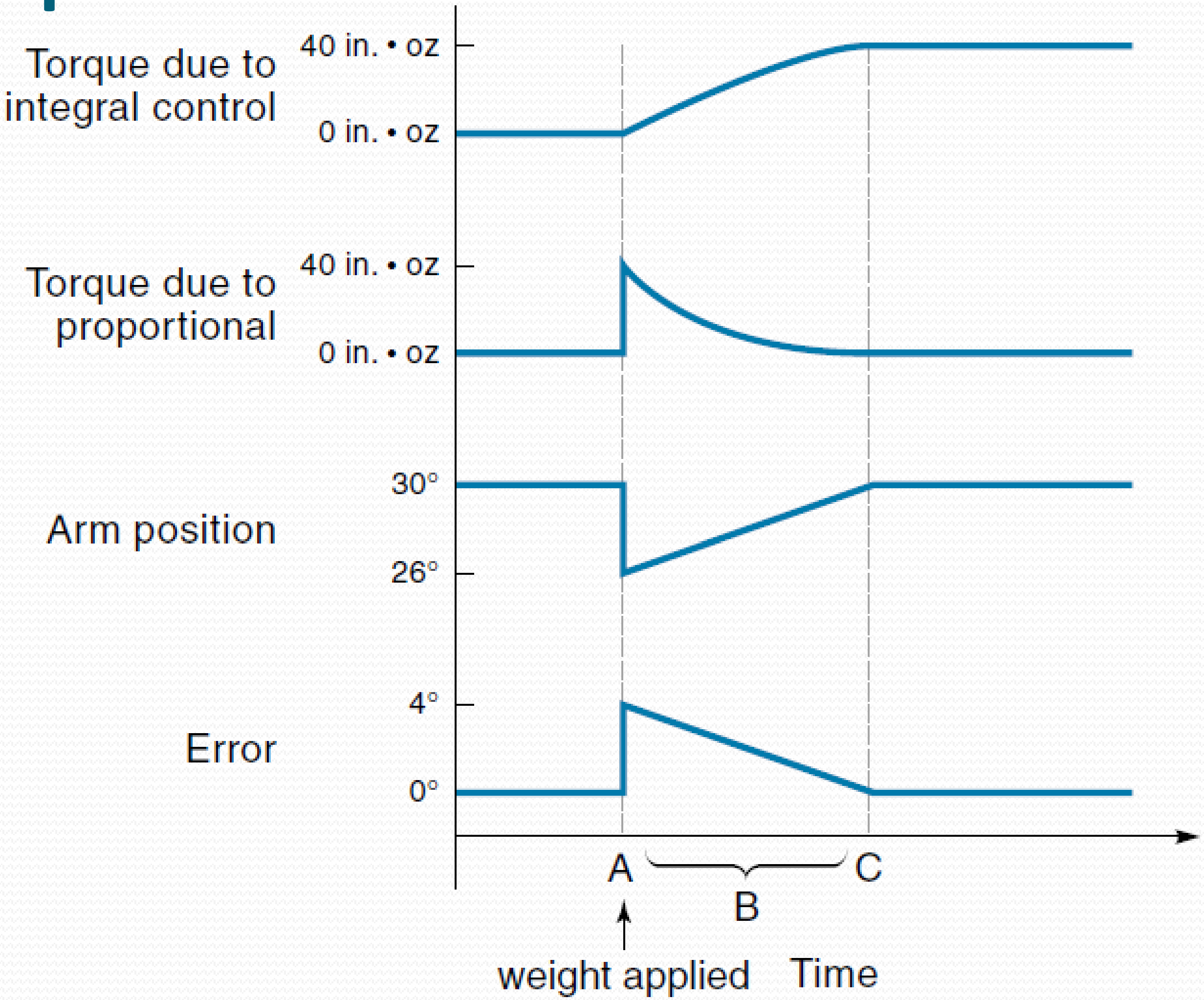
- The proportional control ($K_P = 10$ inch · oz/deg) has been modified to include integral feedback. The arm has been at rest (at the 30° position) when a weight is placed on the end of the arm, causing a downward torque of 40 inch · oz. Describe how the control system responds to the weight.

Example



(a) Arm sags under weight

Example

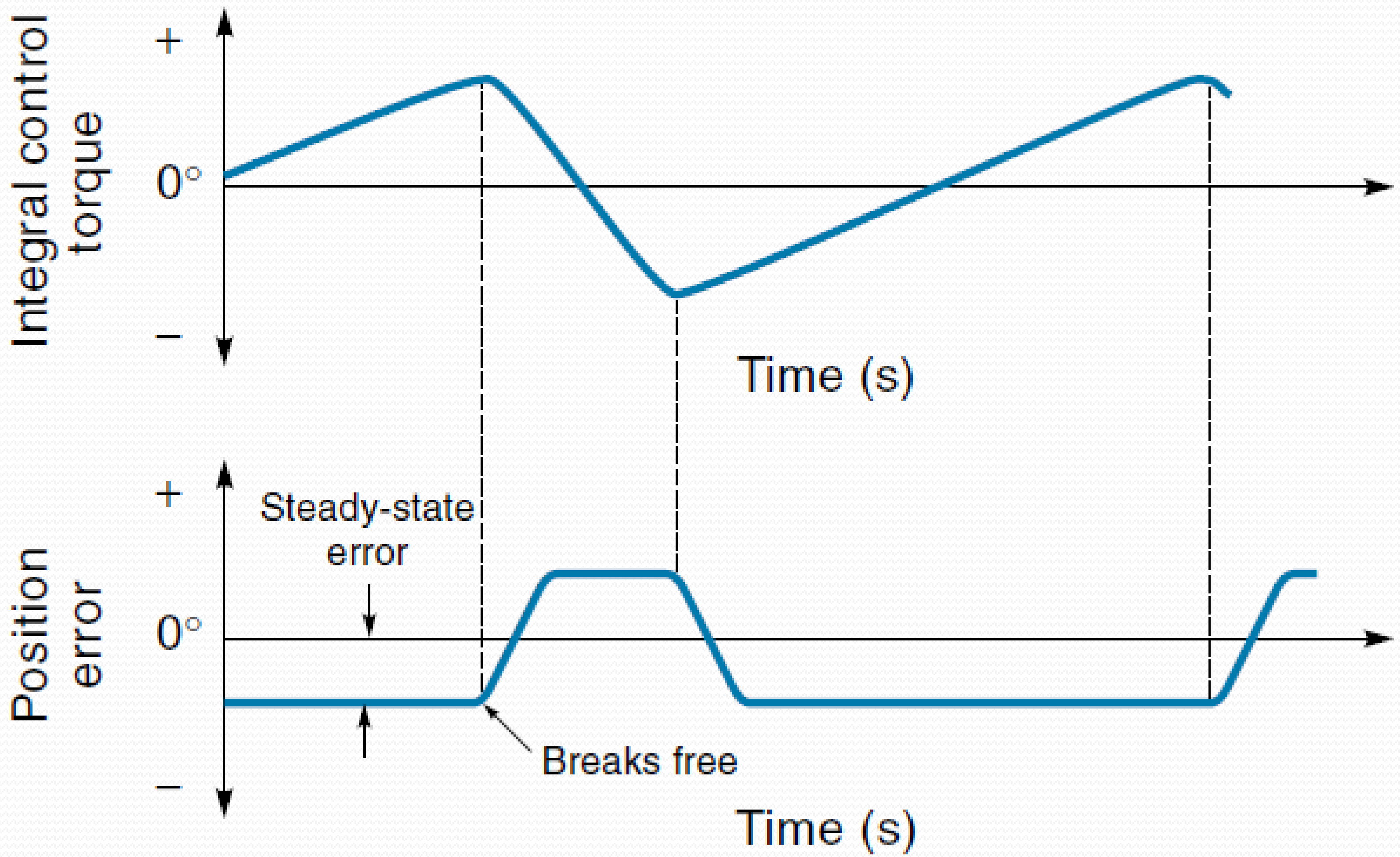


(b) Proportional and integral contributions

Integral Control Problem

- Although integral control eliminates the steady-state-error problem, it reduces the overall system stability because it tends to make the system overshoot, which may lead to oscillations
- No "braking" (slow the object before it gets to the new set point)
- Response is relatively slow because it takes a while for the error · time area to build up

Integral Control Problem



Derivative Control

- Derivative control "applies the brakes", slowing the controlled variable just before it reaches its destination
- One solution to the overshoot problem

Derivative Control

- The contribution from derivative control is expressed :

$$\text{Output}_D = K_D K_P \frac{\Delta E}{\Delta t}$$

where

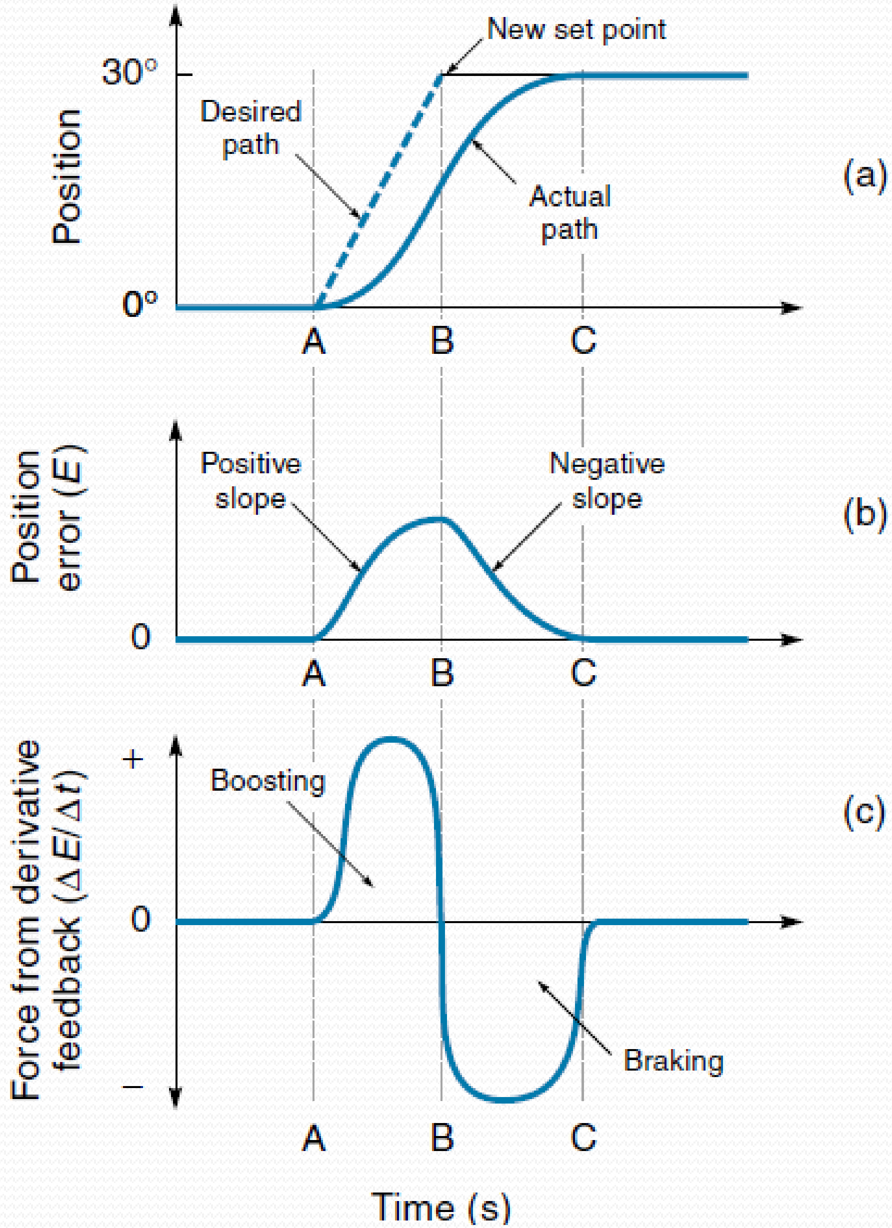
Output_D = controller output of derivative control

K_D = derivative gain constant (sometimes written T_D, unit in time)

K_P = proportional gain constant

$\frac{\Delta E}{\Delta t}$ = error rate of change (slope of error curve)

Example



New set point
30°
0°
Position
Desired path
Actual path
A
B
C
(a)
Position error (E)
Positive slope
Negative slope
0
(b)
Force from derivative feedback ($\Delta E/\Delta t$)
+
–
0
Boosting
Braking
(c)
Time (s)

Example

- The graph shows how a position control system with derivative feedback responds to a set-point change. The controlled variable is initially at 0°. At time A the set point moves rapidly to 30°. Notice that the position error (E) is increasing (positive slope) during A to B. Derivative control, which is proportional to error slope, will have a positive output, which gives the object a boost, to help get it moving. As the controlled variable closes in on the set-point value (B to C), the position error is decreasing (negative slope), so derivative feedback applies a negative force that acts like a brake, helping to slow the object.

Derivative Control Advantages

- Provides an extra boost of force at the beginning of a change to promote faster action
- Provides braking when the object is closing in on the new set point, so it can reduce overshoot and tends to reduce steady-state error

Objectives Completed

- ✓ Understand the concept and characteristics of integral control
- ✓ Understand the concept and characteristics of derivative control