Chapter 4

Controllers and Compensators

CHAPTER HIGHLIGHTS

- *Compensators and Controllers*
- *Series Compensation*
- *Feedback Compensation*
- *Compensators*
- *Lag Compensator*
- *Lead Compensator*
- *Lead – Lag Compensator*
- *Controllers*
- *Proportional Controller*
- *Proportional Plus Integral Controller*
- *Proportional Plus Derivative Controller*
- *Proportional Plus Integral Plus Derivative Controller*

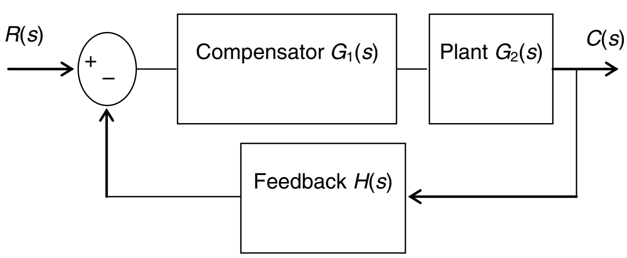
Compensators and Controllers

Every control system is designed for a specific application and to meet certain performance parameters or specifications. System specifications in time domain and/or in frequency domain such as peak overshoot/ settling time, gain margin, phase margin, and so on. A device inserted into the system for the purpose of satisfying the specification is called a compensator.
There are two types of compensation schemes as follows:

1. Series compensation
2. Feedback or parallel compensation

Series Compensation

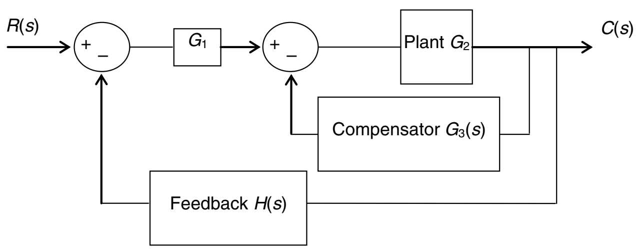
In series compensation, a compensator is introduced in series with the plant to change the system behaviour and to meet the desired specifications.



Block diagram for series compensation

Feedback Compensation

In feedback compensation, a compensator is introduced in the feedback path to meet the desired specifications.



Block diagram of feedback compensation

Compensators

The different types of compensators are as follows:

1. Lag compensator
2. Lead compensator
3. Lead–lag compensator

Lag Compensator

The low-pass filter is known as phase–lag compensator. The ideas to filter and phase shift are useful if designs are carried out in the frequency domain.

The transfer function of a simple lag compensator is given by $\Rightarrow G_c(s) = \dfrac{1+Ts}{1+aTs}$; $a > 1$

Lag compensator improves the steady state behaviour of a system, while transient behaviour remains unchanged.

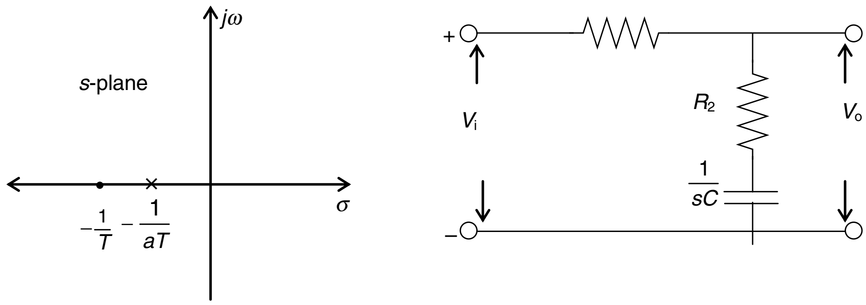


Figure 1 Pole zero configuration of electrical lag compensator.

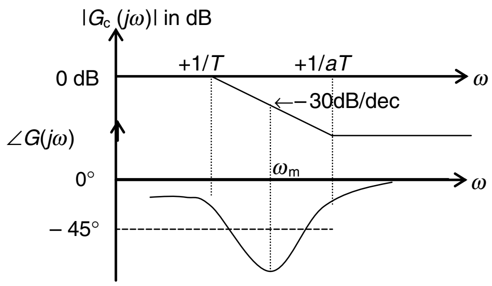


Figure 2 Bode plot of the lag compensator.

The value of phase angle is maximum at a frequency of

$$\omega_m = \sqrt{\omega_{c1} \times \omega_{c2}} = \sqrt{\frac{1}{aT} \times \frac{1}{T}} = \frac{1}{T\sqrt{a}}$$

Therefore, maximum phase angle

$$\angle G(j\omega)\big|_{\omega=\omega_m} = \varphi_m = \tan^{-1}\left(\frac{1-a}{2\sqrt{a}}\right)$$

$$\angle G(j\omega)\big|_{\omega=\omega_m} = \varphi_m = \sin^{-1}\left(\frac{1-a}{1+a}\right)$$

The stability of the system relatively reduces with addition of lag compensator. The gain crossover frequency of the system decreases and thus the bandwidth of the system is reduced. The raise time and settling time of the system are usually longer, because the bandwidth is usually decreased. The system is more sensitive to parameter variations.

Lead Compensator

The high-pass filter is known as phase–lead compensator. These ideas to filter and phase shift are useful if designs are carried in the frequency domain. The transfer function of a simple lead compensator is given by

$$G_c(s) = \frac{1+\zeta s}{1+a\zeta s}\ ;\ a<1$$

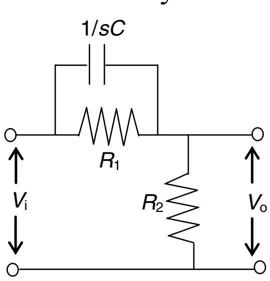


Figure 3 Electrical Lead Compensator.

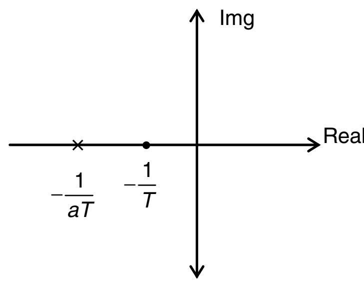


Figure 4 Pole zero configuration of lead compensator.

The value of phase angle is maximum at frequency of

$$\omega_m = \sqrt{\omega_{c1} \times \omega_{c2}} = \frac{1}{T\sqrt{a}}$$

Maximum phase angle $\varphi_m = \tan^{-1}\left(\frac{1-a}{2\sqrt{a}}\right)$.

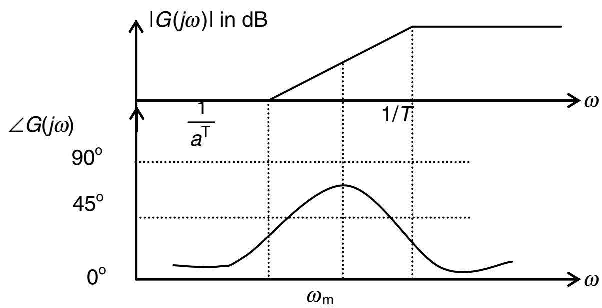


Figure 5 Bode plot of lead compensator.

The lead compensator affects the transient response of the system. It adds damping to the system, and thus, the rise time and settling time are reduced. The gain crossover frequency is increased and improves the phase margin of the closed-loop system. The relative stability of the system is improved with improvement in gain and phase margins.

The bandwidth of the closed-loop system is increased and results in fast response.

The steady-state error of the system is not effected.

Lead–lag Compensator

The combination of lag and lead compensators is used to utilize the advantages of both the schemes. The transfer function of a simple lead–lag compensator is given by

$$G_c(s)=\left(\frac{1+a_1T_1s}{1+T_1s}\right)\left(\frac{1+a_2T_2s}{1+T_2s}\right)(a_1>1, a_2<1)$$

↑ Lead compensator ↑ Lag compensator

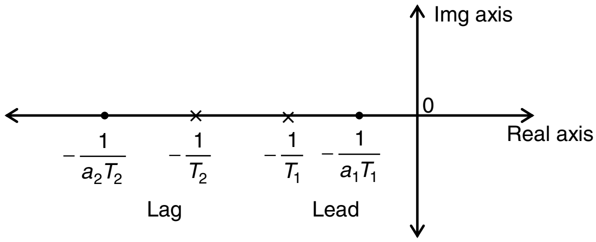


Figure 6 Pole-zero configuration of Lead–lag compensator.

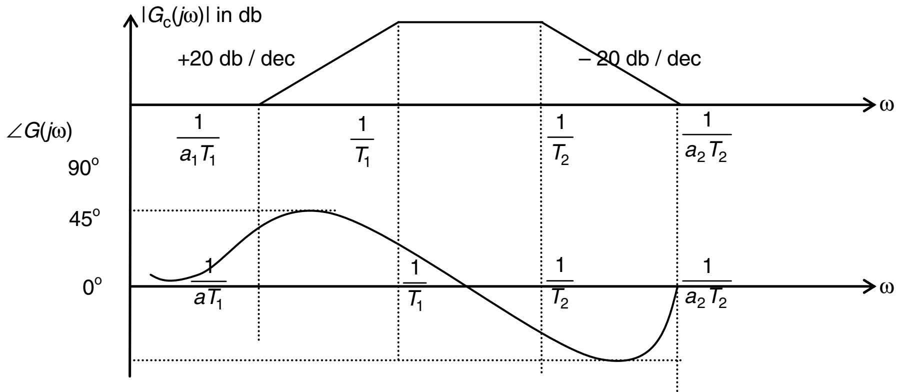


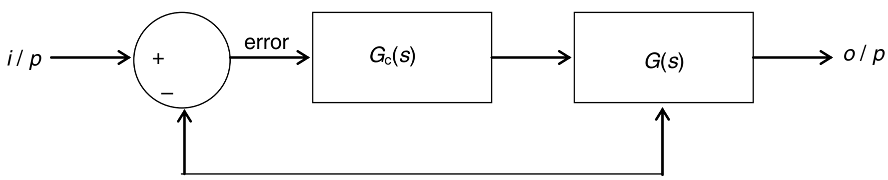
Figure 7 Bode plot of lead-lag compensator.

CONTROLLERS

The cascaded controllers are used to modify the transient and the steady-state response of the system.

The different types of controllers available in control system are given as follows:

1. Proportional controller
2. Proportional plus integral controller (PI–controller)



3. Proportional plus derivative controller (PD–controller)
4. Proportional plus derivative plus integral controller (PID–controller)

Proportional Controller

A controller that produces output proportional to the input signal (error e(t))

Therefore, $u(t) = K_P.e(t)$

where

$u(t)$ = input to the plant

e(t) = Input to the controller

K_P = Gain of the proportional controller

The proportional controller improves the steady-state accuracy, disturbance signal rejection, and relative stability.

It decreases the sensitivity of the system to parameter variation.

The proportional controller is not used alone because it produces a constant steady-state error.

Proportional Plus Integral Controller (PI)

This is a controller that produces output signal $u(t)$ proportional to the input signal (error $e(t)$) and to the integral of input signal.

$$\therefore\ u(t) = K_p\, e(t) + K_i \int e.dt$$

K_p = Proportional controller gain

K_i = Integral controller gain.

The PI controller increases the order and type of the system. It acts as a low pass filter and reduces the steady-state error.

Proportional Plus Derivative Controller (PD)

This is a controller that produces output signal u(t) proportional to the input signal (error e(t) and derivative of the input signal $\left(\frac{de(t)}{dt}\right)$.

$$u(t) = K_p e(t) + K_d \frac{de(t)}{dt}$$

The PD controller increases damping of the system which results in reducing the peak overshoot.

It acts as a high-pass filter and improves gain margin and phase margin.

The PD controller increases bandwidth, reduces rise time, and settling time; hence, system stability is improved.

Proportional Plus Integral Plus Derivative Controller

This is a combination of proportional, integral, and derivative controllers.

$$u(t)=K_p e(t)+K_i\int e(t)\,dt+K_D\frac{de(t)}{dt}$$

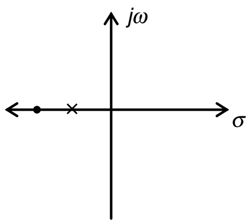
The PID controller decreases the steady state error and increases stability.

Solved Examples

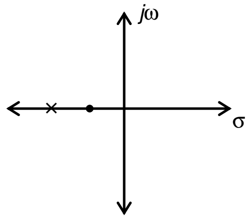
Example 1

The pole zero configuration of a phase lag compensator is given by

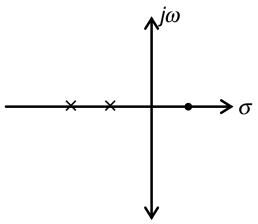
(A)



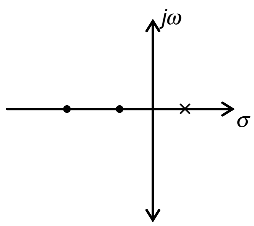
(B)



(C)



(D)



Solution

Lag compensator has a dominant pole with a single pole zero configuration.

Example 2

A lead compensator used for a closed-loop controller has the following transfer function:

$$\frac{k(1+as)}{(1+bs)}$$

For such a lead compensator,

(A) $a < b$ (B) $a > b$ (C) $a > kb$ (D) $a < kb$

Solution

Pole zero value of given compensator are

$$-\frac{1}{a}\text{ and }\frac{-1}{b}$$

For a lead compensator pole is dominating so

$$-\frac{1}{a}>\frac{-1}{b}\Rightarrow\frac{1}{a}<\frac{1}{b}\Rightarrow a>b$$

Example 3

The transfer function of PID controller is given by

(A) $\frac{s}{K_I s^2+K_D s+K_p}$ (B) $\frac{K_D s^2+K_p s+K_I}{s}$

(C) $\frac{s}{K_D s^2+K_p s+K_I}$ (D) $\frac{K_I s^2+K_D s+K_P}{s}$

Solution

The relation between input and output of a PID controller is given by

$$u(t)=K_\text{p}e(t)+K_\text{I}\int e(t)+K_D\frac{de(t)}{dt}$$

Apply Laplace transform on both sides

$$u(s)=\left(K_P+\frac{K_I}{S}+K_D s\right)E(s)$$

$$\frac{u(s)}{E(s)}=\frac{K_D s^2+K_P s+K_I}{S}$$

Example 4

Maximum phase lead of the compensator $D(s)$ is

$$D(s)=\frac{0.4s+1}{0.04s+1}$$

(A) 50° (B) 55°

(C) 60° (D) None of the above

Solution

Compensator $D(s)=\frac{0.4s+1}{0.04s+1}=\frac{1+aTs}{1+Ts}$

$aT = 0.4;\ 0.04 = T$

Therefore, $a = 10$

Maximum phase angle $\varphi_m=\sin^{-1}\left(\frac{a-1}{a+1}\right)=55°$

Example 5

Phase angle of the PID controller at high frequencies is (as frequency tends to infinity)

(A) ∞ (B) 90° (C) –90° (D) 180°

Solution

Transfer function of the PID controller

$$=\frac{K_D s^2+K_P s+K_I}{s}$$

Phase angle of controller

$$=\tan^{-1}\left(\frac{wK_P}{(K_I-w^2K_D)}\right)-\tan^{-1}(w/\infty)$$

$\varnothing = 180° - 90° = 90°$ (as $w\to\infty$)

Example 6

The transfer function of two compensators is given by

$$C_1 = \frac{20(1+s)}{(20+s)}, C_2 = \frac{s+10}{10(s+1)}$$

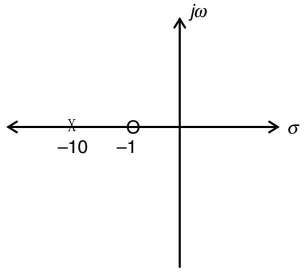
Which of the following statements is correct?

(A) C_1 is a lag compensator and C_2 is a lead compensator.
(B) C_1 is a lead compensator and C_2 is a lag compensator.
(C) Both C_1 and C_2 are lead compensators.
(D) Both C_1 and C_2 are lag compensators.

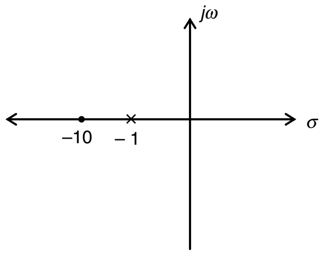
Solution

Compensator $C_1 = \frac{10(s+1)}{(s+10)}$

From pole zero configuration, C_1 is lead compensator.



Compensator $C_2 = \frac{s+10}{10(s+1)}$



From the above pole zero,
Configuration C_2 is lag compensator.

Example 7

The system $\frac{900}{s(s+1)(s+9)}$ is to be such that its gain crossover frequency becomes same as its uncompensated phase crossover frequency and provides 45° phase margin. To achieve this, one may use

(A) A lag–lead compensator that provides an amplification of 20 db and a phase lead of 45° at the frequency of $\sqrt{3}$ rad/sec.
(B) A lag–lead compensator that provides an attenuation of 20 db and phase lead of 45° at a frequency of 3 rad/s.
(C) A lag compensator that provides an attenuation of 20db and a phase angle of 45° at the frequency of $3\sqrt{3}$ rad/s.
(D) A lead compensator that provides an amplification of 20db and a phase lead of 45° at the frequency of 3 rad/s.

Solution

Phase crossover frequency of the system can be calculated as

$$\angle G(j\omega)\big|_{\omega=\omega_{pc}} = -180$$

$$\omega_{pc} = \frac{1}{\sqrt{T_1T_2}} = \frac{1}{\sqrt{1\times\frac{1}{9}}} = 3\,\text{rad/sec}$$

Gain margin of the system (GM)

$$= 20\log\frac{1}{|G(j\omega_{pc})H(j\omega_{pc})|}$$

$$|G(j\omega_{pc})H(j\omega_{pc})| = \left|\frac{900}{s(s+1)(s+9)}\right|$$

$$\left|\frac{900}{\omega\sqrt{(\omega^2+1)}\sqrt{\omega^2+9^2}}\right| = 10$$

$$\text{Gain margin (GM)} = 20\log\frac{1}{|G(j\omega)H(j\omega)|} = 20\text{db}$$

From the given data phase, crossover frequency is equal to gain crossover frequency. For this, we need to make the magnitude of the system at $\omega = \omega_{pc}$ equal to zero. A lag compensator is used to reduce the gain of the system by 20db at $\omega = \omega_{pc}$.

To provide phase margin of 45°, we need to increase the phase angle of the system by 45° which is 0° at $\omega = \omega_{pc}$ 3 rad/s. A lead compensator is used to obtain 45° of phase margin at $\omega = \omega_{pc} = 3$ rad/s.

Exercises

Practice Problems I

Direction for questions 1 to 9: Select the correct alternative from the given choices.

1. Match List–I with List–II and select the correct answer using the codes given below the lists:

List–I
(A) Phase lag controller
(B) Addition of zero at origin
(C) Derivative output compensation
(D) Derivative error compensation

List–II
(1) Improvement in transient response
(2) Reduction in steady-state error
(3) Reduction in settling time
(4) Increase in damping constant

codes

	A	B	C	D
(a)	4	3	1	2
(b)	2	1	3	4
(c)	4	1	3	2
(d)	2	3	1	4

2. The effect of phase lead compensator on gain crossover frequency (ω_{gc}) and on bandwidth (ω_b) is that

(A) both increase
(B) ω_{gc} increases but ω_b decreases
(C) ω_{gc} decreases but ω_b increases
(D) both decrease

Match List–I (circuits) with List–II and select the correct answer using the codes given below the lists for questions (3) and (4).

3. List–I

A.

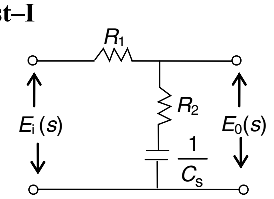


Figure A

B.

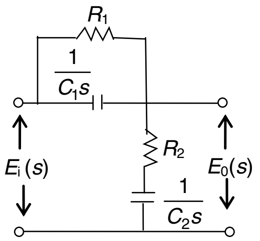


Figure B

C.

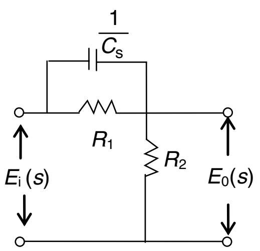


Figure C

List–II

1. Lag network
2. Lead network
3. Lag–lead network

	A	B	C
(A)	1	2	3
(B)	1	3	2
(C)	2	3	1
(D)	2	1	3

4. List–I

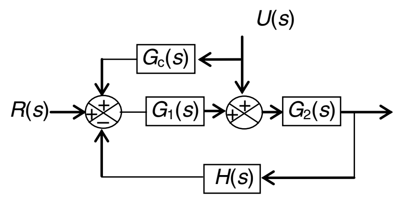


Figure A

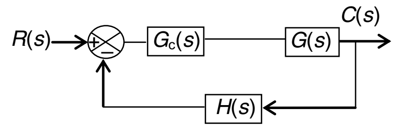


Figure B

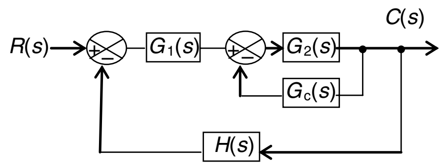


Figure C

List–II

1. Cascade compensation
2. Feedback compensation
3. Feedforward compensation

	A	B	C
(A)	1	2	3
(B)	2	1	3
(C)	2	3	1
(D)	3	1	2

5. Which of the following statements are true?

(i) Adding a zero to the loop transfer function will always decrease the bandwidth of the closed-loop system.
(ii) Adding a pole to the loop transfer function makes the system less stable while decreasing the band width.
(iii) The resonant peak 'M_r' indicates the relative stability of a stable closed-loop system.
(iv) The slope of a magnitude curve of the Bode plot at the gain crossover indicates the relative stability of the closed-loop system.

(A) i and ii
(B) ii, iii, and iv
(C) i and iii
(D) ii and iv

6. Which of the following are effects of phase–lead compensation?

(i) Improves the phase margin of the closed-loop system
(ii) Steady-state error is reduced
(iii) Improves the relative stability
(iv) The rise and settling times are increased

(A) i and ii
(B) ii and iii
(C) i, iii, and iv
(D) i and iii

7. The compensator has the transfer function $G_c(s) = \frac{10(1+0.04s)}{(1+0.01s)}$ the maximum phase–angle lead provided by this compensator will occur at a frequency ω_n equal to

(A) 25 rad/s (B) 50 rad/s
(C) 4 rad/s (D) 10 rad/s

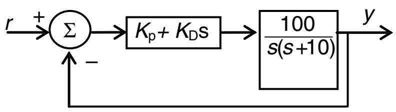
8. Indicate which one of the following transfer functions represent phase–lead compensator?

(A) $\frac{1+0.5s}{1+s}$ (B) $\frac{s+1}{s+2}$

(C) $\frac{6s+3}{6s+2}$ (D) $\frac{s+5}{3s+2}$

9. A control system with a PD controller is shown in the figure. If the velocity error constant $K_v = 1000$ and the damping ratio $\zeta = 0.5$ then the value of K_P and K_D are

(A) $K_P = 100, K_D = 0.09$.
(B) $K_P = 100, K_D = 0.9$.
(C) $K_P = 10, K_D = 0.09$.
(D) $K_P = 10, K_D = 0.9$.



Direction for question 10: The following questions consists of two statements—one assertion and the other reasoning. Select your answer to these questions using the codes given below.

Codes:

10. Assertion(A) Stability of a system deteriorates when integral control is incorporated in it.
Reason (R) With integral control action order of the system increases, and higher the order of the system, the more the system tends to become unstable.

(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

Direction for questions 11 to 18: Select the correct alternative from the given choices.

11. The transfer function $\frac{1+0.4s}{1+s}$ represents a

(A) lag network (B) lead network
(C) lead–lag network (D) None of these

12. The transfer function of a phase–lead compensator is given by $\frac{1+aTs}{1+Ts}$. When a > 1 and $T > 0$. The maximum phase shift provided by such a compensator is

(A) $\tan^{-1}\left(\frac{a-1}{a+1}\right)$ (B) $\tan^{-1}\left(\frac{a+1}{a-1}\right)$

(C) $\sin^{-1}\left(\frac{a-1}{a+1}\right)$ (D) $\sin^{-1}\left(\frac{a+1}{a-1}\right)$

13. Which one of the following is the correct expression for the transfer function of an electrical RC phase–lead compensating network?

(A) $\frac{(1+sT)}{\alpha(1+s\alpha T)}; \alpha < 1$ (B) $\frac{\alpha(1+sT)}{(1+s\alpha T)}; \alpha < 1$

(C) $\frac{\beta(1+sT)}{(1+s\beta T)}; \beta < 1$ (D) $\frac{(1+sT)}{(1+sT\beta)}; \beta > 1$

14. Maximum phase lead of the compensation $D(s) = \frac{(0.5s+1)}{(0.05s+1)}$ is

(A) 55° at 12 rad/s (B) 35° at 10 rad/s
(C) 45° at 4 rad/s (D) 55° at 6.3 rad/s

15. The transfer function of a phase lag compensator is found to be of the form $\frac{s+Z_1}{s+P_1}$ and that of a lead compensator to be of the form $\frac{s+Z_2}{s+P_2}$. Which of the following conditions must be satisfied?

(A) $Z_1 > P_1$ and $Z_2 > P_2$
(B) $Z_1 > P_1$ and $Z_2 < P_2$
(C) $Z_1 < P_1$ and $Z_2 > P_2$
(D) $Z_1 < P_1$ and $Z_2 < P_2$

16. A system gain crossover frequency is less than its phase crossover frequency then

(A) lag–lead compensator which will decrease the gain and increase the phase angle can be used to stabilize the system
(B) lead–lag compensator which will increase the gain and decrease the phase angle can be used to stabilize the system
(C) lead compensator which will increase the gain can stabilize the system
(D) None of the above

17. Match the following:

Transfer function	Type of damping
1. PI controller	P. Improves damping of the system
2. PD controller	Q. Increases band width
3. Lead compensator	R. Decreases band width
4. Lag compensator	S. Decreases steady state error

Codes:

	P	Q	R	S
(A)	2	4	1	3
(B)	3	2	4	1
(C)	2	3	4	1
(D)	3	4	1	2

18. Transfer function of a compensator is given by $\frac{10(s+.001)}{(s+0.1)}$. The compensator offers maximum frequency at

(A) 0.01 rad/s (B) 1 rad/s
(C) 10 rad/s (D) 100 rad/s

Practice Problems 2

Direction for questions 1 to 15: Select the correct alternative from the given choices.

1. Which of the following are the effects of PD control?
 (i) Increases rise time and setting time
 (ii) Improves GM, PM, and M_r
 (iii) Decreases bandwidth
 (iv) Improves damping and reduces maximum over shoot.

(A) i, ii, and iii (B) ii and iv
(C) i, iii, and iv (D) i, and iv

2. Which of the following are effects of PI control?
 (i) Filters out high–frequency noise
 (ii) Increases bandwidth
 (iii) Improves damping and reduces maximum over shoot
 (iv) By proper design PI control can improve transient and the steady-state performances

(A) i, ii, and iii (B) ii and iii
(C) iii and iv (D) i, iii, and iv

3. Phase–lag compensation results in
 (i) increase in gain–crossover frequency
 (ii) reduction of bandwidth
 (iii) more sensitivity
 (iv) improvement of the relative stability

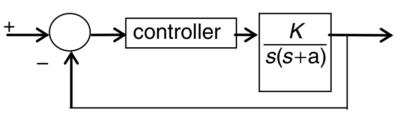
(A) i, ii, and iv (B) ii and iv
(C) ii, iii, and iv (D) iii and iv

4. A double integrator plant $G(s) = \frac{k}{s^2}$, $H(s) = 1$ is to be compensated to achieve the damping ratio $\zeta = 0.5$ and an undamped natural frequency $\omega_n = 5$rad/s. Which one of the following compensator $G_C(s)$ will be suitable?

(A) $\frac{(s+3)}{(s+9.9)}$ (B) $\frac{(s+9.9)}{(s+3)}$

(C) $\frac{(s-6)}{(s+8.33)}$ (D) $\frac{(s+6)}{(s+9.99)}$

5. In the control system shown in the given figure, the controller which can give zero steady–state error to a ramp input, with $k = 9$ is

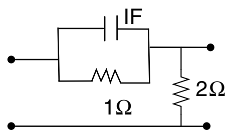


(A) proportional type
(B) integral type
(C) derivative type
(D) PD type

6. The transfer function of a simple RC network functioning as a controller $G_C(s) = \frac{s+z_1}{s+P_1}$ the condition of RC network to act as a phase–lead controller is

(A) $P_1 < z_1$ (B) $P_1 = 0$
(C) $P_1 = z_1$ (D) $P_1 > z_1$

7. For a given phase–lead network, the maximum possible phase–lead is



(A) 90° (B) 45° (C) 30° (D) 15°

8. Consider the following statements: In a feedback control system, lead compensator
 (1) speed up the transient response
 (2) high-frequency gain increases
 (3) bandwidth increases of these statements, which one is correct?

(A) (1) and (2) (B) (1) and (3)
(C) (2) and (3) (D) (1), (2), and (3)

9. The effect of cascade lag compensation on the transient response of a control system can be neutralized by choosing

(A) a slightly higher value of the static position error constant
(B) a slightly higher value of the static velocity error constant
(C) a slightly higher value of damping ratio
(D) a slightly higher value of undamped natural frequency

10. Select the statements regarding the properties of phase–lead compensation.
 (1) It improves phase margin of the closed loop system
 (2) It increases band width of the closed loop system
 (3) It gives slow response.
 Among these, which one is correct?

(A) (1) and (2) (B) (1) and (3)
(C) (2) and (3) (D) (1), (2), and (3)

11. Maximum phase lead of $\dfrac{4(1+0.15s)}{(1+0.05s)}$ is

(A) 45° (B)60° (C) 30° (D) 90°

12. The maximum value of phase lead for which a single stage cascade lead compensator should be designed is

(A) 90° (B) 65° (C) 135° (D) 180°

13. For $G_c(s) = K\dfrac{1+6s}{1+2s}$.

The minimum phase lead and corresponding frequencies are

(A) $45°, \dfrac{1}{2\sqrt{3}}$ (B) $30°, \dfrac{1}{2}$

(C) $30°, \dfrac{1}{2\sqrt{3}}$ (D) $45°, \dfrac{1}{2}$

14. The open loop transfer function of a plant is given as $G(s) = \dfrac{1}{s^2-1}$. If the plant is operated in a unity feedback configuration, then the lead compensator that can stabilize this control system is

(A) $\dfrac{10(s-1)}{s+2}$ (B) $\dfrac{10(s+4)}{s+2}$

(C) $\dfrac{10(s+2)}{s+10}$ (D) $\dfrac{10(s+10)}{s+2}$

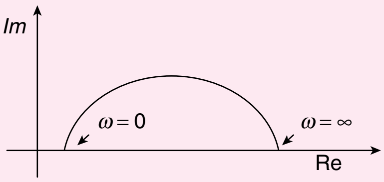
15. The transfer function of a phase–lead compensator is $\dfrac{1+3Ts}{1+Ts}$. The maximum value of phase provided by this compensator is

(A) 90° (B) 60° (C) 45° (D) 30°

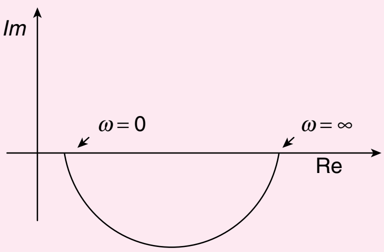
Previous Years' Questions

1. Which one of the following polar diagrams corresponds to a lag network? **[2005]**

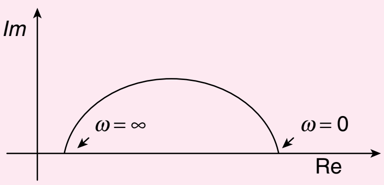
(A)



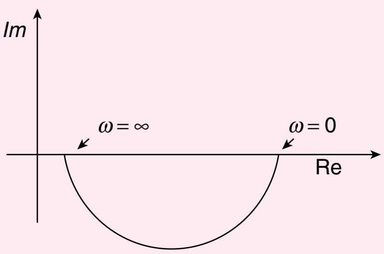
(B)



(C)



(D)

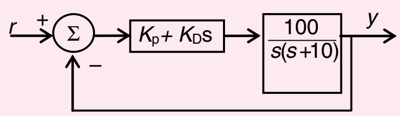


2. A double integrator plant, $G(s) = \dfrac{K}{s^2}, H(S) = 1$ is to be compensated to achieve the damping ratio ξ = 0.5, and an undamped natural frequency, ω_n = 5 rad/s. which one of the following compensator G_c(s) will be suitable? **[2005]**

(A) $\dfrac{s+3}{s+9.9}$ (B) $\dfrac{s+9.9}{s+3}$

(C) $\dfrac{s-6}{s+8.33}$ (D) $\dfrac{s+6}{s}$

3. A control system with a PD controller is shown in the figure, if the velocity error constant K_V = 1000



and the damping ratio ξ= 0.5 , then the values of K_P and K_D are **[2007]**

(A) $K_P = 100, K_D = 0.09$ (B) $K_P = 100, K_D = 0.9$

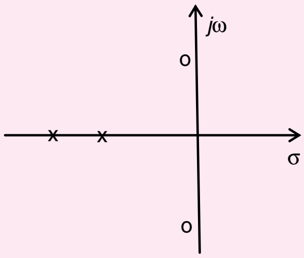
(C) $K_P = 10, K_D = 0.09$ (D) $K_P = 10, K_D = 0.9$

4. The open–loop transfer function of a plant is given as $G(s) = \dfrac{1}{s^2-1}$. If the plant is operated in a unity feedback configuration, then the lead compensator that can stabilize this control system is **[2007]**

(A) $\dfrac{10(s-1)}{s+2}$ (B) $\dfrac{10(s+4)}{s+2}$

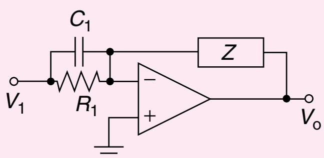
(C) $\dfrac{10(s+2)}{s+10}$ (D) $\dfrac{2(s+2)}{s+10}$

5. The pole-zero plot given below corresponds to a: **[2008]**



(A) Low-pass filter (B) High-pass filter
(C) Band-pass filter (D) Notch filter

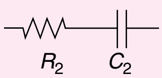
6. Group 1 gives two possible choices for the impedance Z in the diagram. The circuit elements in Z satisfy the condition $R_2C_2 > R_1C_1$. The transfer function $\frac{V_0}{V_1}$ represents a kind of controller. Match the impedances in Group I with the types of controllers in Group II. **[2008]**



Group I

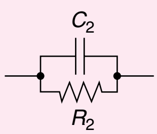
Group II

Q



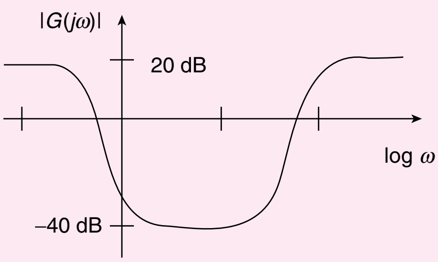
1. PID controller
2. Lead compensato
3. Lag compensator

R



(A) Q–1, R–2 (B) Q–1, R–3
(C) Q–2, R–3 (D) Q–3, R–2

7. The magnitude plot of a rational transfer function $G(s)$ with real coefficients is shown below. Which of the following compensators has such a magnitude plot? **[2009]**



(A) Lead compensator
(B) Lag compensator
(C) PID compensator
(D) Lead–lag compensator

Direction for questions 8 and 9:

The transfer function of a compensator is given as

$$G_c(s) = \frac{s+a}{s+b}$$

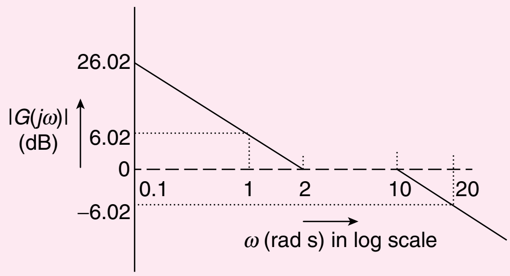
8. $G_c(s)$ is a lead compensator if **[2012]**

(A) $a = 1, b = 2$
(B) $a = 3, b = 2$
(C) $a = -3, b = -1$
(D) $a = 3, b = 1$

9. The phase of the above lead compensator is maximum at **[2012]**

(A) $\sqrt{2}$ rad/s (B) $\sqrt{3}$ rad/s
(C) $\sqrt{6}$ rad/s (D) $1/\sqrt{3}$ rad/s

10. The Bode asymptotic magnitude plot of a minimum phase system is shown in the figure.



If the system is connected in a unity negative feedback configuration, the steady-state error of the closed loop system, to a unit ramp input, is __________. **[2014]**

11. The transfer function of a first-order controller is given as

$$G_c(s) = \frac{K(s+a)}{s+b}$$

where K, a, and b are positive real numbers. The condition for this controller to act as a phase lead compensator is **[2015]**

(A) $a < b$ (B) $a > b$
(C) $K < ab$ (D) $K > ab$

Answer Keys

Exercises

Practice Problems 1

1. B **2.** A **3.** B **4.** D **5.** B **6.** D **7.** B **8.** B **9.** B **10.** A
11. A **12.** C **13.** B **14.** D **15.** B **16.** A **17.** C **18.** A

Practice Problems 2

1. B **2.** D **3.** C **4.** A **5.** B **6.** D **7.** C **8.** D **9.** D **10.** A
11. C **12.** B **13.** C **14.** A **15.** D

Previous Years' Questions

1. D **2.** A **3.** B **4.** A **5.** D **6.** B **7.** C **8.** A **9.** A
10. 0.49 to 0.51 **11.** A