ESE 2020
UPSC ENGINEERING SERVICES EXAMINATION
Preliminary Examination

Electrical Engineering
Topicwise Objective Solved Questions
Volume-II

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ESE-2020 : Preliminary Examination

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Engineering is one of the most chosen graduating field. Taking engineering is usually a matter of interest but this eventually develops into “purpose of being an engineer” when you choose engineering services as a carrier option.

Train goes in tunnel we don’t panic but sit still and trust the engineer, even we don’t doubt on signalling system, we don’t think twice crossing over a bridge reducing our travel time; every engineer has a purpose in his department which when coupled with his unique talent provides service to mankind.

I believe “the educator must realize in the potential power of his pupil and he must employ all his art, in seeking to bring his pupil to experience this power”. To support dreams of every engineer and to make efficient use of capabilities of aspirant, MADE EASY team has put sincere efforts in compiling all the previous years’ ESE-Pre questions with accurate and detailed explanation. The objective of this book is to facilitate every aspirant in ESE preparation and so, questions are segregated chapterwise and topicwise to enable the student to do topicwise preparation and strengthen the concept as and when they are read.

I would like to acknowledge efforts of entire MADE EASY team who worked hard to solve previous years’ papers with accuracy and I hope this book will stand up to the expectations of aspirants and my desire to serve student fraternity by providing best study material and quality guidance will get accomplished.

B. Singh (Ex. IES)  
CMD, MADE EASY Group
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### Electrical Engineering Volume-II

**Objective Solved Questions**

of UPSC Engineering Services Examination

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Control Systems

Syllabus
Principles of feedback, transfer function, block diagrams and signal flow graphs, steady-state errors, transforms and their applications; Routh-hurwitz criterion, Nyquist techniques, Bode plots, root loci, lag, lead and lead-lag compensation, stability analysis, transient and frequency response analysis, state space model, state transition matrix, controllability and observability, linear state variable feedback, PID and industrial controllers.

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</table>
1.1 Match List-I (Physical action or activity) with List-II (Category of system) and select the correct answer.

**List-I**
- Human respiration system
- Pointing of an object with a finger
- A man driving a car
- A thermostatically controlled room heater

**List-II**
- Man-made control system
- Natural including biological control system
- Control system whose components are both man-made and natural

**Codes:**
- A: 2
- B: 1
- C: 3
- D: 1

(a) 2 2 3 1 1
(b) 3 1 2 1
(c) 3 2 2 3
(d) 2 1 3 3

[**ESE-2001**]

1.2 The mechanical system is shown in the given figure

![Mechanical System Diagram](image)

The system is described as:

(a) \( M \frac{d^2y_1(t)}{dt^2} + B \frac{dy_1(t)}{dt} = k[y_2(t) - y_1(t)] + f(t) \)

(b) \( M \frac{d^2y_2(t)}{dt^2} + B \frac{dy_2(t)}{dt} = k[y_1(t) - y_2(t)] + f(t) \)

(c) \( M \frac{d^2y_3(t)}{dt^2} + B \frac{dy_3(t)}{dt} = k[y_1(t) - y_2(t)] + f(t) \)

(d) \( M \frac{d^2y_4(t)}{dt^2} + B \frac{dy_4(t)}{dt} = k[y_1(t) - y_2(t)] + f(t) \)

[**ESE-2001**]

1.3 Select the correct transfer function \( V_o(s)/V_i(s) \) from the following for the given network.

![Transfer Function Network](image)

(a) \( \frac{2}{s(s+1)} \)
(b) \( \frac{s}{(s+2)} \)
(c) \( \frac{s}{2s+1} \)
(d) \( \frac{2s}{s+1} \)

[**ESE-2002**]

1.4 Consider the following diagram:

![Multiple Gear System Diagram](image)

For the multiple gear system shown above, which one of the following gives the equivalent inertia referred to shaft 1?

(a) \( J_1 + J_2 \left( \frac{N_1}{N_2} \right)^2 + J_3 \left( \frac{N_2N_3}{N_2N_4} \right)^2 \)

(b) \( J_1 + J_2 \left( \frac{N_2}{N_1} \right)^2 + J_3 \left( \frac{N_2N_3}{N_2N_4} \right)^2 \)

(c) \( J_1 + J_2 \left( \frac{N_1}{N_2} \right)^2 + J_3 \left( \frac{N_2N_3}{N_2N_4} \right)^2 \)

(d) \( J_1 + J_2 \left( \frac{N_1}{N_2} \right)^2 + J_3 \left( \frac{N_2N_3}{N_2N_4} \right)^2 \)

[**ESE-2004**]
1.5 Consider the following mechanical system shown in the diagram:

Which one of the following circuits shows the correct force-current analogous electrical circuit for the mechanical diagram shown above?

1.7 The transfer function for the diagram shown below is given by which one of the following?

\[
\frac{1}{1 + sRC}
\]

(a) \( \frac{1}{1 + sRC} \)  
(b) \( \frac{sRC}{1 + sRC} \)  
(c) \( \frac{sRC}{1 - sRC} \)  
(d) \( 1 + sRC \)

[ESE-2008]

1.8 What does the function \( f(t) \) plotted in the below figure represent?

(a) Unit step function  
(b) Unit impulse function  
(c) Unit ramp function  
(d) Unit parabolic function

[ESE-2008]

1.9 A mechanical system is as shown in the figure below. The system is set into motion by applying a unit impulse force \( \delta(t) \). Assuming that the system is initially at rest and ignoring friction, what is the displacement \( x(t) \) of mass?

\[
\frac{1}{\sqrt{k}} \exp(-m \cdot t) \quad \frac{1}{\sqrt{mk}} \sin(t)  
\]

(a) \( \frac{1}{\sqrt{k}} \exp(-m \cdot t) \)  
(b) \( \frac{1}{\sqrt{mk}} \sin(t) \) 
(c) \( \frac{1}{\sqrt{mk}} \sin(\sqrt{\frac{k}{m} \cdot t}) \)  
(d) \( \frac{1}{\sqrt{mk}} \left( \frac{k}{m} \cdot t \right) \)

[ESE-2009]

1.10 Which one of the following is the correct free body diagram for the physical system as shown in the figure below?

\[
y_1(t) \quad y_2(t) \quad y_3(t) \quad y_4(t) \quad y_5(t) \quad y_6(t) \quad y_7(t) \quad y_8(t) \]

[Zero friction]

(a) 2 hours  
(b) 1/2 hours  
(c) 1 hours  
(d) 1/4 hours

[ESE-2005]
1.11 For the mechanical system with mass and viscous friction components, shown in figure, \( \frac{X_2(s)}{X_1(s)} \) is

(a) \( \frac{B_2}{Ms + B_1 + B_2} \)  
(b) \( \frac{1}{Ms + (B_1 + B_2)} \)  
(c) \( \frac{B_1}{Ms + B_1 + B_2} \)  
(d) None of these

1.13 Consider the following relations with regard to the below shown gear trains:

1. \( \frac{\theta_1}{\theta_2} = \frac{N_2}{N_1} \)
2. \( T_2 = J_2 \frac{d^2 \theta_2}{dt^2} + B_2 \frac{d \theta_2}{dt} \)
3. \( T_1 = J_2 \left( \frac{N_1}{N_2} \right)^2 \frac{d^2 \theta_1}{dt^2} + B_2 \left( \frac{N_1}{N_2} \right)^2 \frac{d \theta_1}{dt} \)

Which of these relations are correct?
(a) 1, 2 and 3  
(b) 1 and 2 only  
(c) 2 and 3 only  
(d) 1 and 3 only

1.14 The law/principle in mechanical systems, analogous to Kirchhoff’s laws in electrical systems, is
(a) first law of motion  
(b) second law of motion  
(c) third law of motion  
(d) d’Alembert’s principle

1.15 Match List-I (Mechanical translation system) with List-II (Electrical element for analogous) and select the correct answer using the code given below the lists:

<table>
<thead>
<tr>
<th>List-I</th>
<th>List-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Mass</td>
<td>1. Capacitor</td>
</tr>
<tr>
<td>B. Damper</td>
<td>2. Voltage</td>
</tr>
<tr>
<td>C. Spring</td>
<td>3. Resistor</td>
</tr>
<tr>
<td>D. Force</td>
<td>4. Inductor</td>
</tr>
</tbody>
</table>

Codes:
(a) 2 1 3 4  
(b) 4 1 3 2  
(c) 2 3 1 4  
(d) 4 3 1 2

1.12 Match List-I with List-II and select the correct answer using the code given below the lists:

<table>
<thead>
<tr>
<th>List-I</th>
<th>List-II</th>
</tr>
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<tbody>
<tr>
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<td>C. Spring</td>
<td>3. Resistor</td>
</tr>
<tr>
<td>D. Force</td>
<td>4. Inductor</td>
</tr>
</tbody>
</table>

Codes:
(a) 2 1 3 4  
(b) 4 1 3 2  
(c) 2 3 1 4  
(d) 4 3 1 2
1.16 When deriving the transfer function of a linear element
(a) both initial conditions and loading are taken into account
(b) initial conditions are taken into account but the element is assumed to be not loaded.
(c) initial conditions are assumed to be zero but loading is taken into account
(d) initial conditions are assumed to be zero and the element is assumed to be not loaded.

[ESE-2013]

1.17 An open loop T.F. of a unity feedback system is given by
\[ G(s) = \frac{1}{(s+2)^2} \]
The closed loop transfer function will have poles at
(a) \(-2, -2\)
(b) \(-2, -1\)
(c) \(-2 + j, -2 - j\)
(d) \(-2, 2\)

[ESE-2013]

1.18 A transfer function has its zero in the right half of the s-plane. The function
(a) is positive real
(b) is minimum phase
(c) will give stable impulse response
(d) is non-minimum phase

[ESE-2013]

1.19 The transfer function of the network shown below is
\[ \frac{1}{s^2T^2 + 2sT + 1} \]
(a) \( \frac{1}{s^2T^2 + 2sT + 1} \)
(b) \( \frac{1}{s^2T^2 + 3sT + 1} \)
(c) \( \frac{1}{s^2T^2 + sT + 1} \)
(d) \( \frac{1}{s^2T^2 + sT + 1} \)

[ESE-2013]

1.20 Statement (I): Servo motors have small diameter and large axial length.
Statement (II): Servo motors must have low inertia and high starting torque.

Codes:
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

1.21 The transfer function of a low-pass RC network is
\[ \frac{RC}{1 + RC} \]
(a) \( \frac{RC}{1 + RC} \)
(b) \( \frac{1}{1 + RC} \)
(c) \( \frac{s}{1 + RC} \)
(d) \( \frac{1}{1 + RC} \)

[ESE-2014]

1.22 The transfer function of the circuit as shown in the figure is expressed as
\[ \frac{V_o}{V_i} = \frac{R}{1 + sCR} \]
(a) \( \frac{R}{1 + sRC} \)
(b) \( \frac{s}{1 + sCR} \)
(c) \( \frac{1}{1 + sRC} \)
(d) \( 1 + sCR \)

[ESE-2015]

1.23 The servomotor differs from the standard motors principally in that, it has
(a) entirely different construction
(b) high inertia and hence high torque
(c) low inertia and low torque
(d) low inertia and higher starting torque

1.24 The desirable features of a servomotor are
(a) low rotor inertia and low bearing friction
(b) high rotor inertia and high bearing friction
(c) low rotor inertia and high bearing friction
(d) high rotor inertia and low bearing friction

[ESE-2016]
1.3 (c)
Applying nodal analysis
\[ V_1 - V_o = V_o + \frac{V_o}{s} \]
\[ V_1 = 2V_o + \frac{V_o}{s} \]
\[ V_1 = V_o \left( \frac{2s + 1}{s} \right) \]
\[ \therefore \frac{V_o}{V_1} = \frac{s}{2s + 1} \]

1.6 (b)
31.6 = (1 - e^{-\alpha t})
\[ \Rightarrow \tau = \frac{1}{2} \text{ hour} \]

1.7 (b)
T.F. = \[ \frac{V_o}{V_i} = \frac{R}{R + \frac{1}{Cs}} = \frac{RCs}{1 + RCs} \]

1.9 (c)
\[ \delta(t) = \frac{m a^2 x(t)}{dt^2} + k x(t) \]
Taking laplace transform
\[ 1 = ms^2 X(s) + k [X(s)] \]
\[ \therefore X(s) = \frac{1}{ms^2 + k} \]
\[ X(s) = \frac{1}{m \left[ s^2 + \frac{k}{m} \right]} \]
\[ X(t) = \frac{1}{\sqrt{mk}} \sin \left( \frac{k}{\sqrt{m}} t \right) \]

1.12 (d)
Voltage analogy
\[ \frac{X_o(s)}{X_i(s)} = \frac{B_s}{Ms^2 + (B_1 + B_2)s} \]
\[ = \frac{B_1}{Ms + B_1 + B_2} \]

Current analogy

<table>
<thead>
<tr>
<th>Force</th>
<th>Voltage</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>Inductor</td>
<td>Capacitor</td>
</tr>
<tr>
<td>Spring</td>
<td>1/C</td>
<td>1/L</td>
</tr>
<tr>
<td>Damper</td>
<td>R</td>
<td>1/R</td>
</tr>
</tbody>
</table>

Hence, option (d) is correct.

1.13 (a)
Number of teeth is proportional to the radius
\[ \frac{r_1}{r_2} = \frac{N_1}{N_2} \]
Distance travelled on the surface of the gear is the same for both \[ r_1, \theta_1 = r_2, \theta_2 \Rightarrow \frac{r_1}{r_2} = \frac{\theta_2}{\theta_1} \].

Work done by one gear is equal to the other
\[ T_1, \theta_1 = T_2, \theta_2 \Rightarrow \frac{T_1}{T_2} = \frac{\theta_2}{\theta_1} \]

Combining, \[ \frac{T_1}{T_2} = \frac{\theta_2}{\theta_1} = \frac{N_1}{N_2} = \frac{r_1}{r_2} = \frac{\omega_2}{\omega_1} \]
Torque on one gear can be transferred to other gear similar to transformer’s transferred impedance with ratio \[ N_1/N_2 \].
Hence, option (a) is correct.

1.14 (d)
D’Alembert’s principle for the translational mechanical system is as follows:
The algebraic sum of the externally applied forces on a given body and the force resisting the motion of the body in a given direction is zero.
1.15 (d)
By comparing displacement with charge, we came to know that it is force voltage analogy, mass is analogous to inductor, damper to resistor, spring to capacitor and displacement to charge.

1.16 (d)
While deriving the transfer function of a linear element only initial conditions are assumed to be zero, whereas it is independent of loading condition.

1.17 (c)
\[ \text{OLTF} = \frac{G(s)}{1+G(s)H(s)} = \frac{1}{(s+2)^2} \]
For unity feedback system, \( H(s) = 1 \)

\[ \therefore \text{CLTF} = \frac{G(s)}{1+G(s)H(s)} = \frac{1}{1+(s+2)^2} \]

\[ = \frac{1}{s^2+4s+5} \]
\[ \therefore \text{Closed loop poles will be the roots of } \]
\[ s^2 + 4s + 5 = 0 \]
\[ \text{i.e. } s = -2 + j \text{ and } -2 - j \]

1.18 (d)
Non-minimum phase functions have their zeros in the right half of the s-plane.

1.19 (b)
\[ E_o(s) = \frac{1}{sC} I(s) \quad \cdots \text{(i)} \]

\[ I(s) = \frac{E_i(s)}{R + \frac{1}{sC}} \times \frac{1}{sC} \]
\[ \quad \frac{1}{sC + R} \]

1.21 (b)

1.22 (c)

(Using current division rule)
2.1 Consider the following block diagrams:

1. \[ R(s) \xrightarrow{G_1} C(s) \]
2. \[ R(s) \xrightarrow{G_1} C(s) \]
3. \[ R(s) \xrightarrow{1/G_2} G_2 \xrightarrow{1/G_3} C(s) \]
4. \[ R(s) \xrightarrow{1/G_2} G_2 \xrightarrow{1/G_3} C(s) \]

Which of these block diagrams can be reduced to the transfer function \( \frac{C(s)}{R(s)} = \frac{G_1}{1 - G_1 G_2} \)?

(a) 1 and 3  
(b) 2 and 4  
(c) 1 and 4  
(d) 2 and 3  

[ESE-2001]

2.2 In the feedback system \( C(s) \), \( R(s) \) and \( D(s) \) are the system output, input and disturbance, respectively.

\[ R(s) \xrightarrow{G(s)} C(s) \]

Assertion (A): For system \( \frac{C(s)}{R(s) + D(s)} = \frac{H(s)}{1 + G(s) H(s)} \)

Reason (R): Transfer function of a system is defined as the ratio of output Laplace transform and input Laplace transform setting other inputs and the initial conditions to zero.

(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  

[ESE-2001]

2.3 Which of the following are the characteristics of closed loop systems?
1. It does not compensate for disturbances.  
2. It reduces the sensitivity of plant-parameter variations.  
3. It does not involve output measurements.  
4. It has the ability to control the system transient response.

Select the correct answer using the codes given below:
(a) 1 and 4  
(b) 2 and 4  
(c) 1 and 3  
(d) 2 and 3  

[ESE-2002]

2.4 Match List-I (Property) with List-II (Specification) and select the correct answer:

<table>
<thead>
<tr>
<th>List-I</th>
<th>List-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Relative stability</td>
<td>1. Rise time</td>
</tr>
<tr>
<td>B. Speed of response</td>
<td>2. Velocity error constant</td>
</tr>
<tr>
<td>C. Accuracy</td>
<td>3. Return difference</td>
</tr>
<tr>
<td>D. Sensitivity</td>
<td>4. M-peak</td>
</tr>
</tbody>
</table>

Codes:
(a) \( 4 \quad 3 \quad 2 \quad 1 \)  
(b) \( 2 \quad 1 \quad 4 \quad 3 \)  
(c) \( 4 \quad 1 \quad 2 \quad 3 \)  
(d) \( 2 \quad 3 \quad 4 \quad 1 \)  

[ESE-2002]

2.5 The number of forward paths and the number of non-touching loop pairs for the signal flow graph given in the figure below are, respectively.
2.6 Match List-I (Block Diagram) with List-II (Transformed Block Diagram) and select the correct answer:

**List-I**

A. \[ R \xrightarrow{G} C \]

B. \[ R \xrightarrow{G} C \]

C. \[ R \xrightarrow{G} C \]

D. \[ R \xrightarrow{G} C \]

**List-II**

1. \[ R \xrightarrow{G} C \]

2. \[ R \xrightarrow{G} C \]

3. \[ R \xrightarrow{G} C \]

4. \[ R \xrightarrow{G} C \]

**Codes:**

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

2.8 The overall gain \( \frac{C(s)}{R(s)} \) of the block diagram shown below is

\[
\begin{align*}
\frac{G_1 G_2}{1 - G_1 G_2 H_1 H_2} \\
\frac{G_1 G_2}{1 - G_2 H_2 - G_1 G_2 H_1} \\
\frac{G_1 G_2}{1 - G_2 H_2 + G_1 G_2 H_1 H_2} \\
\frac{G_1 G_2}{1 - G_2 H_1 - G_1 G_2 H_2}
\end{align*}
\]

2.9 Which one of the following effects in the system is NOT caused by negative feedback?

(a) Reduction in gain
(b) Increase in bandwidth
(c) Increase in distortion
(d) Reduction in output impedance

2.10 The signal flow graph for a certain feedback control system is given below:

\[ a_1 \xrightarrow{G_1} a_2 \xrightarrow{G_2} a_3 \xrightarrow{G_3} a_4 \xrightarrow{G_4} a_5 \]

Now consider the following set of equations for the nodes:

1. \( x_1 = a_1 x_1 + a_2 x_3 \)
2. \( x_2 = a_2 x_2 + a_3 x_4 \)
3. \( x_4 = a_3 x_3 + a_5 x_4 \)
4. \( x_5 = a_4 x_4 + a_6 x_2 \)

Which of the above equations are correct?

(a) 1, 2 and 3
(b) 1, 3 and 4
(c) 2, 3 and 4
(d) 1, 2 and 4
Answers: Block Diagram, Signal Flow Graph and Feedback Characteristics of Control Systems

2.1 (b)  2.2 (a)  2.3 (b)  2.4 (c)  2.5 (c)  2.6 (c)  2.7 (b)  2.8 (c)  2.9 (c)
2.10 (d)  2.11 (d)  2.12 (b)  2.13 (a)  2.14 (a)  2.15 (a)  2.16 (a)  2.17 (d)  2.18 (a)
2.19 (b)  2.20 (b)  2.21 (a)  2.22 (a)  2.23 (b)  2.24 (d)  2.25 (a)  2.26 (b)  2.27 (a)
2.28 (b)  2.29 (a)  2.30 (b)  2.31 (d)  2.32 (b)  2.33 (d)  2.34 (c)  2.35 (a)  2.36 (b)
2.37 (d)  2.38 (d)  2.39 (d)  2.40 (d)  2.41 (c)  2.42 (c)  2.43 (c)  2.44 (d)  2.45 (b)

Explanations: Block Diagram, Signal Flow Graph and Feedback Characteristics of Control Systems

2.2 (a)
Transfer function is defined for linear systems, so superposition principle is applicable.

2.5 (c)
Forward path = adfl, efl, ahll
Non touching loop pairs = (fg and b) one pair only.

2.7 (b)
P = G_{1}G_{2}; P_{2} = G_{2}G_{3}; \Delta_{1} = \Delta_{2} = 1
L_{1} = -G_{1}G_{2}H_{1}; L_{2} = G_{4}; L_{3} = -G_{3}G_{2}H_{1}
\therefore T(s) = \frac{P_{1}\Delta_{1} + P_{2}\Delta_{2}}{1 - (L_{1} + L_{2} + L_{3})}
= \frac{G_{1}G_{2}G_{2} + G_{2}G_{3}}{1 + G_{2}G_{2}H_{1} + G_{2}G_{2}H_{1} - G_{4}}

2.8 (c)
Making signal flow graph

2.16 (a)
Speed of response is proportional to the bandwidth of the system. Higher the bandwidth faster the response.

2.18 (a)
Solving positive feedback
\[ T_{F} = \frac{G}{1 - GF} \]
Now solving negative feedback path
\[ T_{F1} = \frac{G}{1 + GF} \]
\[ T_{F2} = \frac{G}{1 - GF + GH} \]

2.20 (b)
Only one loop and two path so using Mason's gain formula.
\[ C(s) = \frac{1 + s \cdot a}{1 - (-bs^{-1})} = \frac{1 + \frac{a}{s}}{1 + \frac{b}{s}} = \frac{s + a}{s + b} \]

2.21 (a)
Making signal flow graph

2.11 (d)
Block diagram 'B' can be obtained from 'A' and 'C' can be obtained from 'B'.

2.13 (a)
\[ T(s) = (G_{1} + G_{2}) \frac{G_{2}}{1 + G_{2}H_{1}} = \frac{G_{1}G_{2} + G_{2}G_{3}}{1 + G_{2}H_{1}} \]
2.22 (a)

B.W. = \frac{0.35}{\text{Rise time}}

2.23 (b)

\[ E = RQ - C \]

Which is satisfied by option (b).

2.24 (d)

\[ C = R \left( \frac{G}{1+GH} \right) \]

Which is satisfied by option (d).

\[ C = \frac{R}{H} \left( \frac{GH}{1+GH} \right) = R \left( \frac{G}{1+GH} \right) \]

2.25 (a)

\[ \frac{C(s)}{R(s)} = \frac{k}{s+1} = \frac{k+s+1}{s+1} \]

Comparing with \[ \frac{C(s)}{R(s)} = \frac{s+2}{s+1} \]

\[ \therefore \quad k = 1 \]

2.26 (b)

Negative feedback increases stability but not positive feedback.

2.27 (a)

Transfer function = \[ \frac{P_1 \Delta_1}{\Delta} = \frac{G_1 G_2}{1-(G_1 H_1 + G_2 H_2)} \]

Hence, option (a) is correct.

2.28 (b)

\[ \frac{C(s)}{R(s)} = \frac{P_1 \Delta_1 + P_2 \Delta_2}{\Delta} = \frac{G + H_2}{1-(G H_1)} \]

Hence, option (b) is correct.

2.29 (a)

\[ \text{Transfer function} = \frac{G_1 G_2}{1 + G_1 G_2 (1 + H_1)} \]

Hence, option (a) is correct.

2.30 (b)

\[ \frac{C}{R} = \frac{P_1 \Delta_1 + P_2 \Delta_2 + P_3 \Delta_3}{\Delta} = \frac{5 \times 4 + 2 \times 4 + 3 \times 4}{1 - (5 \times 4 \times 2 - 2 \times 4 \times 2 - 3 \times 4 \times 2)} \]

\[ \Rightarrow \quad \frac{C}{R} = \frac{40}{81} \]

Hence, option (b) is correct.

2.31 (d)

\[ M(s) = \frac{G(s)}{1 + G(s) H(s)} = \frac{G}{1 + GH} \] ...(i)

\[ S_{G M} = \frac{M}{G} \left( \frac{\partial M}{\partial G} \right) \] ...(ii)

Differentiating equation (i) w.r.t. G:

\[ \frac{\partial M}{\partial G} = \frac{1 + GH - GH}{(1 + GH)^2} = \frac{1}{(1 + GH)^2} \]

Equation (ii) becomes:

\[ S_{G M} = \frac{G}{G} \times \frac{1}{1 + GH} = \frac{1}{1 + GH} \]

2.33 (d)

Closed-loop transfer function,

\[ M(s) = \frac{G(s)}{1 + G(s) H(s)} = \frac{1}{s^2 + 4s + 5} \]

Closed-loop poles = \(-2 \pm \sqrt{4-5} = -2 \pm j1\)

2.34 (c)

Statement 4 is correct because sensitivity of closed loop negative feedback control system is less than sensitivity of open loop control system.
4.1 **Assertion (A):** For a system to be stable, all coefficients of the characteristic polynomial must be positive.

**Reason (R):** All positive coefficients of the characteristic polynomial of a system is a sufficient condition for stability.
(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  

[ESE-2001]

4.2 The closed loop system shown below becomes marginally stable if the constant K is chosen to be

\[ K \frac{1}{s(s+1)(s+5)} \]

(a) 10  (b) 20  (c) 30  (d) 40  

[ESE-2002]

4.3 The characteristic equation of a system is given by \(3s^4 \ + \ 10s^3 \ + \ 5s^2 \ + \ 2 = 0\). This system is
(a) stable  (b) marginally stable  (c) unstable  (d) neither (a), (b) nor (c)

[ESE-2002]

4.4 **Assertion (A):** Relative stability of a system reduces due to the presence of transportation lag.

**Reason (R):** Transportation lag can be conveniently handled by Bode plot.
(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

[ESE-2002]

4.5 **Assertion (A):** Stability of a system deteriorates when integral control is incorporated in it.

**Reason (R):** With integral control 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

[ESE-2003]

4.6 A control system is defined in s-domain.
Following points regarding the poles of the transfer function obtained from the characteristic equation were noted:
1. Poles with positive real part denote stable system
2. Complex poles always occur in pairs
3. A pole \(s = -\sigma (\sigma > 0)\) means that the transient response contains exponential decay.
Which of the above are correct?
(a) 1 and 2  (b) 1 and 3  (c) 2 and 3  (d) 1, 2 and 3

[ESE-2004]

4.7 The characteristic equation for a third-order system is \(q(s) = a_3s^3 + a_2s^2 + a_1s + a_0 = 0\).
For the third-order system to be stable, besides that all the coefficients have to be positive, which one of the following has to be satisfied as a necessary and sufficient condition?
(a) \(a_3a_2 > a_2a_3\)  (b) \(a_1a_2 > a_0a_3\)
(c) \(a_2a_3 > a_1a_3\)  (d) \(a_0a_3 > a_1a_2\)

[ESE-2004]

4.8 For which of the following values of \(k\), the feedback system shown in the below figure is stable?
4.9 Consider the following equation:
\[ 2s^4 + s^3 + 3s^2 + 5s + 10 = 0 \]
How many roots does this equation have in the right half of s-plane?
(a) One  (b) Two  (c) Three  (d) Four

4.10 **Assertion (A):** For a stable feedback control system, the zeros of the characteristic equation must all be located in the left half of the s-plane.

**Reason (R):** The poles of the closed-loop transfer function are the zeros of the characteristic equation.
(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

4.11 An electromechanical closed-loop control system has the transfer function
\[ \frac{C(s)}{R(s)} = \frac{k}{s(s^2 + s + 1)(s + 4) + k} \]
Which one of the following is correct?
(a) The system is stable for all positive values of k.
(b) The system is unstable for all values of k.
(c) The system is stable for values of k between zero and 3.36.
(d) The system is stable for values of k between 1.6 and 2.45.

4.12 Which one of the following is the correct statement?
A minimum phase transfer function has
(a) poles in the right half of s-plane
(b) zeros in the right half of s-plane
(c) poles in the left half of s-plane and zeros in the right half of s-plane
(d) no poles or zeros in the right half of s-plane or on the jω-axis excluding the origin

4.13 The transfer function of a system is \( (1 - s)/(1 + s) \).
The system is then which one of the following?
(a) Non-minimum phase system
(b) Minimum phase system
(c) Low-pass system
(d) Second-order system

4.14 The characteristic equation of a system is given as \( s^3 + 2s^2 + 10s + 50 = 0 \).
What is the number of roots in the right half s-plane and on the jω axis, respectively?
(a) 1, 1  (b) 0, 0  (c) 2, 1  (d) 1, 1

4.15 Consider the following statements regarding Routh-Hurwitz criterion for stability:
1. Routh-Hurwitz criterion is a necessary and sufficient condition for stability.
2. The relative stability is dictated by the location of the roots of the characteristic equation.
3. A stable system is a dynamic system with a bounded response to a bounded input.
Which of the statements given above are correct?
(a) 1 and 2  (b) 2 and 3  (c) 1 and 3  (d) 1, 2 and 3

4.16 The open-loop transfer function of a unity feedback control system is given by \( G(s) = Ks^{-T} \), where K and T are constants and these are greater than zero. The stability of close-loop system depends on which of the following?
(a) K only  (b) Both K and T  (c) T only  (d) Neither on K nor on T

4.17 Which one of the following is the correct statement?
A non-minimum phase network is one whose transfer function has
(a) zeros in the left hand plane and poles in the right hand plane.
(b) zeros and poles in the left hand plane.
(c) zeros in the right hand plane and poles in the left hand plane.
(d) arbitrary distribution of zeros and poles in the s-plane.

[ESE-2007]

4.18 If the poles of a system lie on the imaginary axis, the system will be
(a) Stable (b) Conditionally stable
(c) Marginally stable (d) Unstable

[ESE-2008]

4.19 Which of the following transfer functions is/are minimum phase transfer function(s)?

1. \( \frac{1}{(s - 1)} \)
2. \( \frac{(s + 1)}{(s + 3)(s + 4)} \)
3. \( \frac{(s + 2)}{(s + 3)(s - 4)} \)

Select the correct answer using the code given below:
(a) 1 and 3 (b) 1 only
(c) 2 and 3 (d) None of these

[ESE-2008]

4.20 In the time domain analysis of feedback control systems which one pair of the following is not correctly matched?
(a) Under damped : Minimizes the effect of non-linearities
(b) Dominant poles : Transients die out more rapidly
(c) Far away poles to the left half of s-plane : Transients die out more rapidly
(d) A pole near to the left of dominant complex poles and near a zero : Magnitude of transient is small

[ESE-2008]

4.21 What is the range of \( K \) for which the open loop transfer function
\[
G(s) = \frac{K}{s^2(s + a)}
\]
represents an unstable closed loop system?

(a) \( K > 0 \) (b) \( K = 0 \)
(c) \( K < 0 \) (d) \( -\infty < K < \infty \)

[ESE-2008]

4.22 Consider the following statements:
When all the elements in one row of the Routh’s tabulation are zero then this condition indicates:
1. one pair of real roots with opposite sign in s-plane
2. one pair of conjugate roots on the imaginary axis in s-plane
3. conjugate roots forming a quadrat in s-plane
Which of the statements given below is/are correct?
(a) 1 only (b) 2 only
(c) 3 only (d) 1, 2 and 3

[ESE-2008]

4.23 Which one of the following statement is correct for the open-loop transfer function
\[
G(s) = \frac{K(s + 3)}{s(s - 1)}
\] for \( K > 1 \)

(a) Open-loop system is stable but the closed-loop system is unstable.
(b) Open-loop system is unstable but the closed-loop system is stable.
(c) Both open-loop and closed-loop systems are unstable.
(d) Both open-loop and closed-loop systems are stable.

[ESE-2009]

4.24 Consider the following statements:
1. A system is said to be stable if its output is bounded for any input.
2. A system is stable if all the roots of the characteristic equation lie in the left half of the s-plane.
3. A system is stable if all the roots of the characteristic equation have negative real parts.
4. A second order system is always stable for finite positive values of open loop gain.
Which of the above statements is/are correct?
(a) 2, 3 and 4 (b) 1 only
(c) 2 and 3 only (d) 3 and 4 only

[ESE-2009]
4.25 The characteristic equation of a feedback control system is given by:
\[ s^3 + 6s^2 + 9s + 4 = 0 \]
What is the number of roots in the left-half of the s-plane?
(a) three  (b) two  (c) one  (d) zero [ESE-2009]

4.26 The unit step response of a system is \([1 - e^{-t} (1 + t)] u(t)\). What is the nature of the system in turn of stability?
(a) Unstable  (b) Stable  (c) Critically stable  (d) Oscillatory [ESE-2009]

4.27 The feedback system shown in figure below is stable for all values of \(k\) given by
\[ \frac{k}{s(s+1)(s+6)} \]
(a) \(k > 0\)  (b) \(k < 0\)  (c) \(0 < k < 42\)  (d) \(0 < k < 60\) [ESE-2010]

4.28 Using Routh’s criterion, the number of roots of characteristic equation in the right half s-plane for the characteristic equation:
\[ s^4 + 2s^3 + 2s^2 + 3s + 6 = 0 \]
(a) one  (b) two  (c) three  (d) four [ESE-2010]

4.29 The feedback control system represented by the open loop transfer function
\[ G(s)H(s) = \frac{10(s+2)}{(s+1)(s+3)(s-5)} \]
is
(a) unstable  (b) stable  (c) marginally stable  (d) insufficient data [ESE-2010]

4.30 Consider the following statements: in connection with the closed-loop poles of feedback control system
1. Poles on \(j\omega\)-axis will make the output amplitude neither decaying nor growing in time.
2. Dominant closed-loop poles occur in the form of a complex conjugate pair.
3. The gain of a higher order system is adjusted so that there will exist a pair of complex conjugate closed-loop poles on \(j\omega\)-axis.
4. The presence of complex conjugate closed-loop poles reduces the effects of such non-linearities as dead zones, backlash and coulomb friction.
(a) 2 only  (b) 2, 3 and 4 only  (c) 1, 2 and 4 only  (d) 1, 2, 3 and 4 [ESE-2010]

4.31 Consider the following statements in connection with pole location
1. A distinct pole always lies on the real axis.
2. A dominant constant pole has a large time constant.
Which of the above statements is/are correct?
(a) Both 1 and 2  (b) Neither 1 nor 2  (c) 1 only  (d) 2 only [ESE-2010]

4.32 Assertion (A): All the coefficients of the characteristic equation should be positive and no term should be missing in the characteristic equation for a system to be stable.
Reason (R): If some of the coefficients are zero or negative then the system is not stable.
(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 [ESE-2010]

4.33 The characteristic equation of a control system is given below:
\[ F(s) = s^4 + s^3 + 3s^2 + 2s + 5 = 0 \]
The system is
(a) stable  (b) critically stable  (c) conditionally stable  (d) unstable [ESE-2012]

4.34 A unity feedback system has forward transfer function
\[ G(s) = \frac{K}{s(s+3)(s+10)} \]
The range of \(K\) for the system to be stable is
(a) 0 < \(K\) < 390  (b) 0 < \(K\) < 39  (c) 0 < \(K\) < 3900  (d) None of the above [ESE-2012]
4.35 Consider the following statements about Routh-Hurwitz criterion:
If all the elements in one row of Routh array are zero, then there are
1. Pairs of conjugate roots on imaginary axis.
2. Pairs of equal real roots with opposite sign.
3. Conjugate roots forming a quadruple in the s-plane.
Which of these statements are correct?
(a) 1 and 2 only  (b) 1 and 3 only  (c) 2 and 3 only  (d) 1, 2 and 3

4.36 The characteristic equation of a feedback control system is $s^4 + s^3 + 2s^2 + 4s + 15 = 0$. The number of roots in the right half of the s-plane is
(a) 4  (b) 3  (c) 2  (d) 1

4.37 The characteristic equation of a feedback system is $s^3 + Ks^2 + 5s + 10 = 0$. For a stable system, the value of $K$ should be greater than
(a) 1  (b) 2  (c) 3  (d) 4.5

4.38 Consider the following statements with respect to Routh-Hurwitz criterion:
1. It can be used to determine relative stability.
2. It is valid only for real coefficients of the characteristic equation.
3. It is applicable only for non-linear systems.
4. It does not provide the exact location of closed-loop poles in left or right-half of s-plane.
Which of the above statements are correct?
(a) 1, 2 and 3 only  (b) 3 and 4 only  (c) 1, 2 and 4 only  (d) 1, 2, 3 and 4

4.39 The first element of each of the rows of a Routh-Hurwitz stability test showed the signs as follows:

<table>
<thead>
<tr>
<th>Row</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sign</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Consider the following statements:
1. The system has three roots in the right-half of s-plane.
2. The system has three roots in the left-half of s-plane.
3. The system is stable.
4. The system is unstable.
Which of the above statements about the system are correct?
(a) 1 and 3  (b) 1 and 4  (c) 2 and 3  (d) 2 and 4

4.40 How many roots of the following equation lie in the right-half of s-plane?
$2s^4 + s^3 + 2s^2 + 5s + 10 = 0$
(a) 1  (b) 2  (c) 3  (d) 4

4.41 None of the poles of a linear control system lies in the right-half of s-plane. For a bounded input, the output of this system (a) is always bounded (b) could be unbounded (c) always tends to zero (d) None of the above

4.42 For a unity feedback control system, the forward path transfer function is given by
$$ G(s) = \frac{40}{s(s+2)(s^2+2s+30)} $$
The steady-state error of the system for the input $5t^2/2$ is
(a) 0  (b) 0  (c) 20t^2  (d) 30t^2

4.43 When gain $K$ of the open-loop transfer function of order greater than unity is varied from zero to infinity, the closed-loop system (a) may become unstable (b) stability may improve (c) stability may not be affected (d) will become highly stable

4.44 The frequency of sustained oscillation for marginal stability, for a control system
$$ G(s) = \frac{2k}{s(s+1)(s+5)} $$
and operating with negative feedback, is
(a) $\sqrt{5}$ r/s  (b) $\sqrt{6}$ r/s  
(c) 5 r/s  (d) 6 r/s  

4.45 A second-order position control system has an open-loop transfer function

$$G(s) = \frac{57.3 k}{s(s + 10)}$$

What value of $k$ will result in a steady-state error of 1°, when the input shaft rotates at 10 r.p.m.?  
(a) 21.74  (b) 10.47  
(c) 5.23  (d) 0.523  

4.46 Statement (I): Stability of a system deteriorates when integral control is incorporated into it.

Statement (II): With integral control action, the order of a system increases and higher the order of the system, more the system tends to become unstable.

4.47 The closed-loop transfer function of a system is

$$\frac{C(s)}{R(s)} = \frac{s - 2}{s^3 + 8s^2 + 19s + 12}$$

The system is

(a) Stable  (b) Unstable  
(c) Conditionally stable  (d) Critically stable  

4.48 In a system, the damping coefficient is −2. The system response will be

(a) Undamped  (b) Oscillations with decreasing magnitude  
(c) Oscillations with increasing magnitude  (d) Critically damped  

4.49 The open-loop transfer function of a negative feedback is

$$G(s)H(s) = \frac{K}{s(s + 5)(s + 12)}$$

For ensuring system stability the gain $K$ should be in the range

(a) $0 < K < 60$  (b) $0 < K < 600$  
(c) $0 < K < 1020$  (d) $K > 1020$  

4.50 The characteristic polynomial of a feedback control system is given by

$$R(s) = s^5 + 2s^4 + 2s^3 + 4s^2 + 11s + 10$$

For this system, the numbers of roots that lie in the left hand and right hand s-plane respectively, are

(a) 5 and 0  (b) 4 and 1  
(c) 3 and 2  (d) 2 and 3  

4.51 A system with characteristic equation,

$$s^4 + 2s^3 + 11s^2 + 18s + 18 = 0$$

will have closed-loop poles such that,

(a) all poles lie in the left half of the s-plane and no pole lies on imaginary axis.  
(b) all poles lie in the right half of the s-plane.  
(c) two poles lie symmetrically on the imaginary axis of the s-plane.  
(d) all four poles lie on the imaginary axis of the s-plane.  

4.52 A unity negative feedback control system has an open-loop transfer function as,

$$G(s) = \frac{K(s + 1)(s + 2)}{(s + 0.1)(s - 1)}$$

The range of values of $K$ for which the closed loop system is stable will be

(a) $0 < K < 0.3$  (b) $K > 0.3$  
(c) $K > 3$  (d) $K < 0.3$  

4.53 A system with characteristic equation:

$$f(s) = s^4 + 6s^3 + 23s^2 + 40s + 50$$

will have closed-loop poles such that,

(a) all poles lie in the left half of the s-plane and no pole lies on imaginary axis.  
(b) two poles lie symmetrically on the imaginary axis of the s-plane.  
(c) all four poles lie on the imaginary axis of the s-plane.  
(d) all four poles lie in the right half of the s-plane.  

★★★★★
Answers

4.1 (c) 4.2 (c) 4.3 (c) 4.4 (b) 4.5 (a) 4.6 (c) 4.7 (b) 4.8 (c) 4.9 (b)
4.10 (a) 4.11 (c) 4.12 (d) 4.13 (a) 4.14 (b) 4.15 (d) 4.16 (a) 4.17 (c) 4.18 (c)
4.19 (d) 4.20 (b) 4.21 (d) 4.22 (d) 4.23 (b) 4.24 (a) 4.25 (a) 4.26 (b) 4.27 (c)
4.28 (b) 4.29 (a) 4.30 (d) 4.31 (a) 4.32 (a) 4.33 (d) 4.34 (a) 4.35 (d) 4.36 (c)
4.37 (b) 4.38 (c) 4.39 (b) 4.40 (b) 4.41 (d) 4.42 (b) 4.43 (a) 4.44 (a) 4.45 (b)
4.46 (a) 4.47 (a) 4.48 (c) 4.49 (c) 4.50 (c) 4.51 (c) 4.52 (b) 4.53 (a)

Explanations

4.1 (c)
All positive coefficients of the characteristic polynomial of a system is a necessary condition, not a sufficient condition for stability.

4.2 (c)
\[1 + G(s)H(s) = 0\]
\[s^3 + 5s^2 + 6s + K = 0\]

\[\begin{array}{c|cc}
s^2 & 1 & 6 \\
s^3 & 5 & K \\
s^4 & 30-K & 0 \\
s^5 & K & 0 \\
\end{array}\]

For marginal stability \[\frac{30-K}{5} = 0\] \[\therefore K = 30\]

4.3 (c)
There is a missing coefficient so system is unstable.

4.4 (b)
Transportation lag can be conveniently handled on Bode plot as well without the need to make any approximation. The log magnitude of transportation lag is 20\(\log|\text{e}^{-\omega_1 T}| = 0\). Thus the open-loop log-magnitude plot of a system is unaffected by the presence of transportation lag. The lag, of course, contributes a phase angle of \((\omega T \times 180^\circ)/\pi\), thereby causing the modification of the phase plot.

4.6 (c)
Poles with positive real part denote unstable system.

4.7 (b)
Apply Routh-Hurwitz stability criteria.

4.8 (c)
\[1 + G(s)H(s) = 1\]
\[\frac{k}{s(s+1)(s+6)} = 0\]

\[\begin{array}{c|cccc}
s^3 & 1 & 6 \\
s^2 & 7 & k \\
s^1 & 42-k & 0 \\
s^0 & 0 & \end{array}\]

\[\therefore \frac{42-k}{7} = 0\] \[\therefore k = 42\]
\[k > 0\]
\[\therefore \text{Range} \quad 0 < k < 42\]

4.9 (b)

\[\begin{array}{c|cccc}
s^4 & 2 & 3 & 10 \\
s^3 & 1 & 5 \\
s^2 & 3-10 & -7 & 10 \\
s^1 & -35-10 & -7 & 45 \\
s^0 & -7 & 7 & 0 \\
\end{array}\]

There are two sign changes, so two poles on R.H.S. of s-plane.

4.11 (c)
Apply Routh-Hurwitz criteria.

4.12 (d)
Definition of minimum phase transfer function.
4.37 (b)
Using Routh's stability criteria,
\[
\begin{array}{ccc}
 s^3 & 1 & 5 \\
 s^2 & K & 10 \\
 s^1 & 5K - 10 & 0 \\
 s^0 & K & 10 \\
\end{array}
\]
For stability,
\[
\frac{5K - 10}{K} \geq 0 \implies K \geq 2
\]

4.39 (b)
Total number of changes of sign = 3
i.e. number of root at R.H.S = 3
\implies system is unstable.

4.40 (b)
Using Routh's criteria
\[
\begin{array}{ccc}
 s^4 & 2 & 2 & 10 \\
 s^3 & 1 & 5 \\
 s^2 & -8 & 10 \\
 s^1 & 50 & 0 \\
 s^0 & 8 & 10 \\
\end{array}
\]
No. of sign change occurs = 2 times
Hence no. of roots of equation lying in the right half of s plane = 2.

4.41 (d)
If multiple pole lies on jω-axis then system becomes unstable. Hence it could be stable or unstable for bounded input.

4.42 (b)
\[
G(s) = \frac{40}{s(s+2)(s^2+2s+30)}
\]
Since type of system is 1 so steady state error for \(5\omega/2\) will be \(\infty\)

4.43 (a)
When gain \(K\) of the system is varied from 0 to \(\infty\) then the closed loop system may became unstable, because the poles may go to the right half of s plane.

4.44 (a)
\[
G(s)H(s) = \frac{2k}{s(s + 1)(s + 5)}
\]
For marginal stability we need to find frequency of sustained oscillation.
If \(G(s)H(s) = s(s + 1)(s + 5) + 2k = 0\)
\[
\Rightarrow s^3 + 6s^2 + 5s + 2k = 0
\]
Now from Routh Hurwitz criteria
\[
\begin{array}{ccc}
 s^3 & 1 & 5 \\
 s^2 & 6 & 2k \\
 s^1 & 30 - 2k & 0 \\
 s^0 & 2k & 6 \\
\end{array}
\]
so \(k = 15\)
Now we get that \(k = 15\)
From auxiliary equation,
\(6s^2 + 2k = 0\)
So \(6s^2 + 30 = 0\)
\(\omega_{oscillation} = \sqrt{5}\) rad/sec

4.45 (b)
\[
G(s)H(s) = \frac{57.3k}{s(s+10)} \text{; type = 1}
\]
input = 10 rpm = \(10 \times \frac{360^\circ}{60} tu(t)\)
input \(r(t) = 60^\circ tu(t)\)
\[
R(s) = \frac{60^\circ}{s^2}
\]
Steady state error \(e_{ss} = \frac{60^\circ}{K_v} = 1^\circ\)
\[
K_v = \lim_{s \to 0} \frac{57.3k}{s(s+10)} = 5.73 k
\]
\(\therefore \frac{60}{5.73 k} = 1\)
\(k = 10.47\)

4.47 (a)
Characteristic equation:
\(s^3 + 8s^2 + 19s + 12 = 0\)
Using Routh's array,
\[
\begin{array}{ccc}
 s^3 & 1 & 19 \\
 s^2 & 8 & 12 \\
 s^1 & 17.5 \\
 s^0 & 12 \\
\end{array}
\]
As all the elements of first column are positive and non-zero. Therefore the system is stable.
4.48 (c)  
Negative damping ratio implies unstable system.

4.49 (c)  
Characteristic equation: \( s^3 + 17s^2 + 60s + K = 0 \)  
For stability, the value range of \( K \) should be;  
\[ s^3 + 17s^2 + 60s + K = 0 \]  
\( 0 < K < 17 \times 60 \) or \( 0 < K < 1020 \)

4.50 (c)  
\[
\begin{array}{c|ccc}
s^5 & 1 & 2 & 11 \\
s^4 & 2 & 4 & 10 \\
s^3 & e & 6 & 0 \\
s^2 & 4e - 12 & < 0 & 10 \\
s^1 & 24e - 72 - 10e^2 & > 0 & 0 \\
s^0 & 10 & 0 & 0 \\
\end{array}
\]
No sign changes among elements of 1st column and no row becoming zero.  
Hence all roots lie in left side.

4.51 (c)  
\[
\begin{array}{c|ccc}
s^4 & 1 & 11 & 18 \\
s^3 & 2 & 18 & 0 \\
s^2 & 2 & 18 & 0 \\
s^1 & 0 & 0 & 0 \\
s^0 & 0 & 0 & 0 \\
\end{array}
\]
Since, \( s^1 \) row is zero.

4.52 (b)  
\[
q(s) = 1 + \frac{K(s + 1)(s + 2)}{(s + 0.1)(s - 1)}
\]
\[
q(s) = s^2(1 + K) + s(3K - 0.9) + (2K - 0.1) = 0
\]
For stability,  
\[ K > -1 \]  
\[ K > 0.3 \] \( (\therefore K > 0.3) \)  
\[ K > 0.05 \]

4.53 (a)  
\[
F(s) = s^4 + 6s^3 + 23s^2 + 40s + 50 = 0
\]
\[
\begin{array}{c|ccc}
s^4 & 1 & 23 & 50 \\
s^3 & 6 & 40 & \\
s^2 & 16.33 & 50 & \\
s^1 & 21.6 & \\
s^0 & 50 & \\
\end{array}
\]
No sign changes among elements of 1st column and no row becoming zero.  
Hence all roots lie in left side.