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State Space Representation Questions

MCQ Question 1

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A discrete system is represented by the difference equation

$$\begin{bmatrix} X_1(k+1) \\ X_2(k+1) \end{bmatrix} = \begin{bmatrix} a & a-1 \\ a+1 & a \end{bmatrix} \begin{bmatrix} X_1(k) \\ X_2(k) \end{bmatrix}$$

It has initial conditions $X_1(0) = 1$; $X_2(0) = 0$. The pole locations of the system for a = 1, are

1. 1 ± j0
2. -1 ± j0
3. ±1 + j0
4. 0 ± j1

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Answer (Detailed Solution Below)

Option 1 : 1 ± j0

State Space Representation MCQ Question 1 Detailed Solution

Concept:

The poles of the system are the roots of the characteristic equation.

The characteristic equation is: |zI − A| = 0

Calculation:

From the given representation, the matrix A

$$A = \begin{bmatrix} a & a-1 \\ a+1 & a \end{bmatrix}$$

$$zI - A = \begin{bmatrix} z & 0 \\ 0 & z \end{bmatrix} - \begin{bmatrix} a & a-1 \\ a+1 & a \end{bmatrix}$$

$$= \begin{bmatrix} z-a & -a+1 \\ -a-1 & z-a \end{bmatrix}$$

For a = 1,

Characteristic equation: $|zI - A| = 0$

$\Rightarrow (z-1)^2 = 0$

$\Rightarrow z = 1 + j0$

The roots of characteristic equation gives the system poles.

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MCQ Question 2 View this Question Online >

A second-order linear time-invariant system is described by the following state equations

$$\frac{d}{dt}x_1(t) + 2x_1(t) = 3u(t)$$

$$\frac{d}{dt}x_2(t) + x_2(t) = u(t)$$

where x1(t) and x2(t) are the two-state variables and u(t) denotes the input. If the output c(t) = x_1(t), then the system is:

1. controllable but not observable
2. observable but not controllable
3. both controllable and observable
4. neither controllable nor observable

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Answer (Detailed Solution Below)

Option 1 : controllable but not observable

State Space Representation MCQ Question 2 Detailed Solution

Concept:

Controllability:

A system is said to be controllable if it is possible to transfer the system state from any initial state $x(t_0)$ to any desired state x(t) in a specified finite time interval by a control vector u(t)

Kalman's test for controllability:

$\dot{x} = Ax + Bu$

$Q_c = [B\ AB\ A^2B\ \dots\ A^{n-1}B]$

Q_c = controllability matrix

If $|Q_c| = 0$, system is not controllable

If $|Q_c| \neq 0$, system is controllable

Observability:

A system is said to be observable if every state $x(t_0)$ can be completely identified by measurement of output y(t) over a finite time interval.

Kalman's test for observability:

$Q_0 = [C^T\ A^TC^T\ (A^T)^2C^T\ \dots\ (A^T)^{n-1}C^T]$

Q_0 = observability testing matrix

If $|Q_0| = 0$, system is not observable

If $|Q_0| \neq 0$, system is observable.

Application:

Given $\dot{x}_1 = -2x_1 + 3U$

$\dot{x}_2 = -x_2 + U$ and $c(t) = x_1$

$\therefore A = \begin{bmatrix} -2 & 0 \\ 0 & -1 \end{bmatrix}$

$B = \begin{bmatrix} 3 \\ 1 \end{bmatrix}$

$C = [1 \quad 0]$

Controllability matrix $Q_c = [B \quad AB]$

$= \begin{bmatrix} 3 & -6 \\ 1 & -1 \end{bmatrix}$

$|Q_c| = \ (-3) - (-6) = 6 - 3 = 3 \neq 0$

$\therefore$ System is controllable

Observability matrix $Q_0 = [C^T \quad A^TC^T]$, i.e.

$$Q_0 = \begin{bmatrix} 1 & -2 \\ 0 & 0 \end{bmatrix}$$

$|Q_0| = 0$ = not observable

$\therefore$ The system is controllable but not observable

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MCQ Question 3

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The value of A matrix in $X = AX$ **for the system described by** $y' \ + 2y' + 3y = 0$

1. $\begin{bmatrix} 1 & 0 \\ -2 & -1 \end{bmatrix}$

2. $\begin{bmatrix} 1 & 0 \\ -1 & -2 \end{bmatrix}$

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3. $\begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix}$

4. $\begin{bmatrix} 0 & 1 \\ -3 & -2 \end{bmatrix}$

Answer (Detailed Solution Below)

Option 4 : $\begin{bmatrix} 0 & 1 \\ -3 & -2 \end{bmatrix}$

State Space Representation MCQ Question 3 Detailed Solution

Concept:

State-space representation:

State equation: $\dot{X}(t) = A_{n\times n}X(t) + B_{n\times p}U(t)$

Output equation: $Y(t) = C_{q\times n}X(t) + D_{q\times p}U(t)$

If the transfer function is in the form of

$$TF = \frac{b[C_n s^n + C_{n-1}s^{n-1} + \ldots + C_1 s + C_0]}{s^{n+1} + a_n s^n + \ldots + a_1 s + a_0}$$

Then, the above transfer function can be represented as:

Controllable Canonical Form:

$$A = \begin{bmatrix} 0 & 1 & 0 & \ldots & 0 \\ 0 & 0 & 1 & \ldots & 0 \\ 0 & 0 & 0 & \ldots & 0 \\ 0 & 0 & 0 & \ldots & 1 \\ -a_0 & -a_1 & -a_2 & \ldots & -a_n \end{bmatrix}, B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \vdots \\ b \end{bmatrix}$$

$$C = [C_0 \quad C_1 \quad C_2 \quad \ldots \quad C_n]$$

Observable Canonical Form:

$$A = \begin{bmatrix} 0 & 0 & 0 & 0 & -a_0 \\ 1 & 0 & 0 & 0 & -a_1 \\ 0 & 1 & 0 & 0 & -a_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 1 & -a_n \end{bmatrix}, B = \begin{bmatrix} C_0 \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{bmatrix}$$

$$C = [0 \quad 0 \quad 0 \quad \ldots \quad b]$$

Application:

The given system is $y' + 2y' + 3y = 0$

By applying the Laplace transform, we get

$s^2 Y(s) + 2s\,Y(s) + 3\,Y(s) = 1$

$\Rightarrow Y(s) = \frac{1}{s^2 + 2s + 3}$

So, the state space representation for the above transfer function is:

$$A = \begin{bmatrix} 0 & 1 \\ -3 & -2 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}, C = [0 \quad 1]$$

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MCQ Question 4

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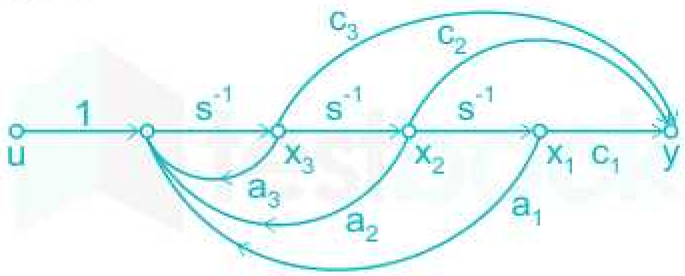
Consider the state space system expressed by the signal flow diagram shown in the figure.



The corresponding system is

1. always controllable
2. always observable
3. always stable
4. always unstable

Answer (Detailed Solution Below)

Option 1 : always controllable

State Space Representation MCQ Question 4 Detailed Solution

Concept:

Since $x = \frac{-b\pm\sqrt{b^2-4ac}}{2a}$ $\frac{1}{s}$ is an integrator, $\dot{x}_1 = x_2$

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Where $\dot{x}$ = differentiation of x_1

Where $\dot{x}$ = differentiation of x_1

Analysis:

The state equation and output equation as:

State equation:

$\dot{x}_1 = x_2$

$\dot{x}_2 = x_3$

$\dot{x}_3 = a_1 x_1 + a_2 x_2 + a_3 x_3 + u$

Output equation:

$y = c_1 x_1 + c_2 x_2 + c_3 x_3$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ a_1 & a_2 & a_3 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} u$$

$$y = [c_1 \ \ c_2 \ \ c_3] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

Here,

$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ a_1 & a_2 & a_3 \end{bmatrix}$ is state matrix

$B = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$ is input matrix

And $C = [c_1 \ \ c_2 \ \ c_3]$ is the output matrix.

Now,

After state modeling the system, let's check for controllability & observability.

Kalman's Test:

(i) For controllability:

$Q_c = [B \ \ AB \ \ A^2B \ \ ...]$

If $|Q_c| \neq 0 \Rightarrow$ Controllable

$= 0 \Rightarrow$ Uncontrollable

(ii) $Q_0 = \begin{bmatrix} C \\ CA \\ CA^2 \end{bmatrix}$

$|Q_0| \neq 0 \Rightarrow$ Observable

$= 0 \Rightarrow$ Unobservable

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$$AB = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ a_1 & a_2 & a_3 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$AB = \begin{bmatrix} 0 \\ 1 \\ a_3 \end{bmatrix}$$

$$A^2 = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ a_1 & a_2 & a_3 \end{bmatrix} \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ a_1 & a_2 & a_3 \end{bmatrix}$$

$$A^2 = \begin{bmatrix} 0 & 0 & 1 \\ a_1 & a_2 & a_3 \\ a_1 a_3 & a_1 + a_2 a_3 & a_2 + a_3^2 \end{bmatrix}$$

$$A^2 B = \begin{bmatrix} 0 & 0 & 1 \\ a_1 & a_2 & a_3 \\ a_1 a_3 & a_1 + a_2 a_3 & a_2 + a_3^2 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$A^2 B = \begin{bmatrix} 1 \\ a_3 \\ a_2 + a_3^2 \end{bmatrix}$$

$$Q_c = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & a_3 \\ 1 & a_3 & a_2 + a_3^2 \end{bmatrix}$$

$$|Q_c| = 0 = 0 + 1\,(0 - 1)$$

$$|Q_c| = -1$$

Since $|Q_c| \neq 0$, hence our system is always controllable.

Since it is MCQ type Question we need not check other options. Option A is correct.

But let's check for the observability.

$$Q_0 = \begin{bmatrix} C \\ CA \\ CA^2 \end{bmatrix}$$

$$CA = [C_1 \ \ C_2 \ \ C_3] \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ a_1 & a_2 & a_3 \end{bmatrix}$$

$CA = [a_1c_3 \ \ c_1 + a_2c_3 \ \ c_2 + c_3a_3]$

$$CA^2 = [c_1 \ \ c_2 \ \ c_3] \begin{bmatrix} 0 & 0 & 1 \\ 0 & a_2 & a_3 \\ a_1a_3 & a_1 + a_2a_3 & a_1 + a_3^2 \end{bmatrix}$$

$$CA^2 = [a_1a_3c_3 \ \ a_2c_2 + a_1c_3 + a_2a_3c_3 \ \ c_1 + c_2a_3 + a_2c_3 + a_3^2c_3]$$

$$Q_0 = \begin{bmatrix} C_1 & c_2 & c_3 \\ a_1c_3 & c_1 + a_2c_3 & c_2 + c_3a_3 \\ a_1a_3c_3 & a_2c_2 + a_1c_3 + a_2a_3c_3 & c_1 + c_2a_3 + a_2c_3 + a_3^2c_3 \end{bmatrix}$$

Since we do not know about the nature of a_1, a_2, a_3, and c_1, c_2, c_3 whether they are positive or negative numbers we cannot comment on $|Q_0|$ & hence we cannot comment on observability.

Similar is the case for stability since for stable system all the roots of characteristic equation must lie in the left half of s-plane characteristic equation: $|SI - A| = 0$

$$[SI - A] = \begin{bmatrix} s & 0 & 0 \\ 0 & s & 0 \\ 0 & 0 & s \end{bmatrix} - \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ a_1 & a_2 & a_3 \end{bmatrix}$$

$$= \begin{bmatrix} s & -1 & 0 \\ 0 & s & -1 \\ -a_1 & -a_2 & s - a_3 \end{bmatrix}$$

$$|SI - A| = S\left(s^2 - a_3s - a_2\right) + (-a_1)$$

$|SI - A| = s^3 - a_3s^2 - a_2\,s - q_1 = 0$

Now, again we cannot comment on stability because we do not know the nature of a_1, a_2 & a_3

Hence, only option A is correct.

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MCQ Question 5

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Let $X' = \begin{bmatrix} 1 & 2 \\ 0 & 2 \end{bmatrix} X + \begin{bmatrix} 0 \\ 1 \end{bmatrix} U$

U = [b, 0] X

Where b is an unknown constant. This system is

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1. Observable for all values of b
2. Unobservable for all values of b
3. Observable for all non-zero values of b
4. Unobservable for all non-zero values of b

Answer (Detailed Solution Below)

Option 3 : Observable for all non-zero values of b

State Space Representation MCQ Question 5 Detailed Solution

Concept:

State space representation:

$\dot{x}(t) = A(t)\, x(t) + B(t)\, u(t)$

$y(t) = C(t)\, x(t) + D(t)\, u(t)$

y(t) is output

u(t) is input

x(t) is a state vector

A is a system matrix

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A is a system matrix

This representation is continuous time-variant.

Controllability:

A system is said to be controllable if it is possible to transfer the system state from any initial state $x(t_0)$ to any desired state x(t) in a specified finite time interval by a control vector u(t)

Kalman's test for controllability:

$\dot{x} = Ax + Bu$

Q_c = {B AB A^2B ... A^{n-1} B]

Q_c = controllability matrix

If $|Q_c| = 0$, system is not controllable

If $|Q_c| \neq 0$, system is controllable

Observability:

A system is said to be observable if every state $x(t_0)$ can be completely identified by measurement of output y(t) over a finite time interval.

Kalman's test for observability:

$Q_0 = [C^T\ A^TC^T\ (A^T)^2C^T\ ....\ (A^T)^{n-1}\ C^T]$

Q_0 = observability testing matrix

If $|Q_0| = 0$, system is not observable

If $|Q_0| \neq 0$, system is observable.

Calculation:

$$A = \begin{bmatrix} 1 & 2 \\ 0 & 2 \end{bmatrix},\ B = \begin{bmatrix} 0 \\ 1 \end{bmatrix},\ C = [b \quad 0]$$

Observability:

$$CA = [b \quad 0] \begin{bmatrix} 1 & 2 \\ 0 & 2 \end{bmatrix} = [b \quad 2b]$$

If $|Q_0| \neq 0$, system is observable.

Observable for all non-zero values of b.

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MCQ Question 6

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Consider a system described by the state model

$$\dot{X} = \begin{bmatrix} 2 & 1 \\ -1 & 2 \end{bmatrix} X + \begin{bmatrix} 1 \\ 1 \end{bmatrix} U$$

Y = [1 1] X

The system is

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1. controllable but not observable
2. uncontrollable and observable
3. both controllable and observable
4. neither controllable nor observable

Answer (Detailed Solution Below)

Option 3 : both controllable and observable

State Space Representation MCQ Question 6 Detailed Solution

Concept:

State space representation:

$\dot{x}(t) = A(t)x(t) + B(t)u(t)$

$y(t) = C(t)x(t) + D(t)u(t)$

y(t) is output

u(t) is input

x(t) is a state vector

A is a system matrix

This representation is continuous time-variant.

Controllability:

A system is said to be controllable if it is possible to transfer the system state from any initial state $x(t_0)$ to any desired state $x(t)$ in a specified finite time interval by a control vector $u(t)$

Kalman's test for controllability:

$\dot{x} = Ax + Bu$

$Q_c = \{B\ AB\ A^2B\ ...\ A^{n-1}\ B]$

Q_c = controllability matrix

If $|Q_c| = 0$, system is not controllable

If $|Q_c| \neq 0$, system is controllable

Observability:

A system is said to be observable if every state $x(t_0)$ can be completely identified by measurement of output $y(t)$ over a finite time interval.

Kalman's test for observability:

$Q_0 = [C^T\ A^TC^T\ (A^T)^2C^T\ ....\ (A^T)^{n-1}\ C^T]$

Q_0 = observability testing matrix

If $|Q_0| = 0$, system is not observable

If $|Q_0| \neq 0$, system is observable.

Calculation:

$$A = \begin{bmatrix} 2 & 1 \\ -1 & 2 \end{bmatrix},\ B = \begin{bmatrix} 1 \\ 1 \end{bmatrix},\ C = [1 \quad 1]$$

Controllability:

$$AB = \begin{bmatrix} 2 & 1 \\ -1 & 2 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 3 \\ 1 \end{bmatrix}$$

Controllability matrix,

$$M = \begin{bmatrix} 1 & 3 \\ 1 & 1 \end{bmatrix}$$

$|M| = -2$

Therefore, the system is controllable.

Observability:

$$CA = [1 \quad 1] \begin{bmatrix} 2 & 1 \\ -1 & 2 \end{bmatrix} = [1 \quad 3]$$

Observability matrix,

$$N = \begin{bmatrix} 1 & 1 \\ 1 & 3 \end{bmatrix}$$

|N| = 2

Therefore, the system is observable

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MCQ Question 7

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The dynamic model of a pendulum is given by $\frac{d^2\theta}{dt^2} + 400\theta = 100T$, where θ is the displacement in rad / s and T is the applied torque in N-m. Its representation in time scale state variable form $\dot{X}$ = α X + βu can have the constants.

1. $\alpha = \begin{bmatrix} 0 & 1 \\ -4 & 0 \end{bmatrix}; \beta = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

2. $\alpha = \begin{bmatrix} 0 & 1 \\ -4 & 0 \end{bmatrix}; \beta = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$

3. $\alpha = \begin{bmatrix} 0 & 0 \\ 4 & 1 \end{bmatrix}; \beta = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

4. $\alpha = \begin{bmatrix} 0 & 0 \\ -4 & 1 \end{bmatrix}; \beta = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$

Answer (Detailed Solution Below)

Option 1 : $\alpha = \begin{bmatrix} 0 & 1 \\ -4 & 0 \end{bmatrix}; \beta = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

State Space Representation MCQ Question 7 Detailed Solution

Let $x_1 = \theta$

$\Rightarrow \dot{x}_1 = d\theta / dt$ ------ (1)

And consider $x_2 = d\theta / dt$ and $u = T$

$\Rightarrow \dot{x}_2 = d^2\theta / dt^2$

From the given dynamic model of a pendulum, we get

$$\frac{d^2\theta}{dt^2} = -400\theta + 100T$$

$\Rightarrow \dot{x}_2 = -400\, x_1 + 100\, u$ ------ (2)

From equations (1) and (2), we can get the state model as

$$\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -400 & 0 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 100 \end{bmatrix} U$$

$$\Rightarrow \begin{bmatrix} \dot{X}_1 \\ X_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -4 & 0 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} U$$

On comparing the above state model with **$\dot{X} = \alpha X + \beta u$, we get**

$$\Rightarrow \alpha = \begin{bmatrix} 0 & 1 \\ -4 & 0 \end{bmatrix}; \ \beta = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

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MCQ Question 8:

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Given the homogeneous state space equation $\dot{x} = \begin{bmatrix} 0 & 1 \\ -1 & -2 \end{bmatrix} x$ and the initial state value $x(0) = \begin{bmatrix} 10 \\ -10 \end{bmatrix}$

The steady state values of $x_{ss1} = \lim x_1(t)$ and $x_{ss2} = \lim x_2(t)$ are

The steady state values of $\lim_{t\to\infty}$ and $\lim_{t\to\infty}$ are

1. 0, 0
2. 10, 0
3. 10, -10
4. 0, -10

Answer (Detailed Solution Below)

Option 1 : 0, 0

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MCQ Question 9:

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Which of the following is not an advantage of state space approach in analyzing the performance of a control system?

1. State space approach can be used to represent non linear systems having backlash.
2. State space approach can handle system with nonzero initial conditions.
3. Multiple input/output system can be handled effectively by state space approach.
4. The physical interpretation of the model in state space approach is easily obtained.

Answer (Detailed Solution Below)

Option 4 : The physical interpretation of the model in state space approach is easily obtained.

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MCQ Question 10:

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A second order system is given by

$$x = \begin{bmatrix} 1 & 1 \\ -3 & -2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u$$

$$y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

1. The system is state controllable and output controllable
2. The system is state controllable but not output controllable
3. The system is output controllable but not state controllable
4. The system is neither state controllable nor output controllable

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Answer (Detailed Solution Below)

Option 1 : The system is state controllable and output controllable

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