Basic terminologies in control system

System: A combination or arrangement of a number of different physical components to form a whole unit such that that combining unit performs to achieve a certain goal.

Control: The action to command, direct or regulate a system.

Plant or process: The part or component of a system that is required to be controlled.

Input: It is the signal or excitation supplied to a control system.

Output: It is the actual response obtained from the control system.

Controller: The part or component of a system that controls the plant.

Disturbances: The signal that has adverse effect on the performance of a control system.

Control system: A system that can command, direct or regulate itself or another system to achieve a certain goal.

Automation: The control of a process by automatic means

Control System: An interconnection of components forming a system configuration that will provide a desired response.

Actuator: It is the device that causes the process to provide the output. It is the device that provides the motive power to the process.

Design: The process of conceiving or inventing the forms, parts, and details of system to achieve a specified purpose.

Simulation: A model of a system that is used to investigate the behaviour of a system by utilizing actual input signals**.**

Optimization: The adjustment of the parameters to achieve the most favourable or Advantageous design.

Feedback Signal: A measure of the output of the system used for feedback to control the system.

Negative feedback: The output signal is feedback so that it subtracts from the input signal.

Block diagrams: Unidirectional, operational blocks that represent the transfer functions of the elements of the system.

Signal Flow Graph (SFG): A diagram that consists of nodes connected by several directed branches and that is a graphical representation of a set of linear relations.

Specifications: Statements that explicitly state what the device or product is to be and to do. It is also defined as a set of prescribed performance criteria.

Open-loop control system: A system that utilizes a device to control the process without using feedback. Thus the output has no effect upon the signal to the process.

Closed-loop feedback control system: A system that uses a measurement of the output and compares it with the desired output.

Regulator: The control system where the desired values of the controlled outputs are more or less fixed and the main problem is to reject disturbance effects.

Servo system: The control system where the outputs are mechanical quantities like acceleration, velocity or position.

Stability: It is a notion that describes whether the system will be able to follow the input command. In a non-rigorous sense, a system is said to be unstable if its output is out of control or increases without bound.

Multivariable Control System: A system with more than one input variable or more than one output variable.

Trade-off: The result of making a judgment about how much compromise must be made between conflicting criteria.

Natural control system: It is a control system that is created by nature, i.e. solar system, digestive system of any animal, etc.

Man-made control system: It is a control system that is created by humans, i.e. automobile, power plants etc.
Automatic control system: It is a control system that is made by using basic theories from mathematics and engineering. This system mainly has sensors, actuators and responders.
Combinational control system: It is a control system that is a combination of natural and man-made control systems, i.e. driving a car etc.
Time-variant control system: It is a control system where any one or more parameters of the control system vary with time i.e. driving a vehicle.
Time-invariant control system: It is a control system where none of its parameters vary with time i.e. control system made up of inductors, capacitors and resistors only.
Linear control system: It is a control system that satisfies properties of homogeneity and additive.
Non-linear control system: It is a control system that does not satisfy properties of homogeneity and additive
Continuous-Time control system: It is a control system where performances of all of its parameters are function of time, i.e. armature type speed control of motor.
Discrete -Time control system: It is a control system where performances of all of its parameters are function of discrete time i.e. microprocessor type speed control of motor.
Deterministic control system: It is a control system where its output is predictable or repetitive for certain input signal or disturbance signal.
Stochastic control system: It is a control system where its output is unpredictable or Non-repetitive for certain input signal or disturbance signal.
SISO control system: It is a control system that has only one input and one output.
MIMO control system: It is a control system that has only more than one input and more than one output.
Open-loop control system: It is a control system where its control action only depends on input signal and does not depend on its output response.
Closed-loop control system: It is a control system where its control action depends on both of its input signal and output response.

Sl. No.	Open-loop control systems	Closed-loop control systems
1	No feedback is given to the control system	A feedback is given to the control system
2	Cannot be intelligent	Intelligent controlling action
3	There is no possibility of undesirable system oscillation(hunting)	Closed loop control introduces the possibility of undesirable system oscillation(hunting)
4	The output will not very for a constant input, provided the system parameters remain unaltered	In the system the output may vary for a constant input, depending upon the feedback
5	System output variation due to variation in parameters of the system is greater and the output very in an uncontrolled way	System output variation due to variation in parameters of the system is less.
6	Error detection is not present	Error detection is present
7	Small bandwidth	Large bandwidth
8	More stable	Less stable or prone to instability
9	Affected by non-linearities	Not affected by non-linearities
10	Very sensitive in nature	Less sensitive to disturbances
11	Simple design	Complex design
12	Cheap	Costly

Basics of Laplace Transform:
Initial value theorem:

$$\lim_{t\to 0}[y(t)] = \lim_{s\to\infty}\left[sY(s)\right]$$

Final value theorem:

$$\lim_{t\to\infty}(y(t)) = \lim_{s\to 0}\left[sY(s)\right]$$

$$\mathrm{L}\{x(t)\} = X(s) = \int_0^{\infty} x(t)e^{-st}\,dt \qquad (2.2)$$

No.	Function	Time-domain $x(t)=\mathcal{L}^{-1}\{X(s)\}$	Laplace domain $X(s)=\mathcal{L}\{x(t)\}$
1	Delay	$\delta(t-\tau)$	$e^{-\tau s}$
2	Unit impulse	$\delta(t)$	1
3	Unit step	$u(t)$	$\frac{1}{s}$
4	Ramp	t	$\frac{1}{s^2}$
5	Exponential decay	$e^{-\alpha t}$	$\frac{1}{s+\alpha}$
6	Exponential approach	$\left(1-e^{-\alpha t}\right)$	$\frac{\alpha}{s(s+\alpha)}$
7	Sine	$\sin \omega t$	$\frac{\omega}{s^2+\omega^2}$
8	Cosine	$\cos \omega t$	$\frac{s}{s^2+\omega^2}$
9	Hyperbolic sine	$\sinh \alpha t$	$\frac{\alpha}{s^2-\alpha^2}$
10	Hyperbolic cosine	$\cosh \alpha t$	$\frac{s}{s^2-\alpha^2}$
11	Exponentially decaying sine wave	$e^{-\alpha t}\sin \omega t$	$\frac{\omega}{(s+\alpha)^2+\omega^2}$
12	Exponentially decaying cosine wave	$e^{-\alpha t}\cos \omega t$	$\frac{s+\alpha}{(s+\alpha)^2+\omega^2}$

Transfer Function: It is the ratio of Laplace transform of output signal to Laplace transform of input signal assuming all the initial conditions to be zero

Properties of Transfer function:

Zero initial condition It is same as Laplace transform of its impulse response Replacing 's' by *d/dt* in the transfer function, the differential equation can be obtained Poles and zeros can be obtained from the transfer function Stability can be known Can be applicable to linear system only

Advantages of Transfer function:

It is a mathematical model and gain of the system Replacing 's' by *d/dt* in the transfer function, the differential equation can be obtained
Poles and zeros can be obtained from the transfer function Stability can be known
Impulse response can be found

Disadvantages of Transfer function:

Applicable only to linear system
Not applicable if initial condition cannot be neglected

It gives no information about the actual structure of a physical system
Mechanical systems are of two types, i.e.
(i) Translational mechanical system
(ii) Rotational mechanical system.

Translational mechanical system

There are three basic elements in a translational mechanical system, i.e.
(a) Mass, (b) spring and (c) damper.

Rotational mechanical system

There are three basic elements in a Rotational mechanical system, i.e.
(a) Inertia, (b) spring and (c) damper.

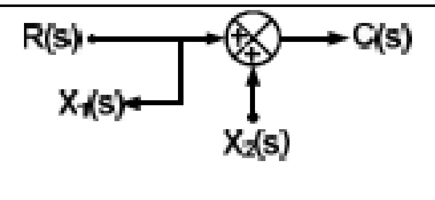
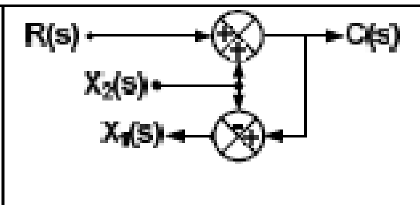
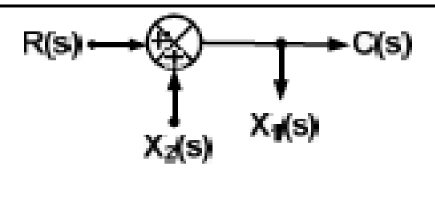
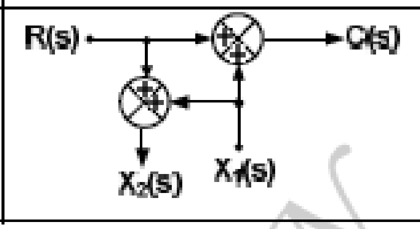
F-V analogy:

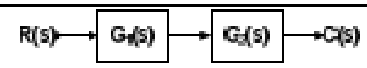
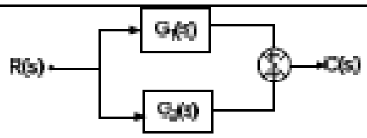
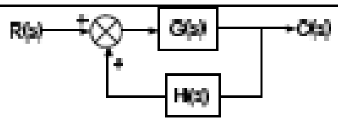
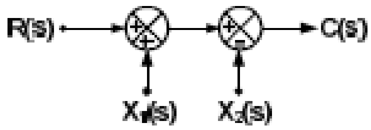
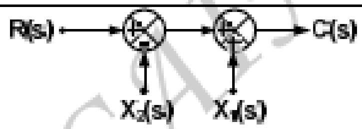
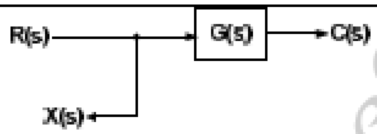
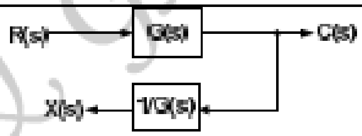
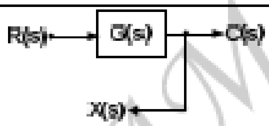
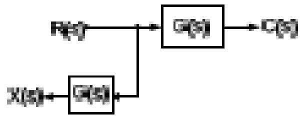
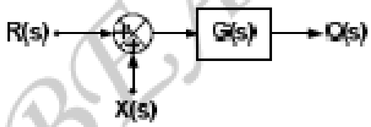
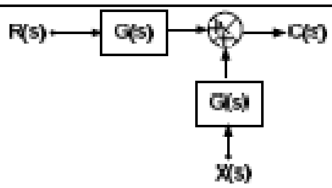
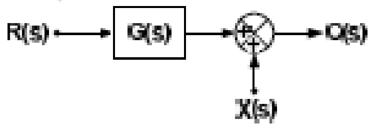
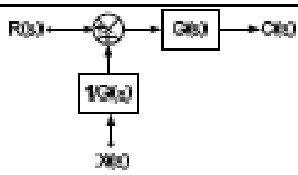
Translational	Rotational	Electrical
Force (f)	Torque (T)	Voltage (v)
Mass (M)	Inertia (J)	Inductance (L)
Damper (D)	Damper (D)	Resistance (R)
Spring (K)	Spring (K)	Elastance (1/C)
Displacement (x)	Displacement (Θ)	Charge (q)
Velocity (u) = $\dot{x}$	Velocity (u) = $\dot{\theta}$	Current (i) = $\dot{q}$

F-C analogy:

Translational	Rotational	Electrical
Force (f)	Torque (T)	Current (i)
Mass (M)	Inertia (J)	Capacitance (C)
Damper (D)	Damper (D)	Conductance (1/R)
Spring (K)	Spring (K)	Reciprocal of Inductance (1/L)
Displacement (x)	Displacement (Θ)	Flux linkage (ψ)
Velocity (u) = $\dot{x}$	Velocity (u) = $\dot{\theta}$	Voltage (v) = $\dot{\psi}$

Rules for reduction of block diagram:

9	Rule 9			Move take-off point after a summing-point
10	Rule 10			Move take-off point before a summing-point

Sl No.	Rule No.	Configuration	Equivalent	Name
1	Rule 1			Cascade
2	Rule 2			Parallel
3	Rule 3			Loop
4	Rule 4			Associative Law
5	Rule 5			Move take-off point after a block
6	Rule 6			Move take-off point before a block
7	Rule 7			Move summing-point point after a block
8	Rule 8			Move summing-point point before a block

Mason's gain formula:

$$G(s)=\frac{C(s)}{R(s)}=\frac{\sum_{k=1}^{N}P_k\Delta_k}{\Delta}$$

Types of feedback:

Degenerative feedback control system: It is a control system where the feedback signal opposes the input signal.

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Error Constant	Equation	Steady-state error (e_{ss})
Position Error Constant (K_P)	$K_p = \lim_{s\to 0} G(s)H(s)$	$e_{ss} = \frac{A}{1+K_p}$
Velocity Error Constant (K_V)	$K_V = \lim_{s\to 0} sG(s)H(s)$	$e_{ss} = \frac{A}{K_V}$
Acceleration Error Constant (K_A)	$K_A = \lim_{s\to 0} s^2G(s)H(s)$	$e_{ss} = \frac{A}{K_A}$

Type	Step input		Ramp input		Parabolic input	
	K_P	e_{ss}	K_V	e_{ss}	K_A	e_{ss}
Type 0	K	$\frac{A}{1+K}$	0	∞	0	∞
Type 1	∞	0	K	$\frac{A}{K}$	0	∞
Type 2	∞	0	∞	0	K	$\frac{A}{K}$

ζ <1 under damped
ζ =1 undamped
ζ >1 over damped
ζ =1 critical damped

Delay time, td: It is the time required to reach 50% of output.

Rise time, tr: The time required by the system response to reach from 10% to 90% of the final value for over-damped case, from 0% to 100% of the final value for under-damped case and from 5% to 95% of the critically value for over-damped case.

Peak time, tp: The time required by the system response to reach the first maximum value.

Peak overshoot, Mp: It is the time required to reach 50% of output.

Settling time, ts: It is the time taken by the system response to settle down and stay within 2% or 5% its final value.

Necessary condition of stability:
Coefficients of the characteristic polynomial must be positive.

Advantages of Routh-Hurwitz stability
(i) It is valid for only real coefficient of the characteristic equation
(ii) Unable to give exact locations of closed-loop poles
(iii) Does not suggest methods for stabilizing an unstable system
(iv) Applicable only to the linear system

Root locus: The locus of all the closed-loop poles for various values of the open-loop gain K is called **root locus**.

Behaviors of closed-loop poles

Closed-loop poles negative and real	Exponential decay	Stable
Closed-loop poles complex with negative real parts	Decaying and oscillatory	Stable
Closed-loop poles positive and real	Exponential increase	Unstable
Closed-loop poles complex with positive real parts	Exponential and oscillatory increase	Unstable

Polar Plots
It is a graphical method of determining stability of feedback control systems by using the polar plot of their open-loop transfer functions.
Nyquist plot: Nyquist criterion is a graphical method of determining stability of feedback control systems by using the Nyquist plot of their open-loop transfer functions.

Feedback transfer function

$$\frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)}$$

Gain Margin and Phase Margin
Phase crossover frequency *p* is the frequency at which the open-loop transfer function has a phase of 180.
The gain crossover frequency *g* is the frequency at which the open-loop transfer function has a unit gain.
Types of controllers
(i) P-controller
(ii) PI-controller
(iii) PD-controller
(iv) PID-controller