CHAPTER#1

1. Basic Concept of Control System

Control Engineering is concerned with techniques that are used to solve the following six problems in the most efficient manner possible.

(a)The identification problem :to measure the variables and convert data for analysis.

(b)The representation problem:to describe a system by an analytical form or mathematical model

(c)The solution problem:to determine the above system model response.

(d)The stability problem:general qualitative analysis of the system

(e)The design problem: modification of an existing system or develop a new one

(f)The optimization problem: from a variety of design to choose the best.

The two basic approaches to solve these six problems are conventional and modern approach. The electrical oriented conventional approach is based on complex function theory. The modern approach has mechanical orientation and based on the state variable theory.

Therefore, control engineering is not limited to any engineering discipline but is equally applicable to aeronautical, chemical, mechanical, environmental, civil and electrical engineering. For example, a control system often includes electrical, mechanical and chemical components. Furthermore, as the understanding of the dynamics of business, social and political systems increases; the ability to control these systems will also increase.

1.1. 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 behavior of a system by utilizing actual input signals.

Optimization: The adjustment of the parameters to achieve the most favorable 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.

1.2. Classification

1.2.1. Natural control system and Man-made control system:

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.

1.2.2. Automatic control system and Combinational control system:

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.

1.2.3. Time-variant control system and Time-invariant control system:

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.

1.2.4. Linear control system and Non-linear control system:

Linear control system: It is a control system that satisfies properties of homogeneity and additive.

- Homogeneous property: $f(x+y)=f(x)+f(y)$
- Additive property: $f(\alpha x)=\alpha f(x)$

Non-linear control system: It is a control system that does not satisfy properties of homogeneity and additive, i.e. $f(x)=x^3$

1.2.5. Continuous-Time control system and Discrete-Time control system:

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.

1.2.6. Deterministic control system and Stochastic control system:

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.

1.2.7. Lumped-parameter control system and Distributed-parameter control system:

Lumped-parameter control system: It is a control system where its mathematical model is represented by ordinary differential equations.

Distributed-parameter control system: It is a control system where its mathematical model is represented by an electrical network that is a combination of resistors, inductors and capacitors.

1.2.8. Single-input-single-output (SISO) control system and Multi-input-multi-output (MIMO) control system:

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.

1.2.9. Open-loop control system and Closed-loop control system:

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.

1.3. Open-loop control system and Closed-loop control system

1.3.1. 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 as shown in Fig.1.1.

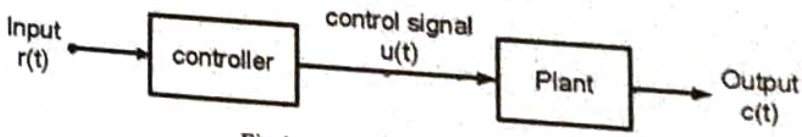

Fig.1.1. An open-loop system

Examples: traffic signal, washing machine, bread toaster, etc.

Advantages:

- Simple design and easy to construct
- Economical
- Easy for maintenance
- Highly stable operation

Dis-advantages:

- Not accurate and reliable when input or system parameters are variable in nature
- Recalibration of the parameters are required time to time

1.3.2. Closed-loop control system:

It is a control system where its control action depends on both of its input signal and output response as shown in Fig.1.2.

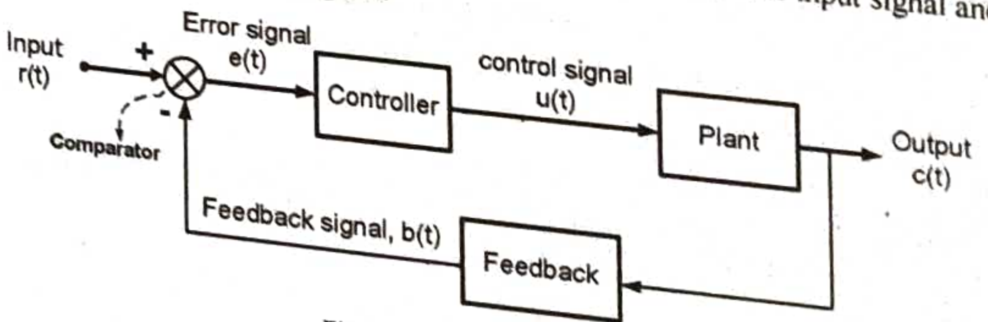

Fig.1.2. A closed-loop system

Examples: automatic electric iron, missile launcher, speed control of DC motor, etc.

Advantages:

- More accurate operation than that of open-loop control system
- Can operate efficiently when input or system parameters are variable in nature
- Less nonlinearity effect of these systems on output response
- High bandwidth of operation
- There is facility of automation
- Time to time recalibration of the parameters are not required

Dis-advantages:

- Complex design and difficult to construct

- Expensive than that of open-loop control system
- Complicate for maintenance
- Less stable operation than that of open-loop control system

1.3.3. Comparison between Open-loop and Closed-loop control systems:

It is a control system where its control action depends on both of its input signal output response.

Sl. No.	Open-loop control systems	Closed-loop control system
1	No feedback is given to the control system	A feedback is given to the control sy
2	Cannot be intelligent	Intelligent controlling action
3	There is no possibility of undesirable system oscillation(hunting)	Closed loop control introduces possibility of undesirable sy 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 constant input, depending upon 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 variati 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

1.4. Servomechanism

It is the feedback unit used in a control system. In this system, the control variable is a mechanical signal such as position, velocity or acceleration. Here, the output signal is directly fed to the comparator as the feedback signal, b(t) of the closed-loop control system. This type of system is used where both the command and output signals are mechanical in nature. A position control system as shown in Fig.1.3 is a simple example of this type mechanism. The block diagram of the servomechanism of an automatic steering system is shown in Fig.1.4.

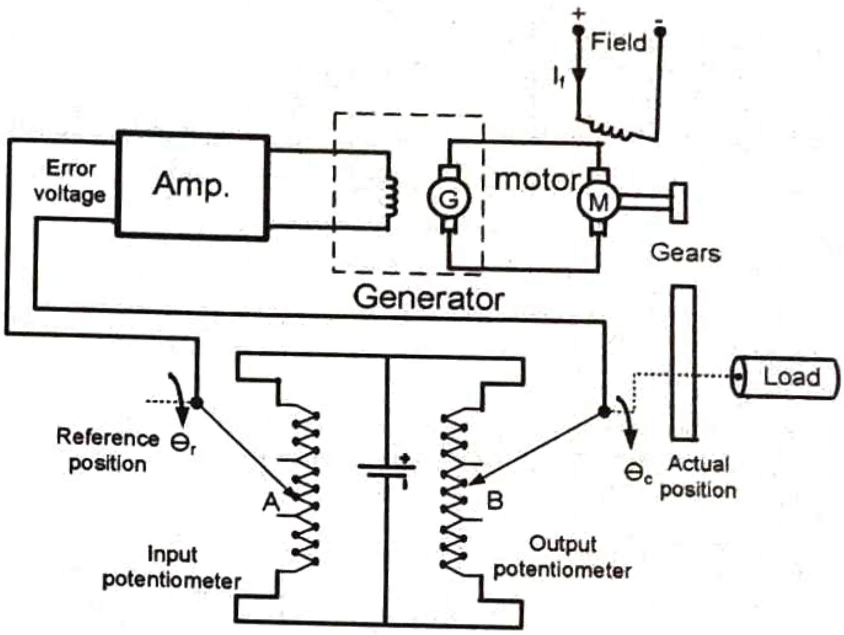

Fig.1.3. Schematic diagram of a servomechanism

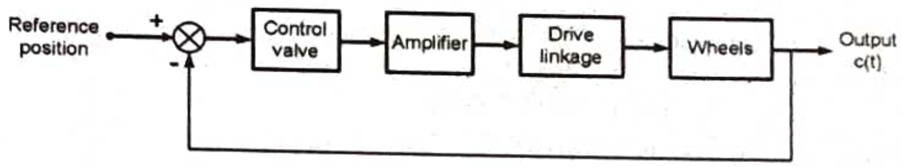

Fig.1.4. Block diagram of a servomechanism

Examples:

- Missile launcher
- Machine tool position control
- Power steering for an automobile
- Roll stabilization in ships, etc.

1.5. Regulators

It is also a feedback unit used in a control system like servomechanism. But, the output is kept constant at its desired value. The schematic diagram of a regulating system is shown in Fig.1.5. Its corresponding simplified block diagram model is shown in Fig.1.6.

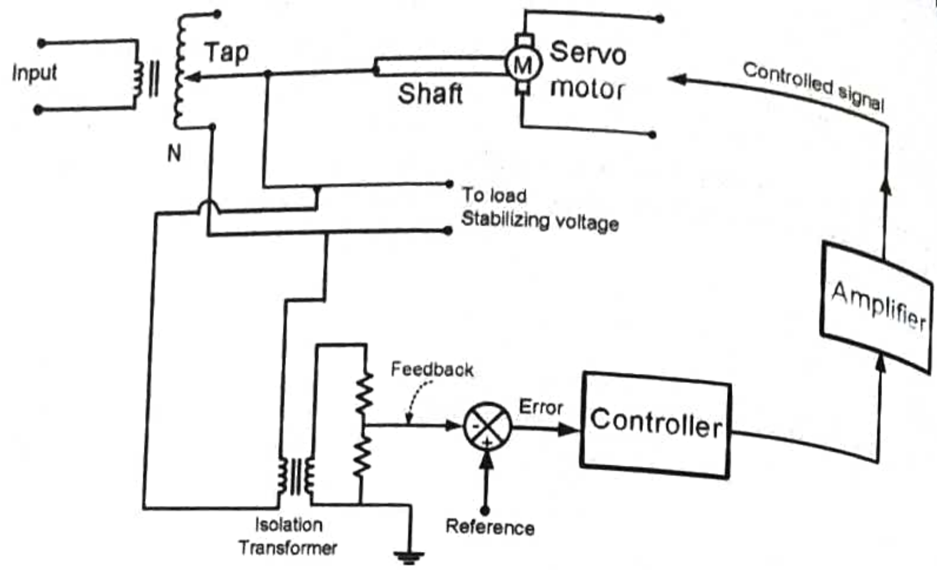

Fig.1.5. Schematic diagram of a regulating system

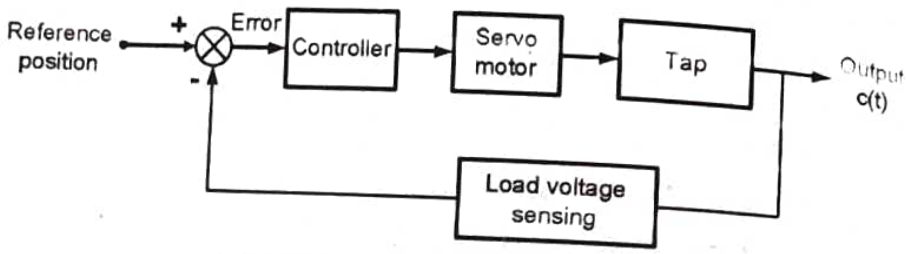

Fig.1.6. Block diagram of a regulating system

Examples:

- Temperature regulator
- Speed governor
- Frequency regulators, etc.

CHAPTER#2

2. Control System Dynamics

2.1. Definition: It is the study of characteristics behaviour of dynamic system, i.e.

(a) Differential equation

i. First-order systems
ii. Second-order systems

(b) System transfer function: Laplace transform

2.2. Laplace Transform: Laplace transforms convert differential equations into algebraic equations. They are related to frequency response.

$$L\{x(t)\} = X(s) = \int_0^\infty x(t)e^{-st}\,dt \tag{2.1}$$

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

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	$(1-e^{-\alpha t})$	$\frac{\alpha}{s(s+\alpha)}$
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	$e^{-\alpha t}\cos \omega t$	$\frac{s+\alpha}{(s+\alpha)^2+\omega^2}$

2.3. Solution of system dynamics in Laplace form: Laplace transforms can be solved using partial fraction method.

A system is usually represented by following dynamic equation.

$$N(s) = \frac{A(s)}{B(s)} \tag{2.3}$$

The factor of denominator, B(s) is represented by following forms,

i. Unrepeated factors