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Department of Electrical and Electronics Engineering

Bridge Course
On
Control Systems Engineering

By

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Ohm's Law

$$E = IR \qquad I = \frac{E}{R} \qquad R = \frac{E}{I}$$

Joule's Law

$$P = IE \qquad P = \frac{E^2}{R} \qquad P = I^2R$$

Where,

$E =$ Voltage in volts

$I =$ Current in amperes (amps)

$R =$ Resistance in ohms

$P =$ Power in watts

Kirchhof's Laws:

"The algebraic sum of all voltages in a loop must equal zero."
—Kirchhoff's Voltage Law (KVL)

"The algebraic sum of all currents entering and exiting a node must equal zero."
—Kirchhoff's Current Law (KCL)

- Components in a series circuit share the same current:
  - $I_{total} = I_1 = I_2 = \ldots I_n$
- Total resistance in a series circuit is equal to the sum of the individual resistances, making it greater than any of the individual resistances:
  - $R_{total} = R_1 + R_2 + \ldots R_n$
- Total voltage in a series circuit is equal to the sum of the individual voltage drops:
  - $E_{total} = E_1 + E_2 + \ldots E_n$
- Components in a parallel circuit share the same voltage:
  - $E_{total} = E_1 = E_2 = \ldots E_n$
- Total resistance in a parallel circuit is less than any of the individual resistances:
  - $R_{total} = 1 / (1/R_1 + 1/R_2 + \ldots 1/R_n)$
- Total current in a parallel circuit is equal to the sum of the individual branch currents:
  - $I_{total} = I_1 + I_2 + \ldots I_n$

Basic concepts of Control Systems

Control Systems Engineering With Classical and Modern Techniques And Advanced Concepts. Methods considered here will consist of both "Classical" control methods, and

"Modern" control methods. Also, discretely sampled systems (digital/computer systems) will be considered in parallel with the more common analog methods.

This will require prior knowledge of linear algebra, integral and differential calculus, and at least some exposure to ordinary differential equations. In addition, a prior knowledge of integral transforms, specifically the Laplace and Z transforms will be very beneficial. Also, prior knowledge of the Fourier Transform will shed more light on certain subjects.

What are Control Systems?

The study and design of automatic Control Systems, a field known as control engineering, has become important in modern technical society. From devices as simple as a toaster or a toilet, to complex machines like space shuttles and power steering, control engineering is a part of our everyday life. This introduces the field of control engineering and explores some of the more advanced topics in the field. Note, however, that control engineering is a very large field, foundation of control engineering and introduction to selected advanced topics in the field.Control systems are components that are added to other components, to increase functionality, or to meet a set of design criteria.

For example, We have a particular electric motor that is supposed to turn at a rate of 40 RPM. To achieve this speed, we must supply 10 Volts to the motor terminals. However, with 10 volts supplied to the motor at rest, it takes 30 seconds for our motor to get up to speed. This is valuable time lost.This simple example, however can be complex to both users and designers of the motor system. It may seem obvious that the motor should start at a higher voltage, so that it accelerates faster. Then we can reduce the supply back down to 10 volts once it reaches ideal speed.This is clearly a simplistic example, but it illustrates an important point: we can add special "Controller units" to preexisting systems, to improve performance and meet new system specifications.

CONTROL SYSTEMS CLASSIFICATION

Continuous System : All Signals in the system are continuous.

Discrete System : There exists discrete signals in the system

Linear System : The system satisfies super position principle.

Non-linear System : The system doesn’t satisfies super position principle.

Time Invariant System : Parameters of the system don’t change over time.

Time Varying System : Parameters of the system change over time.

SISO System : Single Input Single Output System

MIMO System : Multi Input Multi Output System

When a number of elements are combined together to form a system to produce desired output then the system is referred as control system. As this system controls the output, it is so referred. Each element connected to the system has its own effect on the output.

Definition of Control System

A control system is a system of devices or set of devices, that manages, commands, directs or regulates the behavior of other device(s) or system(s) to achieve desire results. In other words the definition of control system can be rewritten as A control system is a system, which controls other system. As the human civilization is being modernized day by day the demand of automation is increasing accordingly. Automation highly requires control of devices.In recent years, control systems plays main role in the development and advancement of modern technology and civilization. Practically every aspects of our day-to-day life is affected less or more by some control system. A bathroom toilet tank, a refrigerator, an air conditioner, a geezer, an automatic iron, an automobile all are control system. These systems are also used in industrial process for more output. We find control system in quality control of products, weapons system, transportation systems, power system, space technology, robotics and many more. The principles of control theory is applicable to engineering and non engineering field both.

Feature of Control System

The main feature of control system is, there should be a clear mathematical relation between input and output of the system. When the relation between input and output of the system can be represented by a linear proportionality, the system is called linear control system. Again when the relation between input and output cannot be represented by single linear proportionality, rather the input and output are related by some non-linear relation, the system is referred as non-linear control system.

Requirement of Good Control System

Accuracy : Accuracy is the measurement tolerance of the instrument and defines the limits of the errors made when the instrument is used in normal operating conditions. Accuracy can be improved by using feedback elements. To increase accuracy of any control system error detector should be present in control system.

Sensitivity : The parameters of control system are always changing with change in surrounding conditions, internal disturbance or any other parameters. This change can be expressed in terms of sensitivity. Any control system should be insensitive to such parameters but sensitive to input signals only.

Noise : An undesired input signal is known as noise. A good control system should be able to reduce the noise effect for better performance.

Stability : It is an important characteristic of control system. For the bounded input signal, the output must be bounded and if input is zero then output must be zero then such a control system is said to be stable system.

Bandwidth : An operating frequency range decides the bandwidth of control system. Bandwidth should be large as possible for frequency response of good control system.

Speed : It is the time taken by control system to achieve its stable output. A good control system possesses high speed. The transient period for such system is very small.

Oscillation : A small numbers of oscillation or constant oscillation of output tend to system to be stable.

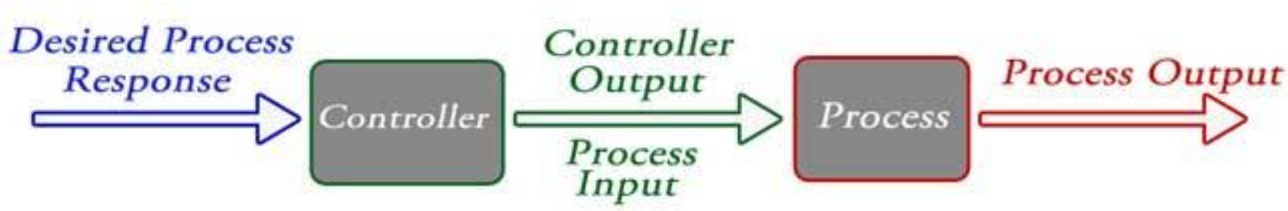
Types of Control Systems

There are various types of control system but all of them are created to control outputs. The system used for controlling the position, velocity, acceleration, temperature, pressure, voltage and current etc. are examples of control systems.Let us take an example of simple temperature controller of the room, to clear the concept. Suppose there is a simple heating element, which is heated up as long as the electric power supply is switched on. As long as the power supply switch of the heater is on the temperature of the room rises and after achieving the desired temperature of the room, the power supply is switched off. Again due to ambient temperature, the room temperature falls and then manually the heater element is switched on to achieve the desired room temperature again. In this way one can manually control the room temperature at desired level. This is an example of manual control system**.** This system can further be improved by using timer switching arrangement of the power supply where the supply to the heating element is switched on and off in a predetermined interval to achieve desired temperature level of the room. There is another improved way of controlling the temperature of the room. Here one sensor measures the difference between actual temperature and desired temperature. If there is any difference between them, the heating element functions to reduce the difference and when the difference becomes lower than a predetermined level, the heating elements stop functioning. Both forms of the system are automatic control system. In former one the input of the system is entirely independent of the output of the system. Temperature of the room (output) increases as long as the power supply switch is kept on. That means heating element produces heat as long as the power supply is kept on and final room temperature does not have any control to the input power supply of the system. This system is referred as open loop control system**.**

The heating elements of the system function, depending upon the difference between, actual temperature and desired temperature. This difference is called error of the system. This error signal is fed back to the system to control the input. As the input to output path and the error feedback path create a closed loop.

Open Loop Control System

A control system in which the control action is totally independent of output of the system then it is called open loop control system. Manual control system is also an open loop control system. Fig - 1 shows the block diagram of open loop control system in which process output is totally independent of controller action.



Practical Examples of Open Loop Control System

1. Electric Hand Drier - Hot air (output) comes out as long as you keep your hand under the machine, irrespective of how much your hand is dried.
2. Automatic Washing Machine - This machine runs according to the pre-set time irrespective of washing is completed or not.
3. Bread Toaster - This machine runs as per adjusted time irrespective of toasting is completed or not.
4. Automatic Tea/Coffee Maker - These machines also function for pre adjusted time only.
5. Timer Based Clothes Drier - This machine dries wet clothes for pre-adjusted time, it does not matter how much the clothes are dried.
6. Light Switch - Lamps glow whenever light switch is on irrespective of light is required or not.
7. Volume on Stereo System - Volume is adjusted manually irrespective of output volume level.

Advantages of Open Loop Control System

1. Simple in construction and design.
2. Economical.
3. Easy to maintain.
4. Generally stable.
5. Convenient to use as output is difficult to measure.

Disadvantages of Open Loop Control System

1. They are inaccurate.

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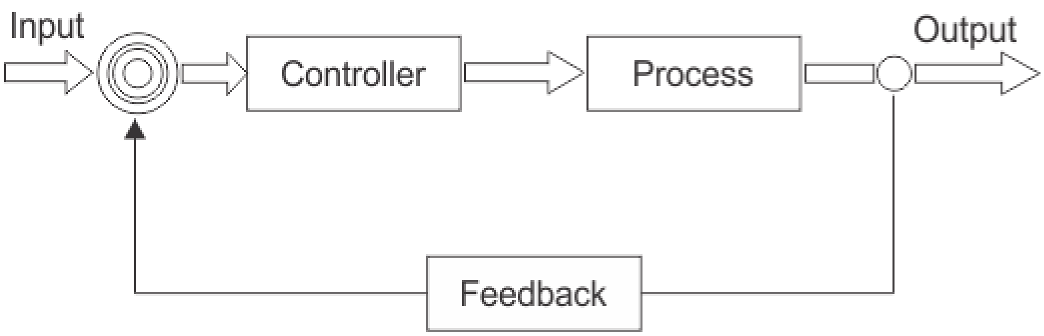
2. They are unreliable.
3. Any change in output cannot be corrected automatically.

Closed Loop Control System

Control system in which the output has an effect on the input quantity in such a manner that the input quantity will adjust itself based on the output generated is called closed loop control system**.** Open loop control system can be converted in to closed loop control system by providing a feedback. This feedback automatically makes the suitable changes in the output due to external disturbance. In this way closed loop control system is called automatic control system. Figure below shows the block diagram of closed loop control system in which feedback is taken from output and fed in to input.



Practical Examples of Closed Loop Control System

1. Automatic Electric Iron - Heating elements are controlled by output temperature of the iron.
2. Servo Voltage Stabilizer - Voltage controller operates depending upon output voltage of the system.
3. Water Level Controller - Input water is controlled by water level of the reservoir.
4. Missile Launched and Auto Tracked by Radar - The direction of missile is controlled by comparing the target and position of the missile.
5. An Air Conditioner - An air conditioner functions depending upon the temperature of the room.
6. Cooling System in Car - It operates depending upon the temperature which it controls.

Advantages of Closed Loop Control System

1. Closed loop control systems are more accurate even in the presence of non-linearity.
2. Highly accurate as any error arising is corrected due to presence of feedback signal.
3. Bandwidth range is large.
4. Facilitates automation.
5. The sensitivity of system may be made small to make system more stable.
6. This system is less affected by noise.

Disadvantages of Closed Loop Control System

1. They are costlier.
2. They are complicated to design.
3. Required more maintenance.
4. Feedback leads to oscillatory response.
5. Overall gain is reduced due to presence of feedback.
6. Stability is the major problem and more care is needed to design a stable closed loop system.

Transient Response of Control System

As the name suggests transient response of control system means changing so, this occurs mainly after two conditions and these two conditions are written as follows-

Condition one : Just after switching 'on' the system that means at the time of application of an input signal to the system.

Condition second : Just after any abnormal conditions. Abnormal conditions may include sudden change in the load, short circuiting etc.

Steady State Response of Control System

Steady state occurs after the system becomes settled and at the steady system starts working normally**.** Steady state response of control system is a function of input signal and it is also called as forced response.

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Table of Laplace Transforms

	$f(t)=\mathfrak{L}^{-1}\{F(s)\}$	$F(s)=\mathfrak{L}\{f(t)\}$		$f(t)=\mathfrak{L}^{-1}\{F(s)\}$	$F(s)=\mathfrak{L}\{f(t)\}$
1.	1	$\frac{1}{s}$	2.	$\mathbf{e}^{at}$	$\frac{1}{s-a}$
3.	$t^n, \quad n=1,2,3,\ldots$	$\frac{n!}{s^{n+1}}$	4.	$t^p, p > -1$	$\frac{\Gamma(p+1)}{s^{p+1}}$
5.	$\sqrt{t}$	$\frac{\sqrt{\pi}}{2s^{\frac{3}{2}}}$	6.	$t^{n-\frac{1}{2}}, \quad n=1,2,3,\ldots$	$\frac{1\cdot 3\cdot 5\cdots(2n-1)\sqrt{\pi}}{2^n s^{n+\frac{1}{2}}}$
7.	$\sin(at)$	$\frac{a}{s^2+a^2}$	8.	$\cos(at)$	$\frac{s}{s^2+a^2}$
9.	$t\sin(at)$	$\frac{2as}{(s^2+a^2)^2}$	10.	$t\cos(at)$	$\frac{s^2-a^2}{(s^2+a^2)^2}$
11.	$\sin(at)-at\cos(at)$	$\frac{2a^3}{(s^2+a^2)^2}$	12.	$\sin(at)+at\cos(at)$	$\frac{2as^2}{(s^2+a^2)^2}$
13.	$\cos(at)-at\sin(at)$	$\frac{s(s^2-a^2)}{(s^2+a^2)^2}$	14.	$\cos(at)+at\sin(at)$	$\frac{s(s^2+3a^2)}{(s^2+a^2)^2}$
15.	$\sin(at+b)$	$\frac{s\sin(b)+a\cos(b)}{s^2+a^2}$	16.	$\cos(at+b)$	$\frac{s\cos(b)-a\sin(b)}{s^2+a^2}$
17.	$\sinh(at)$	$\frac{a}{s^2-a^2}$	18.	$\cosh(at)$	$\frac{s}{s^2-a^2}$
19.	$\mathbf{e}^{at}\sin(bt)$	$\frac{b}{(s-a)^2+b^2}$	20.	$\mathbf{e}^{at}\cos(bt)$	$\frac{s-a}{(s-a)^2+b^2}$
21.	$\mathbf{e}^{at}\sinh(bt)$	$\frac{b}{(s-a)^2-b^2}$	22.	$\mathbf{e}^{at}\cosh(bt)$	$\frac{s-a}{(s-a)^2-b^2}$
23.	$t^n\mathbf{e}^{at}, \quad n=1,2,3,\ldots$	$\frac{n!}{(s-a)^{n+1}}$	24.	$f(ct)$	$\frac{1}{c}F\left(\frac{s}{c}\right)$
25.	$u_c(t)=u(t-c)$ Heaviside Function	$\frac{\mathbf{e}^{-cs}}{s}$	26.	$\delta(t-c)$ Dirac Delta Function	$\mathbf{e}^{-cs}$
27.	$u_c(t)f(t-c)$	$\mathbf{e}^{-cs}F(s)$	28.	$u_c(t)g(t)$	$\mathbf{e}^{-cs}\mathfrak{L}\{g(t+c)\}$
29.	$\mathbf{e}^{ct}f(t)$	$F(s-c)$	30.	$t^n f(t), \quad n=1,2,3,\ldots$	$(-1)^n F^{(n)}(s)$
31.	$\frac{1}{t}f(t)$	$\int_s^\infty F(u)\,du$	32.	$\int_0^t f(v)\,dv$	$\frac{F(s)}{s}$
33.	$\int_0^t f(t-\tau)g(\tau)\,d\tau$	$F(s)G(s)$	34.	$f(t+T)=f(t)$	$\frac{\int_0^T \mathbf{e}^{-st}f(t)\,dt}{1-\mathbf{e}^{-sT}}$
35.	$f'(t)$	$sF(s)-f(0)$	36.	$f''(t)$	$s^2F(s)-sf(0)-f'(0)$
37.	$f^{(n)}(t)$	$s^nF(s)-s^{n-1}f(0)-s^{n-2}f'(0)\cdots-sf^{(n-2)}(0)-f^{(n-1)}(0)$			

Table Notes

1. This list is not a complete listing of Laplace transforms and only contains some of the more commonly used Laplace transforms and formulas.

2. Recall the definition of hyperbolic functions.

$$\cosh(t) = \frac{\mathbf{e}^{t} + \mathbf{e}^{-t}}{2} \qquad \sinh(t) = \frac{\mathbf{e}^{t} - \mathbf{e}^{-t}}{2}$$

3. Be careful when using "normal" trig function vs. hyperbolic functions. The only difference in the formulas is the "+ a^2" for the "normal" trig functions becomes a "- a^2" for the hyperbolic functions!

4. Formula #4 uses the Gamma function which is defined as

$$\Gamma(t) = \int_0^{\infty} \mathbf{e}^{-x} x^{t-1}\, dx$$

If n is a positive integer then,

$$\Gamma(n+1) = n!$$

The Gamma function is an extension of the normal factorial function. Here are a couple of quick facts for the Gamma function

$$\Gamma(p+1) = p\Gamma(p)$$

$$p(p+1)(p+2)\cdots(p+n-1) = \frac{\Gamma(p+n)}{\Gamma(p)}$$

$$\Gamma\left(\frac{1}{2}\right) = \sqrt{\pi}$$

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Differentiation Formulas

$$\frac{d}{dx}k = 0 \quad (1)$$

$$\frac{d}{dx}[f(x) \pm g(x)] = f'(x) \pm g'(x) \quad (2)$$

$$\frac{d}{dx}[k \cdot f(x)] = k \cdot f'(x) \quad (3)$$

$$\frac{d}{dx}[f(x)g(x)] = f(x)g'(x) + g(x)f'(x) \quad (4)$$

$$\frac{d}{dx}\left(\frac{f(x)}{g(x)}\right) = \frac{g(x)f'(x) - f(x)g'(x)}{[g(x)]^2} \quad (5)$$

$$\frac{d}{dx}f(g(x)) = f'(g(x)) \cdot g'(x) \quad (6)$$

$$\frac{d}{dx}x^n = nx^{n-1} \quad (7)$$

$$\frac{d}{dx}\sin x = \cos x \quad (8)$$

$$\frac{d}{dx}\cos x = -\sin x \quad (9)$$

$$\frac{d}{dx}\tan x = \sec^2 x \quad (10)$$

$$\frac{d}{dx}\cot x = -\csc^2 x \quad (11)$$

$$\frac{d}{dx}\sec x = \sec x \tan x \quad (12)$$

$$\frac{d}{dx}\csc x = -\csc x \cot x \quad (13)$$

$$\frac{d}{dx}e^x = e^x \quad (14)$$

$$\frac{d}{dx}a^x = a^x \ln a \quad (15)$$

$$\frac{d}{dx}\ln|x| = \frac{1}{x} \quad (16)$$

$$\frac{d}{dx}\sin^{-1} x = \frac{1}{\sqrt{1-x^2}} \quad (17)$$

$$\frac{d}{dx}\cos^{-1} x = \frac{-1}{\sqrt{1-x^2}} \quad (18)$$

$$\frac{d}{dx}\tan^{-1} x = \frac{1}{x^2+1} \quad (19)$$

$$\frac{d}{dx}\cot^{-1} x = \frac{-1}{x^2+1} \quad (20)$$

$$\frac{d}{dx}\sec^{-1} x = \frac{1}{|x|\sqrt{x^2-1}} \quad (21)$$

$$\frac{d}{dx}\csc^{-1} x = \frac{-1}{|x|\sqrt{x^2-1}} \quad (22)$$

Integration Formulas

$$\int dx = x + C \quad (1)$$

$$\int x^n\,dx = \frac{x^{n+1}}{n+1} + C \quad (2)$$

$$\int \frac{dx}{x} = \ln|x| + C \quad (3)$$

$$\int e^x\,dx = e^x + C \quad (4)$$

$$\int a^x\,dx = \frac{1}{\ln a}a^x + C \quad (5)$$

$$\int \ln x\,dx = x\ln x - x + C \quad (6)$$

$$\int \sin x\,dx = -\cos x + C \quad (7)$$

$$\int \cos x\,dx = \sin x + C \quad (8)$$

$$\int \tan x\,dx = -\ln|\cos x| + C \quad (9)$$

$$\int \cot x\,dx = \ln|\sin x| + C \quad (10)$$

$$\int \sec x\,dx = \ln|\sec x + \tan x| + C \quad (11)$$

$$\int \csc x\,dx = -\ln|\csc x + \cot x| + C \quad (12)$$

$$\int \sec^2 x\,dx = \tan x + C \quad (13)$$

$$\int \csc^2 x\,dx = -\cot x + C \quad (14)$$

$$\int \sec x \tan x\,dx = \sec x + C \quad (15)$$

$$\int \csc x \cot x\,dx = -\csc x + C \quad (16)$$

$$\int \frac{dx}{\sqrt{a^2-x^2}} = \sin^{-1}\frac{x}{a} + C \quad (17)$$

$$\int \frac{dx}{a^2+x^2} = \frac{1}{a}\tan^{-1}\frac{x}{a} + C \quad (18)$$

$$\int \frac{dx}{x\sqrt{x^2-a^2}} = \frac{1}{a}\sec^{-1}\frac{|x|}{a} + C \quad (19)$$