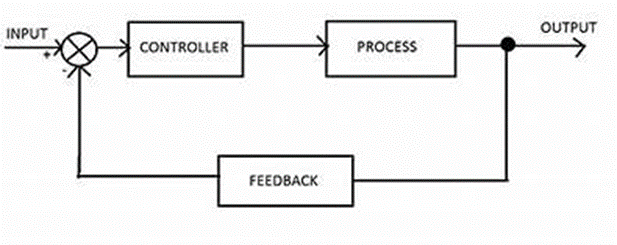
Control systems

**INTRODUCTION**

A control system is a system in which the output is controlled by varying the input. The first control system device was James watt’s fly ball governor, which was invented in 1767.

The aim of inventing Fly ball governor was to keep the speed of the engine constant by regulating the supply of the steam to the engine.

In a control system, the behaviour of the system is described by the differential equations. The differential equations can be either ordinary differential equations or the difference equation.

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What is control systems?

A control system is defined as a system of devices that manages, commands, directs, or regulates the behaviour of other devices or systems to achieve a desired result.

A control system achieves this through control loops, which are a process designed to maintain a process variable at a desired set point.

In other words, the definition of a control system can be simplified as a system, which controls other systems. As human civilization is being modernized day by day the demand for automation has increased alongside it. Automation requires control over systems of interacting devices.

In recent years, control systems have played a central role in the development of modern technology and civilization. Practically every aspect of our day-to-day life is affected more or less by some type of control system.

Examples of control systems in your day-to-day life include an air conditioner, a refrigerator, a bathroom toilet tank, an automatic iron, and many processes within a car-such as cruise control.

In industrial settings, we find control systems in the quality control products, weapon systems, space technology, robotics, and much more.

**Need for a control system**

Control systems are considered as one of the major aspects of our growing technology**.** Every sectorof the industry is linked with the control system in some or the other way.

Like in space technology, power system, transportation system, robotics, machine tool controlling etc., everything needs controlling. So, these are basically control systems.

These basically provide the desired responses or application when proper controlling is provided to them.

**Advantages of using control systems**:

* Power amplification.
* Remote control.
* Convenience of input form.
* Compression for disturbances.

**Feature of control system**

The main feature of a control system is that there should be a clear mathematical relationship between the 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 a linear control system.

Again, when the relationship between input and output cannot be represented by single linear proportionality, rather the input and output are related by some non-linear control system.

**Requirements of a good control system**

1. **sensitivity:** sensitivity is the ability to show instant variation in output whenever there exists any change in input. There are external parameters like temperature change or other atmospheric conditions that hinder the actual performance of the system. So, a control system must be sensitive only to the actually applied input and not to other external parameters.
2. **Stability:** The system must be stable while providing the output without showing fluctuation with time. It is an important characteristic of the control system. For the bounded input signal, the output must be bounded and if the input is zero then the output must be zero then such a control system is said to be a stable system.
3. **Bandwidth:** The permissible frequency range of the system specifies its bandwidth. And so, to have a good frequency response the system must possess high bandwidth.
4. **Noise:** Unwanted signals that hinders the performance of the system adversely is known as noise. A good control system must show the least susceptibility towards the noise.
5. **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 the accuracy of any control system error detector should be present in the control system.

1. **Speed:** Speed defines the processing time of the system within which the specified output is achieved. so, the speed of the system must be high enough to deliver the output timely.
2. **Oscillation:** A small number of oscillations or constant oscillations of output tends to indicate the system to be stable.

**Basic components**

The basic components of a control system are as below:

* Plant
* Feedback
* Controller
* Error detector

The combined unit or error detector, controller, plant, and feedback make a complete automatic control system.

* **Plant:**
* A plant may be a piece of equipment, perhaps just a set of machine parts functioning together, the purpose of which is to perform a particular operation.
* We shall call any physical object to be controlled such as a mechanical device, a heating furnace, a chemical reactor, or a space craft) a plant.
* **Process:**
* A process is any operation to be controlled. Processes can be chemical, economic, biological, etc.
* **System:**
* A system is a combination of components that act together and perform a certain objective.
* **Disturbances:**
* A disturbance is a signal that tends to adversely affect the value of the output of a system.
* If a disturbance is generated within the system, it is called internal, while an external disturbance is generated outside the system and is an input.
* **Feedback control:**
* Feedback control is an operation in which the difference between the output of the system and the reference input by comparing these using the difference as a means of control.
* The feedback signal is fed to the error detector, Negative feedback is preferred as it results in better stability and accuracy. The other disturbance signals are rejected.
* **Controlled variable**:
* The controlled variable is the quantity or condition that is measured and controlled.
* **Manipulated variable or control signal:**
* The manipulated variable or control signal is the quantity or condition that is varied by the controller so as to affected the value of the controlled variable.
* Normally, the controlled variable is the output of the system.
* **Control:**
* Control means measuring the value of the controlled variable of the system and applying the control signal to the system to correct or limit deviation of the measured value from a desired value.
* **Error detector:**
* The function of error detector is to compare the reference input with the feedback signal. It produces an error signal which is a difference of two inputs which are reference signal and a feedback signal.
* The error signal is fed to the controller for necessary controlled action. This error signal is used to correct the output if there is a deviation from the desired value.

**Types of control systems**

A control system is a system of devices that manages, commands, directs or regulates the behaviour of other devices to achieve a desired result.

In other words, the definition of a control system can be simplified as a system which controls other systems to achieve a desired state.

There are various types of control systems those are:

1. Linear control systems

In order to understand the linear control system, we should first understand the principle of superposition. The principle of superposition theorem includes two the important properties and they are explained below:

Homogeneity : A system is said to be homogeneous, if we multiply input with some constant A then the output will also be multiplied by the same value of constant (i.e. A).

**Additivity :** suppose we have a system S and we are giving the input to this system as a1 for the first time and we are getting the output as b1 corresponding to input a1. On the second time we are giving input a2 and corresponds to this we are getting the output as b2.

Now suppose this time we are giving input as a summation of the previous inputs (i.e., a1+a2) and corresponding to this input suppose we are getting the output as (b1+b2) then we can say that system S is following the property of additivity.

**Examples of linear control system**

Consider a purely resistive network with a constant DC source. This circuit follows the principle of homogeneity and additivity. All the undesired effects are neglected and assuming ideal behaviour of each element in the network, we say that we will get linear voltage and current characteristic. This is the example of a linear control system.

**Non-linear control systems**

We can simply define a nonlinear control system as a control system which does not follow the principle of homogeneity. In real life, all control systems are non-linear systems (linear control systems only exists in theory). The describing function is an approximate procedure for Analysing certain nonlinear control problems.

**Examples of non-linear system**

A well-known example of a non-linear system is a magnetization curve or no-load curve of a DC machine. We will discuss briefly no-load curve of DC machines here: no load curve gives us the relationship between the air gap flux and the field winding mmf.it is very clear from the curve given below that in the beginning, there is a linear relationship between the air gap flux but after this, saturation has come which shows the nonlinear behaviour of the curve or characteristics of the **nonlinear system**

**Analog or continuous system**

In these types if control systems, we have a continuous signal as the input to the system. These signals are the continuous function if time. We may have various sources of continuous input signal like sinusoidal type signal input source, square type of signal input source; the signal may be in the form of continuous triangle etc.

**Digital or discrete system**

In these types of control systems, we have a discrete signal (or signal may be in the form of pulse) as the input to the system. These signals have a discrete interval of time. We can convert various sources of continuous input signal like sinusoidal type signal input source, square type if signal input source etc into a discrete form using the switch.

Now there are various advantages of discrete or digital system over the Analog system and these advantages are written below:

* Digital systems can handle nonlinear control systems more effectively than the Analog type of systems.
* Power requirement in case of a discrete or digital system is less as compared to Analog systems.
* Digital system has a higher rate of accuracy and can perform various complex computations easily as compared to Analog systems.
* Reliability of the digital system is more as compared to Analog system. They also have a small and compact size.
* Digital system works on the logical operations which increases their accuracy many times.
* Losses in case of discrete systems are less as compared to Analog systems in general.

**Single input single output systems**

These are also known as SISO type of system. In this, the system has single input for a single output. Various example of this kind of system may include temperature control, position control system, etc.

**Multiple input multiple output systems**

These are also known as MIMO type of system. In this, the system has multiple outputs for multiple inputs. Various example of this kind of system may include PLC type system etc.

**Lumped parameter system**

In these types of control systems, the various **active and passive components** are assumed to be concentrated at a point and that’s why these are called lumped parameter type of system. Analysis of such type of system is very easy which includes differential equations.

**Distributed parameter system**

In these types of control systems, the various active (like inductors and capacitors) are assumed to be distributed uniformly along the length and that’s why these are called distributed parameter type of system. Analysis of such type of system is slightly difficult which includes partial differential equations.

**Deterministic versus stochastic control system**

A control system is deterministic if the response to input is predictable and repeatable. If not, the control system is a stochastic control system.

**Open loop control system**

Definition: An open-loop system is a type of control system in which the output of the system depends on the input but the input or the controller is independent of the output of the system. These systems do not contain any feedback loop and thus are also known as non-feedback system.

In open-loop systems, the output is neither measured nor fed back to the input for further consideration.

**Open loop system**

A control system directs the operation of a system in order to carry out a specified objective.

Everything around us that provides an output requires proper controlling. Like a fan, tv, refrigerator to satellites etc. everything needs controlling, thus are control systems.

In open-loop control system, a reference input is given to the system in order to get the desired output. But the achieved output is not considered by the system for further reference input.

The figure here represents the block diagram of an open-loop control system:

Here as we can see that the system consists of two blocks, one is the controller while other is controlled process.

Basically, according to the required output, an input is provided to the controller of the system. Depending on the achieved input, the controller generates the control signal which is fed to the processing unit. Thus, according to the control signal, proper processing is performed and output is achieved.

But as there is no feedback path present in the system, thus whether the achieved output is desired or not the input has nothing to do with it.

So, this is the reason we say that in an open-loop system the input is independent of the output.

It is noteworthy here that this is generally produces an error in the system because there exist no chances to adjust the input when the output shows variation from the expected value.

**Practical examples of open loop control systems**

Examples of open-loop control systems in daily life include:

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-** This machine dries wet clothes for pre-adjusted time, it does not matter how much the clothes are dried.
5. **Timer Based Clothes Drier-** Lamp’s glow whenever the light switch is on irrespective of light is required or not.
6. **Volume on Stereo System-** Volume is adjusted manually irrespective of output volume level.

**Advantages of open-loop control system**

* These systems possess simplicity in construction and ease of maintenance.
* Due to the lesser number of units, overall, the system is economic.
* The output provided by the system shows stability.
* The operation is quite convenient.

**Disadvantages of open-loop control system**

* These systems require timely recalibration.
* The systems are more prone to errors.
* The changes in the desired output can be the result of internal or external disturbances.

**Applications**

Open-loop systems widely find their applications in the following domains:

* In the traffic light controlling system,
* Tv remote control,
* Immersion rod
* Automatic washing machines,
* In room heaters,
* Automatic door opening and closing systems etc.

So, we can conclude that the open-loop system never uses a feedback loop in the circuit as it has nothing to do with the output for further reference input.

**Closed-loop control system**

Definition: A closed-loop control system is a type of control system in which the controlling action shows dependency on the generated output of the system. In simple words, in these systems, the output of the system controls the input applied to the system.

The variation in input according to the output leads to produce more accurate system output. Thus, controllability in the closed-loop system is achieved through the output generated by utilizing a feedback path.

Closed-loop systems are considered as fully automatic control system because it is designed in a way that the achieved output is automatically compared with the reference input to have the required output.

**Need for closed-loop control system**

A control system is a system that is designed to produce a specified output by the action of required controlling.

Now the controlling provided to the system can be either output independent or output dependent. This variation leads to give two different categories of control system.

Basically, a closed loop system was designed to overcome the disadvantages associated with an open-loop system. We know that open-loop systems do not hold the ability to automatically provide accurate output.

We all are aware of the fact that the basic requirement of using an electrical or electronic system is to generate the desired output. And in any system, if the measurement is not performed and the required output is not achieved then it becomes almost impossible to get the accurate system response.

So, to have the accurate system response the easiest way is to compare the applied input with the achieved output. this helps in determining the error which is present inside the system. Therefore, once the error is measured then it can be reduced to the lowest possible value in order to get the desired output.

Thus, in closed-loop system, a feedback signal is provided to the input. This feedback signal and the reference input signal acts as system excitation to get the desired response. Thus, in this way, the output performs the controlling action in a closed-loop system.

**What is feedback?**

Feedback acts as the characteristic if the system that allows comparison between achieved output and reference input of a system.

A feedback is generally a part of the output signal which is given back to the input signal so that the two can be compared and the desired output can be achieved if the present output shows variation with the desired output.

Thus, feedback loop is considered as the key parameter of a closed-loop control system.

Feedback in any circuit can be generally of 2 types:

1. Positive feedback.
2. Negative feedback.

**Positive feedback:** The type of feedback in a control system in which the input signal and the feedback signal are in phase with each other is known as a positive feedback system.

In these systems, the reference input gets added with the feedback signal thereby increasing the gain of the overall system.

**Negative feedback control system:** In the case of negative feedback, the input signal and the feedback signal show out- of -phase relationship with respect to each other.

Thus, the applied input signal and the feedback signal are subtracted to get the error signal. This leads to reduction in the overall gain of the system.

Thus, we can say it is the factor that is most importantly responsible to have the desired response of a system.

**Operation of a closed loop system**

The figure shows the detailed block diagram representation of a closed-loop control system:

Here as we can see that command input is fed to a transducer.

This is so because it is not always necessary that the available input is acceptable by the controller. Thus, in such cases, the input cannot be directly applied to the system. As it must be changed from one form to another so that it can perform the role of reference input for the system.

This is the reason input is initially applied to the transducer so that it can be changed to a form acceptable by the system according to the nature of controller and process.

When the controller produces the control signal according to input applied, then the required action according to the generated signal takes place inside the system.

This leads to the generation of a specific output. but it is necessary to measure the generated output in order to find whether it is the desired output or not. So, for this, a part of the achieved output is given back to the input. This signal acts as a feedback signal.

This feedback signal, when compared with reference input, generates an error signal. This error signal is further provided to the controller that produces a manipulated signal (proportional to error signal) which is nothing but a control signal that guides the process to eliminate the error there by producing the desired output.

The achieved output is known as the controlled output of the system and holds accuracy.

**Transfer function of closed loop control system**

Transfer function indicates the behaviour of the system as it is defined as the mathematical relation between the input and output of the system.

The gain of the system defines the ratio of output to input. Thus, we can say the output of the system is the product of transfer function and input.

Consider the closed-loop system given below

So, for the above-given system,

**C(S) = E(S). G(S)**

**E(S)=R(S)-H(S)C(S)**

On substituting the value of E(S) in the 1st equation.

**C(S) = [ R(S)- H(S) C(S)]. G(S)**

**C(S) = R(S) G(S) – H(S) C(S) G(S)**

On transposing

**R(S) G(S) = C(S) + H(S) C(S) G(S)**

**R(S) G(S) = C(S). [ 1 + G(S) H(S)]**

**C(S)/R(S)=G(S)/ [1- G(S) H(S)]**

This is the transfer function of a closed-loop system with negative feedback.

For a positive feedback system, it is given as:

**C(S)/R(S)= G(S)/ [1- G(S) H(S)]**

For a unity feedback system with a high value of gain. The transfer function is unity.

**Examples of closed-loop control system**

**1.Automatic electric iron**

Consider an example of automatic electric iron which acts as a closed-loop system. The figure below represents the block diagram with major components:

An automatic electric iron consists of a thermostat that acts as a controller of the system, a resistive heating element is present that generates heat.

The sole-plate of the iron instrument acta as a process of the overall system.

The basic working performed by an automatic electric iron is such that when the temperature of the sole-plate attains a predefined value then the heating action gets stopped automatically. And when the temperature falls below a certain specified value then the again heating starts inside it.

So, it is clear that in this type of system the controlling depends on the output of the system.

Initially, in electric iron, the thermostat is provided with a certain specific value which acts as a reference input for the system.

When the input is provided to the system, then the resistive heating element generates heat inside the system. This leads to rising up the temperature of the iron sole. Through a feedback element, this output temperature is compared with the reference input of the thermostat.

If the achieved output shows lesser value than the reference input, then the difference temperature actuates the thermostat and this switches on the heating element.

This resultantly causes an increase in the temperature of the iron sole.

Once the temperature exceeds the reference value then the heating element automatically turns off. And after a certain point of time, the temperature starts to decrease.

However, the comparison still goes on and as the temperature falls below the specific value, the heating element again begins to raise the temperature of the sole.

In this way the continuous process inside an electric iron takes place.

**2.Temperature control system**

The main purpose possessed by a temperature control system is to maintain a constant temperature of water. Generally, these systems are used to provide an invariable temperature (hot) at the output.

The figure below represents the block diagram representation of a closed-loop control system:

Basically, in such type of systems water from an outlet come with a constant flow rate. Also, internally generated steam from a value is mixed with the water to have a predetermined temperature of water.

A pressure thermometer is used inside the system that acts as feedback. So, when a reference input is provided to the system then the value present generates a control signal that indicates the system to provide the required amount of steam.

When the steam mixes with the water coming from the outlet then the temperature of the water is measured by the pressure thermometer and Is compared with the reference input given to the system.

If the desired temperature shows equivalency with the generated temperature, then the control signal is generated and the flow of steam is stopped.

But if some amount of variation exists between the two temperature values, then the controller generates the control signal regarding the level of temperature difference which is further compensated during the process.

In this way, the continuous process inside the system takes place and a controlled level of temperature is maintained.

**Advantages**

* The closed-loop system is more accurate than the open-loop system because of controlling through the output signal.
* These types of systems are less affected by noise and other environmental disturbances.
* It provides a high-frequency range of operation.
* These are more flexible as compared to the open-loop system.

**Disadvantages**

* The addition of the feedback elements leads to the generation of complex structures.
* Closed-loop systems are not economical.
* The problem of instability in output is a crucial factor of the closed-loop system as the presence of feedback causes timely variation in the system’s output.

**Applications**

* Automatic toaster.
* Water level controller.
* Home heating system to dc motor speed control and missile launching system.
* Automatic washing machine.
* Air conditioner.

**Open loop vs closed loop control systems**

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| --- | --- | --- |
| **Serial number** | **Open loop control system** | **Closed loop control system** |
| **1** | The feedback element is absent. | The feedback element is always present. |
| **2** | An error detector is not present. | An error detector is always present. |
| **3** | It is a stable one. | It may become unstable. |
| **4** | Easy to construct. | Complicated construction. |
| **5** | It is economical. | It is costly. |
| **6** | Having a small bandwidth. | Having a large bandwidth. |
| 7 | It is inaccurate. | It is accurate. |
| **8** | Less maintenance. | More maintenance. |
| **9**  **10** | It is unreliable.  Examples: hand drier, tea maker | It is reliable.  Examples: servo voltage stabilizer, perspiration |