MUTHAYAMMAL ENGINEERING COLLEGE
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Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

L 1

LECTURE HANDOUTS

EEE

III/V

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : I- CONTROL SYSTEM MODELING **Date of Lecture:**

Topic of Lecture:
Basic elements in control systems.

Introduction :

- A control system manages commands, directs or regulates the behavior of other devices or systems using control loops.
- It can range from a single home heating controller using a thermostat controlling a domestic boiler to large Industrial control systems which are used for controlling processes or machines.
- A control system is a system, which provides the desired response by controlling the output.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Signals and Systems
- Amplifier

Detailed content of the Lecture:

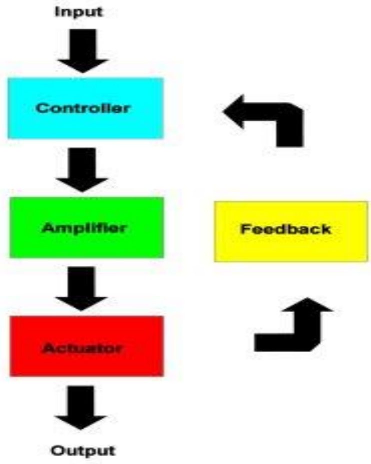
Concept of control system :

- A control system manages commands, directs or regulates the behavior of other devices or systems using control loops.
- It can range from a single home heating controller using a thermostat controlling a domestic boiler to large Industrial control systems which are used for controlling processes or machines.
- A control system is a system, which provides the desired response by controlling the output. The following figure shows the simple block diagram of a control system.

- Examples − Traffic lights control system, washing machine Traffic lights control system is an example of control system.
- Here, a sequence of input signal is applied to this control system and the output is one of the three lights that will be on for some duration of time.
- During this time, the other two lights will be off. Based on the traffic study at a particular junction, the on and off times of the lights can be determined.
- Accordingly, the input signal controls the output. So, the traffic lights control system operates on time basis.

Basic elements in control systems:

There are four basic elements of a typical motion control system. These are the controller, amplifier, actuator, and feedback.



Controller:

- Controller section of the AC drive is the brain if the system.
- It typically consists of a microprocessor based CPU and memory that is used to process data once it is collected and stored.
- This controller section of the AC drive will process information received from the inputs of the drive and also from the feedback signals that will usually be a representation of the position or speed of the actuator.

Amplifier:

- The amplifier section of the drive receives the commands from the control section.
- The amplifier then generates the power signal necessary for the actuator to drive the load with the correct speed and direction.

Actuator:

- The actuator portion of the system will most often be an induction AC motor or permanent magnet AC motor with windings and insulation that are specially designed to handle the heat and stress generated by a pulse width modulated output.

Feedback:

- The feedback element of the motion control system may be handled by the system in a number of ways depending on the information needed.
- Encoders or resolvers can be used to provide feedback signals from the actuator in a closed loop control or Hall Effect sensors can provide feedback from the output of the AC drive in an open loop control.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=u1pgaJHiiew

Important Books/Journals for further learning including the page nos.:

- M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:2-3)

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L 2

LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : I- CONTROL SYSTEM MODELING **Date of Lecture:**

Topic of Lecture:

Open and closed loop systems.

Introduction :

- In recent years, control systems have gained an increasingly importance in the development and advancement of the modern civilization and technology.
- Disregard the complexity of the system; it consists of an input (objective), the control system and its output (result).
- Practically our day-to-day activities are affected by some type of control systems.

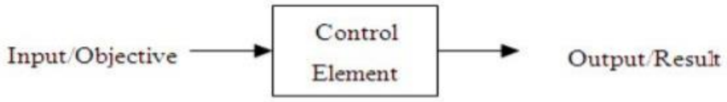
Prerequisite knowledge for Complete understanding and learning of Topic:

- System, Feedback & Error detector

Detailed content of the Lecture:

There are two main branches of control systems:

1) Open-loop systems
2) Closed-loop systems.



Basic Components of Control System

1.Open-loop systems:

- The open-loop system is also called the non-feedback system. This is the simpler of the two systems.
- In this open-loop system, there is no way to ensure the actual speed is close to the desired speed automatically.
- The actual speed might be way off the desired speed because of the wind speed and/or road conditions, such as uphill or downhill etc.

Basic Open Loop System

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.

Advantages of Open Loop Control System:

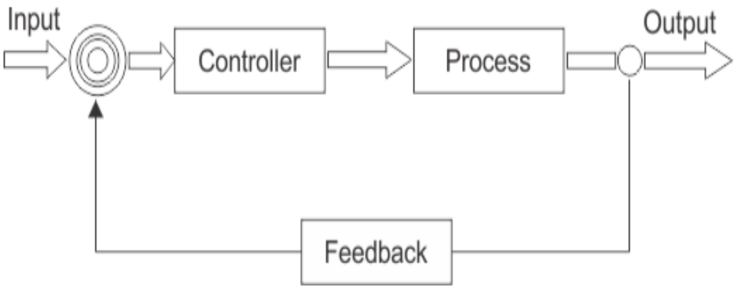
1. Simple in construction and design.
2. Economical.
3. Easy to maintain.
4. Generally stable.
5. Convenient to use as output is difficult to measure.

Disadvantages of Open Loop Control System:

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

2. Closed-loop systems:

- The closed-loop system is also called the feedback system. A simple closed system is shown in Figure.
- It has a mechanism to ensure the actual speed is close to the desired speed automatically.



Closed loop system

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.

Advantages of Closed Loop Control System

1. Closed loop control systems are more accurate even in the presence of nonlinearity.
2. Highly accurate as any error arising is corrected due to presence of feedback signal.
3. Bandwidth range is large.
4. Facilitates automation.

Disadvantages of Closed Loop Control System

1. They are costlier.
2. They are complicated to design.
3. Required more maintenance.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=FurC2unHeXI

Important Books/Journals for further learning including the page nos.:

M. Gopal, 'Control Systems, Principles and Design', 4th Edition, Tata McGraw Hill, New Delhi, 2012. Pgno. 2-3

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L 3

LECTURE HANDOUTS

EEE | **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : I- CONTROL SYSTEM MODELING **Date of Lecture:**

Topic of Lecture:

Differential equation

Introduction :

Two systems are said to be analogous to each other if the following two conditions are satisfied.

- The two systems are physically different
- Differential equation modeling of these two systems are same

Prerequisite knowledge for Complete understanding and learning of Topic:

- Force, Newton's second law, Torque
- Laplace transform
- Differential equation

Detailed content of the Lecture:

Write the differential equations governing the mechanical rotational system shown n fig 1.12.1. Draw the torque-voltage and torque-current electrical analogous circuits nd verify by writing mesh and node equations.

OLUTION

The given mechanical rotational stem has two nodes (moment of inertia of asses). The differential equations governing : mechanical rotational system are given torque balance equations at these nodes.

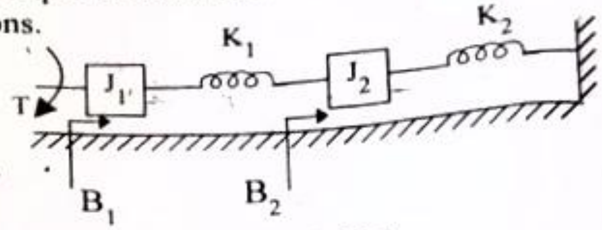
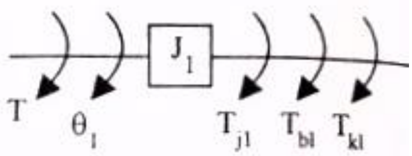


Fig 1.12.1

Let the angular displacements of J_1 and J_2 be θ_1 and θ_2 respectively. The responding angular velocities be ω_1 and ω_2. The free body diagram of J_1 is shown in 1.12.2. The opposing torques are marked as T_{j1}, T_{b1} and T_{k1}.

$$T_{j1} = J_1 \frac{d^2\theta_1}{dt^2} \;;\; T_{b1} = B_1 \frac{d\theta_1}{dt} \quad \text{and}$$

$$T_{k1} = K_1(\theta_1 - \theta_2)$$



By Newton's second law, $T_{j1} + T_{b1} + T_{k1} = T$

Fig 1.12.2

$$J_1 \frac{d^2\theta_1}{dt^2} + B_1 \frac{d\theta_1}{dt} + K_1(\theta_1 - \theta_2) = T \quad .....(1.12.1)$$

The free body diagram of J_2 is shown in fig 1.12.3. The opposing torques ar rked as T_{j2}, T_{b2}, T_{k2} and T_{k1}.

$$T_{j2} = J_2 \frac{d^2\theta_2}{dt^2} \; ; \qquad T_{b2} = B_2 \frac{d\theta_2}{dt}$$

$$T_{k2} = K_2\theta_2 \quad \text{and } T_{k1} = K_1(\theta_2 - \theta_1)$$

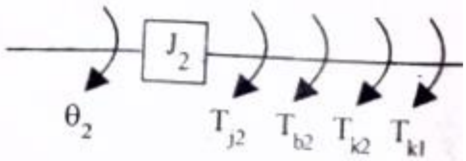


Fig 1.12.3

By Newton's second law, $T_{j2} + T_{b2} + T_{k2} + T_{k1} = 0$

$$J_2 \frac{d^2\theta_2}{dt^2} + B_2 \frac{d\theta_2}{dt} + K_2\theta_2 + K_1(\theta_2 - \theta_1) = 0 \quad .....(1.12.2)$$

On replacing the angular displacements by angular velocity in the differential ations (1.12.1) and (1.12.2) governing the mechanical rotational system we get,

$$J_1 \frac{d\omega_1}{dt} + B_1(\omega_1 - \omega_2) + K_1\int(\omega_1 - \omega_2)\, dt = T$$

$$J_2 \frac{d\omega_2}{dt} + B_2(\omega_2 - \omega_3) + B_1(\omega_2 - \omega_1) + K_1\int(\omega_2 - \omega_1)\, dt = 0$$

$$J_3 \frac{d\omega_3}{dt} + B_2(\omega_3 - \omega_2) + K_3\int\omega_3 dt = 0$$

VOLTAGE ANALOGOUS CIRCUIT

ie electrical analogous elements for the elements of mechanical rotational system n below.

$\rightarrow e(t)$ $\quad \omega_1 \rightarrow i_1 \quad J_1 \rightarrow L_1 \quad B_1 \rightarrow R_1 \quad K_1 \rightarrow 1/C_1$

$\omega_2 \rightarrow i_2 \quad J_2 \rightarrow L_2 \quad B_2 \rightarrow R_2 \quad K_3 \rightarrow 1/C_3$

$\omega_3 \rightarrow i_3 \quad J_3 \rightarrow L_3$

he mesh basis equations using Kirchoff's voltage law for the circuit shown in fig re given below *[Refer fig (1.13.6), (1.13.7) and (1.13.8)]*.

$$L_1 \frac{di_1}{dt} + R_1(i_1 - i_2) + \frac{1}{C_1}\int(i_1 - i_2)dt = e(t) \quad .....(1.13.7)$$

$$L_2 \frac{di_2}{dt} + R_2(i_2 - i_3) + R_1(i_2 - i_1) + \frac{1}{C_1}\int(i_2 - i_1)\, dt = 0 \quad .....(1.13.8)$$

$$L_3 \frac{di_3}{dt} + R_2(i_3 - i_2) + \frac{1}{C_3}\int i_3 dt = 0$$

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=-jyP7J3iDMI

Important Books/Journals for further learning including the page nos.:

M. Gopal, 'Control Systems, Principles and Design', 4th Edition, Tata McGraw Hill, New Delhi, 2012- P45.

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L 4

LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : I- CONTROL SYSTEM MODELING **Date of Lecture:**

Topic of Lecture:

Transfer function

Introduction :

- The transfer function of a system is defined as the ratio of Laplace transform of output to the Laplace transform of input where all the initial conditions are zero.
- That is, the transfer function of the system multiplied by the input function gives the output function of the system.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Laplace transform
- Differential equation

Detailed content of the Lecture:

- A **transfer function** represents the relationship between the output signal of a control system and the input signal, for all possible input values.
- A block diagram is a visualization of the control system which uses blocks to represent the transfer function, and arrows which represent the various input and output signals.
- For any control system, there exists a reference input known as excitation or cause which operates through a transfer operation (i.e. the transfer function) to produce an effect resulting in controlled output or response.
- Thus the cause and effect relationship between the output and input is related to each other through a **transfer function**.

- In a Laplace Transform, if the input is represented by R(s) and the output is represented by C(s), then the transfer function will be:

$$G(s) = \frac{C(s)}{R(s)} \Rightarrow R(s).G(s) = C(s)$$

That is, the transfer function of the system multiplied by the input function gives the output function of the system.

Procedure for determining the transfer function of a control system are as follows:

- We form the equations for the system.
- Now we take Laplace transform of the system equations, assuming initial conditions as zero.
- Specify system output and input.
- Lastly we take the ratio of the Laplace transform of the output and the Laplace transform of the input which is the required transfer function.

Methods of Obtaining a Transfer Function:

There are major two ways of obtaining a transfer function for the control system. The ways are:

- Block Diagram Method: It is not convenient to derive a complete transfer function for a complex control system. Therefore the transfer function of each element of a control system is represented by a block diagram. Block diagram reduction techniques are applied to obtain the desired transfer function.
- Signal Flow Graphs: The modified form of a block diagram is a signal flow graph. Block diagram gives a pictorial representation of a control system. Signal flow graph further shortens the representation of a control system.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=ZOnolyI634k

Important Books/Journals for further learning including the page nos.:

M. Gopal, 'Control Systems, Principles and Design', 4th Edition, Tata McGraw Hill, New Delhi, 2012- P45.

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L 5

LECTURE HANDOUTS

EEE

III/V

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : I- CONTROL SYSTEM MODELING **Date of Lecture:**

Topic of Lecture:
Modeling of Electric systems

Introduction :
Two systems are said to be analogous to each other if the following two conditions are satisfied.
- The two systems are physically different
- Differential equation modeling of these two systems are same

Prerequisite knowledge for Complete understanding and learning of Topic:
- Force, Newton's second law, Torque
- Laplace transform
- Differential equation

Detailed content of the Lecture:

1. **Obtain mathematical models ($\frac{X(s)}{U(s)}$) of the mechanical systems shown below.**

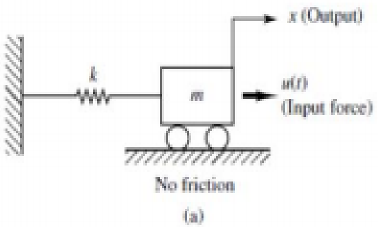
Solution

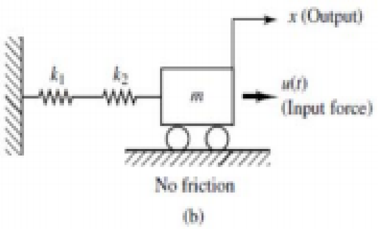
a)

Here, the input is u(t) and the output is the displacement x as shown in the figure.

$$u(t) = m\ddot{x} + kx$$

- **the rollers under the mass means there is no friction.**





Converting the above equation to Laplace domain.

$$U(s) = ms^2X(s) + kX(s)$$

Taking X(s) out of the brackets:

$$U(s) = (ms^2 + k)X(s)$$

Then the transfer function (T.F) equal to:

$$\frac{X(s)}{U(s)} = \frac{1}{ms^2 + k}$$

b)

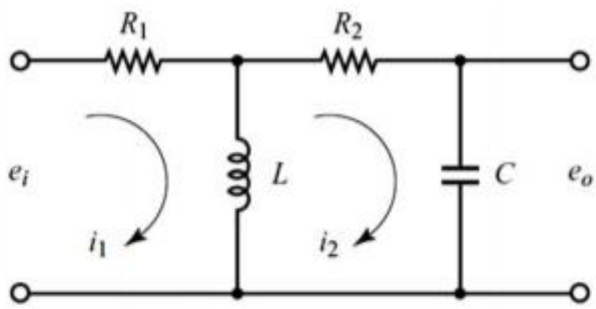
The solution will be the same procedure, but the spring factor will be:

$$k_T = \frac{k_1 k_2}{k_1 + k_2}$$

Then the T.F would be:

$$\frac{X(s)}{U(s)} = \frac{1}{ms^2 + k_T}$$

2. **Obtain the transfer function $Eo(s)/Ei(s)$ of the electrical circuit shown in.**



The equations for the given circuit are as follow:

$$R_1 L_1 + L\left(\frac{di_1}{dt} - \frac{di_2}{dt}\right) = e_i$$
$$R_2 i_2 + \frac{1}{c}\int i_2 dt + L\left(\frac{di_2}{dt} - \frac{di_1}{dt}\right) = 0$$
$$\frac{1}{c}\int i_2 dt = e_0$$

The Laplace transforms of these three equations, with zero initial conditions, are

$$R_1 I_1(s) + L[sI_1(s) - sI_2(s)] = E_i(s)$$
$$R_2 I_2(s) + \frac{1}{Cs} I_2(s) + L[sI_2 - sI_1(s)] = 0$$
$$\frac{1}{Cs} I_2(s) = E_0(s)$$

From Equation (2) we obtain.

$$\left(R_2 + \frac{1}{Cs} + Ls\right) I_2(s) = LsI_1(s)$$

or

$$I_2(s) = \frac{LCs^2}{LCs^2+R_2Cs+1} I_1(s) \qquad (4)$$

Or

Substituting equation (4) into equation (1), we get

$$(R_1 + Ls - Ls\frac{LCs^2}{LCs^2+R_2Cs+1})I_1(s) = E_i(s)$$

Or

$$\frac{LC(R_1+R_2)s^2+(R_1R_2C+L)s+R_1}{LCs^s+R_2Cs+1} I_1(s) = E_1(s) \qquad (5)$$

From Equation (3) and (4), we get

$$\frac{Ls}{LCs^2+R_2Cs+1} I_1(s) = E_0(s) \qquad (6)$$

From equation (5) and (6), we obtain

$$\frac{E_0(s)}{E_i(s)} = \frac{Ls}{LC(R_1+R_2)s^2 + (R_1R_2C + L)s + R_1}$$

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=-jyP7J3iDMI

Important Books/Journals for further learning including the page nos.:

M. Gopal, 'Control Systems, Principles and Design', 4th Edition, Tata McGraw Hill, New Delhi, 2012- P45.

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L 6

LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : I- CONTROL SYSTEM MODELING **Date of Lecture:**

Topic of Lecture:
Electrical analogy of mechanical systems

Introduction :
Two systems are said to be analogous to each other if the following two conditions are satisfied.

- The two systems are physically different
- Differential equation modeling of these two systems are same

Prerequisite knowledge for Complete understanding and learning of Topic:

- Force, Newton's second law, Torque
- Laplace transform
- Differential equation

Detailed content of the Lecture:

- Electrical systems and mechanical systems are two physically different systems.
- There are two types of electrical analogies of translational mechanical systems.
- Those are force voltage analogy and force current analogy.

Force Voltage Analogy:

In force voltage analogy, the mathematical equations of translational mechanical system are compared with mesh equations of the electrical system.

Rotational Mechanical System	Electrical System
Torque(T)	Voltage(V)
Moment of Inertia(J)	Inductance(L)
Rotational friction coefficient(B)	Resistance(R)
Torsional spring constant(K)	Reciprocal of Capacitance (1c)(1c)
Angular Displacement(θ)	Charge(q)
Angular Velocity(ω)	Current(i)

Force Current Analogy:

In force current analogy, the mathematical equations of the translational mechanical system are compared with the nodal equations of the electrical system.

Translational Mechanical System	Electrical System
Force(F)	Current(i)
Mass(M)	Capacitance(C)
Frictional coefficient(B)	Reciprocal of Resistance(1R)(1R)
Spring constant(K)	Reciprocal of Inductance(1L)(1L)
Displacement(x)	Magnetic Flux(ψ)
Velocity(v)	Voltage(V)

Torque Voltage Analogy:

In this analogy, the mathematical equations of rotational mechanical system are compared with mesh equations of the electrical system.

Rotational Mechanical System	Electrical System
Torque(T)	Voltage(V)
Moment of Inertia(J)	Inductance(L)
Rotational friction coefficient(B)	Resistance(R)
Torsional spring constant(K)	Reciprocal of Capacitance (1c)(1c)
Angular Displacement(θ)	Charge(q)
Angular Velocity(ω)	Current(i)

Torque Current Analogy:

In this analogy, the mathematical equations of the rotational mechanical system are compared with the nodal mesh equations of the electrical system.

Rotational Mechanical System	Electrical System
Torque(T)	Current(i)
Moment of inertia(J)	Capacitance(C)
Rotational friction coefficient(B)	Reciprocal of Resistance(1R)(1R)
Torsion spring constant(K)	Reciprocal of Inductance(1L)(1L)
Angular displacement(θ)	Magnetic flux(ψ)
Angular velocity(ω)	Voltage(V)

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=vqI791VCjjA

Important Books/Journals for further learning including the page nos.:

M. Gopal, 'Control Systems, Principles and Design', 4th Edition, Tata McGraw Hill, New Delhi, 2012. P4

Course Faculty

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LECTURE HANDOUTS

L 7

EEE

III/V

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : I- CONTROL SYSTEM MODELING **Date of Lecture:**

Topic of Lecture:
Electrical analogy of thermal systems

Introduction :

- A common part of a thermal model is a controlled power source that generates a predetermined amount of power, or heat, in a system.
- This power can either be constant or a function of time. In the electrical analogy, the power source is represented by a current source.

Prerequisite knowledge for Complete understanding and learning of Topic:

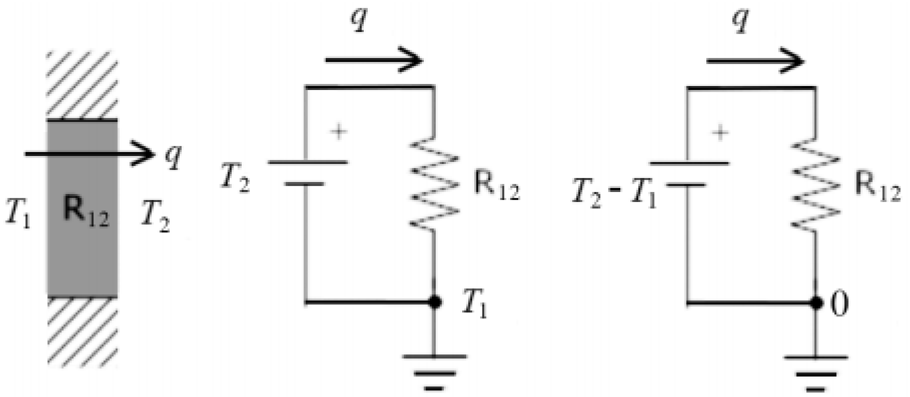
- Resistance, Capacitance and Heat flow rate.

Detailed content of the Lecture:

- There are two fundamental physical elements that make up thermal networks, thermal resistances and thermal capacitance.
- There are also three sources of heat, a power source, a temperature source, and fluid flow.
- In practice temperature when we discuss temperature we will use degrees Celsius (°C), while SI unit for temperature is to use Kelvins (0°K = -273.15°C).
- However, we will generally be interested in temperature differences, not absolute temperatures (much as electrical circuits deal with voltage differences).
- Therefore, we will generally take a reference temperature (which we will label T1), and measure all temperatures relative to this reference.
- We will also assume that the reference temperature is constant.
- Thus, if T1 is =25°C, and the temperature of interest is Ti=32°C, we will say that Ti=7° above reference.
- Note: this is consistent with electrical systems in which we assign one voltage to be ground (and assume that it is constant) and assign it the value of zero volts. We then measure all voltages relative to ground.

Thermal resistance:

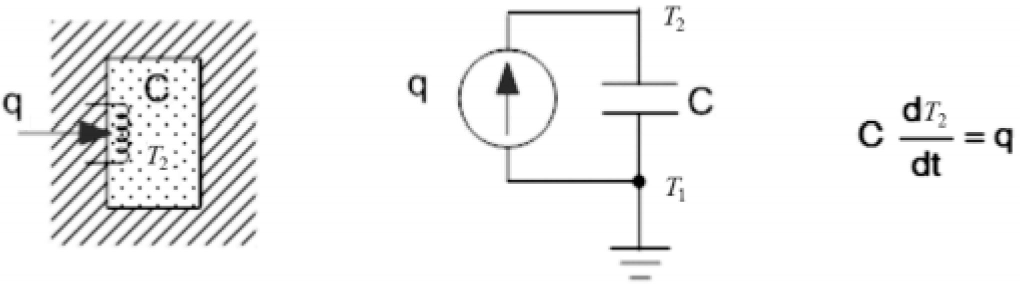
- Consider the situation in which there is a wall, one side of which is at a temperature T1, with the other side at temperature T2. The wall has a thermal resistance of R12.



Thermal-electrical analogy of conduction heat transfer.

Thermal capacitance:

- In addition to thermal resistance, objects can also have thermal capacitance (also called thermal mass).
- The thermal capacitance of an object is a measure of how much heat it can store.
- If an object has thermal capacitance its temperature will rise as heat flows into the object, and the temperature will lower as heat flows out.
- To understand this, envision a rock in the sun.
- During the day heat goes in to the rock from the sunlight, and the temperature of the rock increases as energy is stored in the rock as an increased temperature.
- At night energy is released, and the rock cools down.



Thermal-electrical analogy of thermal capacitance.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=_avuJI3ctdg

Important Books/Journals for further learning including the page nos.:

M. Gopal, 'Control Systems, Principles and Design', 4th Edition, Tata McGraw Hill, New Delhi, 2012. P-50

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L 8

LECTURE HANDOUTS

EEE | **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : I- CONTROL SYSTEM MODELING **Date of Lecture:**

Topic of Lecture:

Block diagram reduction techniques

Introduction :

- A control system may consist of a number of components.
- A block diagram of a system is a pictorial representation of the function performed by each component and of the flow of signals.
- Such a diagram depicts the inter-relationships which exists between the various components.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Signal system
- Transfer function

Detailed content of the Lecture:

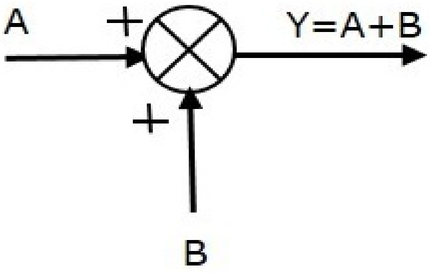
- The basic elements of block diagram such as
  1. Block
  2. Summing point
  3. Branch point

Block:

- The transfer function of a component is represented by a block.
- Block has single input and single output.
- The following figure shows a block having input X(s), output Y(s) and the transfer function G(s).

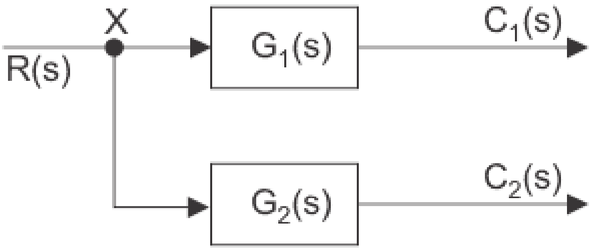
Summing Point:

- The summing point is represented with a circle having cross (X) inside it.
- It has two or more inputs and single output.
- It produces the algebraic sum of the inputs.
- It also performs the summation or subtraction or combination of summation and subtraction of the inputs based on the polarity of the inputs.
- Let us see these three operations one by one.
- The following figure shows the summing point with two inputs (A, B) and one output (Y). Here, the inputs A and B have a positive sign.
- So, the summing point produces the output, Y as sum of A and B. i.e.,Y = A + B.



Branch point:

- The take-off point is a point from which the same input signal can be passed through more than one branch.
- That means with the help of take-off point, we can apply the same input to one or more blocks, summing points.
- In the following figure, the take-off point is used to connect the same input, R(s) to two more blocks.



Block Diagram Reduction Rules:

- Follow these rules for simplifying (reducing) the block diagram, which is having many blocks, summing points and take-off points.

  Rule 1 − Check for the blocks connected in series and simplify.

  Rule 2 − Check for the blocks connected in parallel and simplify.

  Rule 3 − Check for the blocks connected in feedback loop and simplify.

  Rule 4 − If there is difficulty with take-off point while simplifying, shift it towards right.

  Rule 5 − If there is difficulty with summing point while simplifying, shift it towards left.

  Rule 6 − Repeat the above steps till you get the simplified form, i.e., single block.

- Note − The transfer function present in this single block is the transfer function of the overall block diagram

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=4KUTNL9dA8E

Important Books/Journals for further learning including the page nos.:

M. Gopal, 'Control Systems, Principles and Design', 4th Edition, Tata McGraw Hill, New Delhi, 2012- P52.

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LECTURE HANDOUTS

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EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

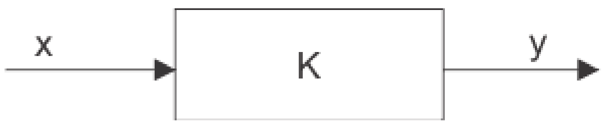
Unit : I- CONTROL SYSTEM MODELING **Date of Lecture:**

Topic of Lecture:
Signal flow graphs

Introduction :
- The block diagram reduction process takes more time for complicated systems.
- Because, we have to draw the (partially simplified) block diagram after each step.
- So, to overcome this drawback, use signal flow graphs (representation).

Prerequisite knowledge for Complete understanding and learning of Topic:
- Signal system
- Transfer function

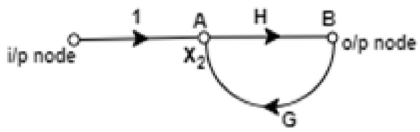
Detailed content of the Lecture:
- Signal flow graph of control system is further simplification of block diagram of control system.
- Here, the blocks of transfer function, summing symbols and take off points are eliminated by branches and nodes.
- The transfer function is referred as transmittance in signal flow graph.
- Let us take an example of equation y = Kx.
- This equation can be represented with block diagram as below.



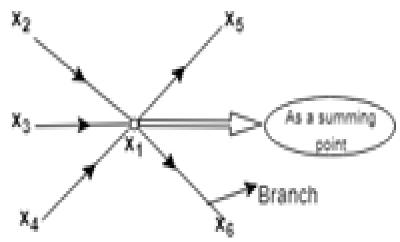
- The same equation can be represented by signal flow graph, where x is input variable node, y is output variable node and the transmittance of the branch connecting directly these two nodes.

Key Definitions:

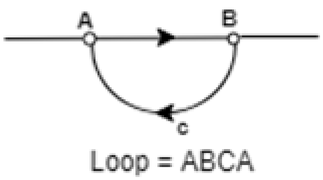
- **Node**: It represents the system variable which equals to the sum of all signals. Outgoing signal from the node does not affect the value of node variables.

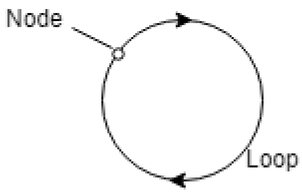


- **Branch:** Branch is defined as a path from one node to another node, in the direction indicated by the branch arrow.

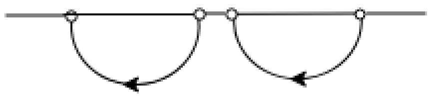


- **Input node or source**: It is the node which have only outgoing branches.
- **Output node or sink**: It is a node which has only incoming branches.
- Forward Path**: It is a path from an input node to an output node in the direction of branch arrow.**
- **Loop**: It is a path that starts and ends at the same node.

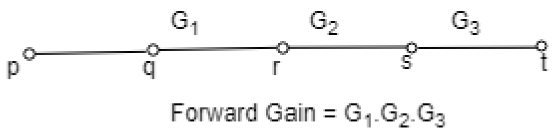




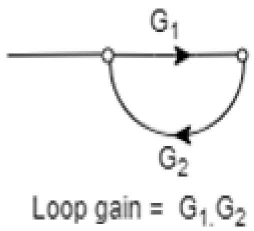
- **Non-touching loop**: Loop is said to be non-touching if they do not have any common node.



- **Forward path gain**: A product of all branches gain along the forward path is called Forward path gain.



- **Loop Gain**: Loop gain is the product of branch gain which travels in the loop.



Mason's gain formula is

$$T = \frac{C(s)}{R(s)} = \frac{\Sigma_{i=1}^{N} P_i \Delta_i}{\Delta}$$

Where,

C(s) is the output node

R(s) is the input node

T is the transfer function or gain between R(s)R(s) and C(s)C(s)

Pi is the ith forward path gain

- Δ=1−(sum of all individual loop gains) +(sum of gain products of all possible two nontouching loops) −(sum of gain products of all possible three nontouching loops)+... Δi is obtained from Δ by removing the loops which are touching the ith forward path.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=-jyP7J3iDMI

Important Books/Journals for further learning including the page nos.:

M. Gopal, 'Control Systems, Principles and Design', 4th Edition, Tata McGraw Hill, New Delhi, 2012- P45.

Course Faculty

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Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : II-TIME RESPONSE ANALYSIS **Date of Lecture:**

Topic of Lecture: Time response analysis

Introduction :

- If the output of control system for an input varies with respect to time, then it is called the time response of the control system. The time response consists of two parts.
  - Transient response
  - Steady state response

Prerequisite knowledge for Complete understanding and learning of Topic:

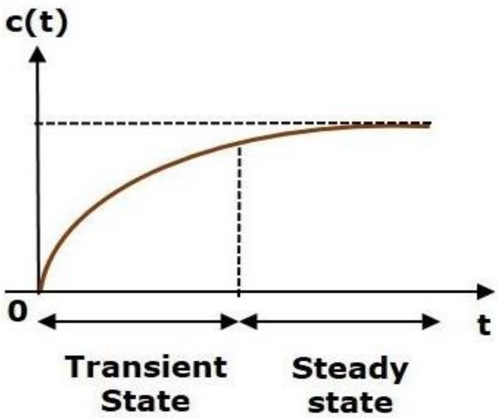
1.Time domain

2.Frequency domain

Detailed content of the Lecture:

Transient Response:

- After applying input to the control system, output takes certain time to reach steady state.
- So, the output will be in transient state till it goes to a steady state.
- Therefore, the response of the control system during the transient state is known as transient response.



- The transient response will be zero for large values of ‘t’. Ideally, this value of ‘t’ is infinity and practically, it is five times constant.
- Mathematically, we can write it as

$$\lim_{t\to\infty} c_{tr}(t) = 0$$

Steady state Response:

- The part of the time response that remains even after the transient response has zero value for large values of 't' is known as steady state response.
- This means, the transient response will be zero even during the steady state.
- Let us find the transient and steady state terms of the time response of the control system c(t)=10+5e−t.
- Here, the second term 5e−t5e−t will be zero as t denotes infinity. So, this is the transient term.
- The first term 10 remains even as t approaches infinity. So, this is the steady state term.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=uIdc_kaI5xI

Important Books/Journals for further learning including the page nos.:

M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:257)

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LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : II-TIME RESPONSE ANALYSIS **Date of Lecture:**

Topic of Lecture: First Order Systems

Introduction :
The response up to the settling time is known as transient response and the response after the settling time is known as steady state response.

- The different time domains are
  - Delay time
  - Rise time
  - Peak time
  - Peak overshoot
  - Settling time

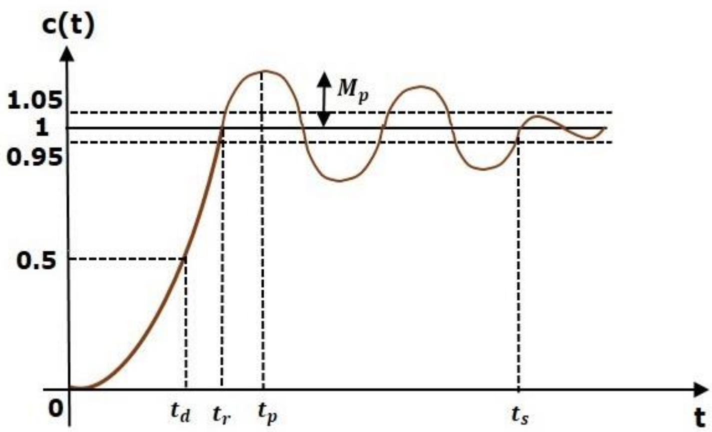
Prerequisite knowledge for Complete understanding and learning of Topic:

1.Transient Response

2.Steady state response

Detailed content of the Lecture:

The step response of the second order system for the underdamped case is shown in the following figure.



Delay Time:

- It is the time required for the response to reach half of its final value from the zero instant. It is denoted by t_d.

Rise Time:

- It is the time required for the response to rise from 0% to 100% of its final value. This is applicable for the under-damped systems.

Peak Time:

- It is the time required for the response to reach the peak value for the first time.

Peak Overshoot:

- Peak overshoot Mp is defined as the deviation of the response at peak time from the final value of response. It is also called the maximum overshoot.

Settling Time:

- It is the time required for the response to reach the steady state and stay within the specified tolerance bands around the final value.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=MzrgBc4s-jk

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:258)

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LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : II-TIME RESPONSE ANALYSIS Date of Lecture:

Topic of Lecture: Impulse and Step Response analysis of second order systems

Introduction :

- The order of the system is defined by the number of independent energy storage elements in the system, and intuitively by the highest order of the linear differential equation that describes the system.
- First order of system is defined as first derivative with respect to time.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Time domain

2.Frequency domain

Detailed content of the Lecture:

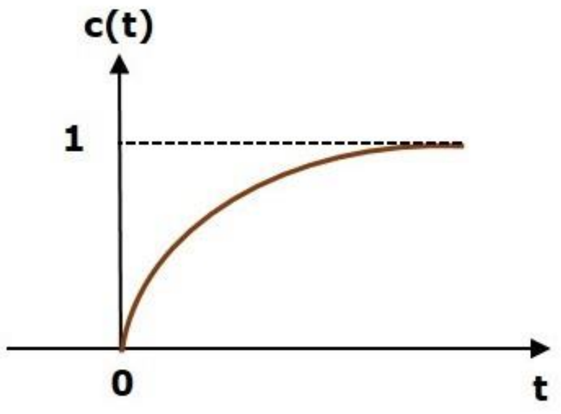
- A first order differential equation contains a first order derivative but no derivative higher than first order – the order of a differential equation is the order of the highestorder derivative present in the equation.
- First order control system tell us the speed of the response that what duration it reaches to the steady state.
- If the input is unit step, R(s) = 1/s so the output is step response C(s). The general equation of 1st order control system is $C(s) = R(s)G(s)$, i.e $C(s) = a/s(s+a)$ *and* $G(s)$ is transfer function.
- There are two poles, one is input pole at the origin s = 0 and other is system pole at s = -a, this pole is at negative axis of pole plot.

First order system step response:

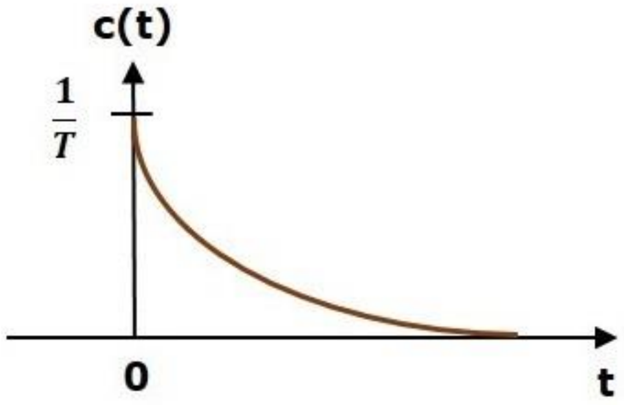
- The power of s is one in the denominator term. Hence, the above transfer function is of the first order and the system is said to be the first order system.
- We can re-write the above equation as

C(s)=(1sT+1)R(s)

C(s) is the Laplace transform of the output signal c(t),
R(s) is the Laplace transform of the input signal r(t), and
T is the time constant



The unit impulse response is shown in the following figure.



The unit impulse response, c(t) is an exponential decaying signal for positive values of 't' and it is zero for negative values of 't'.

Unit ramp response:

The unit ramp response **c**(t) has both the transient and the steady state terms.

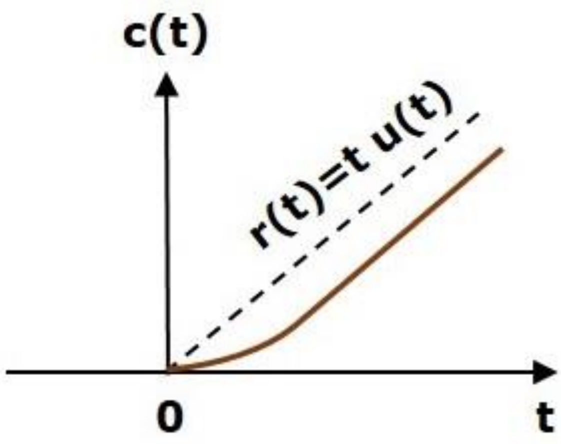
The transient term in the unit ramp response is -

$$c_{tr}(t)=Te^{-\left(\frac{t}{T}\right)}u(t)c_{tr}(t)=Te-(tT)u(t)$$

The steady state term in the unit ramp response is -

$$c_{ss}(t)=(t-T)u(t)c_{ss}(t)=(t-T)u(t)$$

The following figure shows the unit ramp response.



- The unit ramp response, c(t) follows the unit ramp input signal for all positive values of t. But, there is a deviation of T units from the input signal.

Time Constant:

- It can be defined as the time it takes for the step response to rise up to 63% or 0.63 of it's final value.
- We call it as t = 1/a. If we take reciprocal of time constant, its unit is 1/seconds, or frequency.

Rise Time:

- Rise time is defined as the time for waveform to go from 0.1 to 0.9 or 10% to 90% of its final value.

Settling Time:

- It is defined as the time for the response to reach and stay within 2% of its final value. We can limit the percentage up to 5% of its final value.
- The equation of settling time is given by: Ts = 4/a.

Conclusion of First Order Control System:

- A pole of the input function generates the form of the forced response. It is because of pole at the origin which generates a step function at output.
- A pole of the transfer function generates the natural response. It the pole of the system.
- A pole on the real axis generates an exponential frequency of the form e-at. Thus, the farther the pole to the origin, the faster the exponential transient response will decay to zero.
- Using poles and zeros, we can speed up the performance of system and get the desired output.
- The order of a control system is determined by the power of 's' in the denominator of its transfer function.

- If the power of s in the denominator of the transfer function of a control system is 2, then the system is said to be second order control system.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=T8ATyg_Fo6Y
https://www.youtube.com/watch?v=AnB6VR-g6PI

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:33)

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L 13

LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : II-TIME RESPONSE ANALYSIS **Date of Lecture:**

Topic of Lecture: Impulse and Step Response analysis of second order systems

Introduction :

- If the output of control system for an input varies with respect to time, then it is called the time response of the control system. The time response consists of two parts.
  - Transient response
  - Steady state response

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Time domain

2.Frequency domain

Detailed content of the Lecture:

Figures 5–58(a) shows a mechanical vibratory system. When 2 lb of force (step input) is applied to the system, the mass oscillates, as shown in Figure 5–58(b). Determine m, b, and k of the system from this response curve. The displacement x is measured from the equilibrium position.

Solution. The transfer function of this system is

$$\frac{X(s)}{P(s)} = \frac{1}{ms^2 + bs + k}$$

Since

$$P(s) = \frac{2}{s}$$

we obtain

$$X(s) = \frac{2}{s(ms^2 + bs + k)}$$

It follows that the steady-state value of x is

$$x(\infty) = \lim_{s\to 0} sX(s) = \frac{2}{k} = 0.1 \text{ ft}$$

Hence

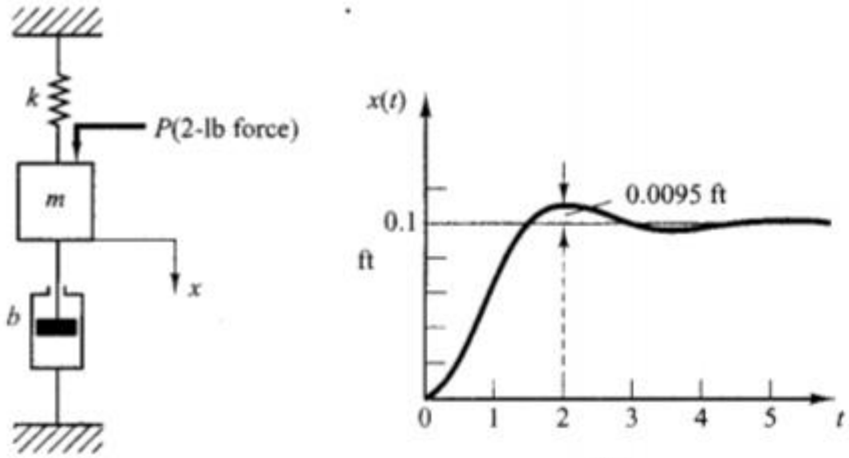
$$k = 20\ \text{lb}_f/\text{ft}$$

Note that $M_p = 9.5\%$ corresponds to $\zeta = 0.6$. The peak time t_p is given by

$$t_p = \frac{\pi}{\omega_d} = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}} = \frac{\pi}{0.8\omega_n}$$

The experimental curve shows that $t_p = 2$ sec. Therefore,

$$\omega_n = \frac{3.14}{2 \times 0.8} = 1.96\ \text{rad/sec}$$



Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=uIdc_kaI5xI

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:257)

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LECTURE HANDOUTS

EEE

III/V

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : II-TIME RESPONSE ANALYSIS Date of Lecture:

Topic of Lecture: P, PI, PD and PID controllers

Introduction :

- System whose input-output equation is a second order differential equation is called Second Order System.
- There are a number of factors that make second order systems important.
- They are simple and exhibit oscillations and overshoot.
- Higher order systems are based on second order systems.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Step response

2.Poles and Zeroes

Detailed content of the Lecture:

- The order of a control system is determined by the power of 's' in the denominator of its transfer function.
- If the power of s in the denominator of the transfer function of a control system is 2, then the system is said to be second order control system.
- The general expression of the transfer function of a second order control system is given as

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

- Here, ζ and ωn are the damping ratio and natural frequency of the system, respectively (we will learn about these two terms in detail later on).
- Rearranging the formula above, the output of the system is given a

$$C(s) = R(s) \cdot \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

<u>Critical Damping Time Response of Control System:</u>

- The time response expression of a second order control system subject to unit step input is

$$c(t) = 1 - \frac{e^{-\zeta\omega_n t}}{\sqrt{1-\zeta^2}} \sin\left\{\left(\omega_n\sqrt{1-\zeta^2}\right)t + \tan^{-1}\left(\frac{\sqrt{1-\zeta^2}}{\zeta}\right)\right\}$$

- The reciprocal of constant of negative power of exponential term in the error part of the output signal is actually responsible for damping of the output response. Here in this equation it is ζωn.
- The reciprocal of constant of negative power of exponential term in error signal is known as time constant.

Under damped response:

- when the value of ζ (also know as damping ratio) is less than unity, the oscillation of the response decays exponentially with a time constant 1/ζωn. This is called under damped response.

Over damped response:

- On the other hand. when ζ is greater than unity, the response of the unit step input given to the system, does not exhibit oscillating part in it. This is called **over damped response.**

Critical Damping:

- When damping ratio is unity that is ζ = 1. In that situation the damping of the response is governed by the natural frequency ωn only. The actual damping at that condition is known as **critical damping** of the response.

Damping ratio:

- The ratio of time constant of critical damping to that of actual damping is known as damping ratio. As the time constant of time response of control system is 1/ζωn when ζ≠ 1 and time constant is 1/ωn when ζ = 1.

$$\frac{Time\ Constant\ of\ critical\ damping}{Time\ Constant\ of\ actual\ damping} = \frac{\frac{1}{\omega_n}}{\frac{1}{\zeta\omega_n}} = \zeta$$

Second Order System Transfer Function:

- The general equation for the transfer function of a second order control system is given as

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=19eCOPJdNKs
https://www.youtube.com/watch?v=O-ZMhu-aEwI

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:63)

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L 15

LECTURE HANDOUTS

EEE

III/V

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : II-TIME RESPONSE ANALYSIS Date of Lecture:

Topic of Lecture: Steady state errors

Introduction :

- The coefficient of error is a standard statistical value that is used extensively in the stereological literature.
- The definition of the CE is rather simple. It is defined as the standard error of the mean of repeated estimates divided by the mean.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Steady state

2.Transient

Detailed content of the Lecture:

- The deviation of the output of control system from desired response during steady state is known as steady state error. It is represented as essess. We can find steady state error using the final value theorem as follows.

  $e_{ss}=\lim_{t\to\infty}e(t)=\lim_{s\to 0}sE(s)$

  Where,E(s) is the Laplace transform of the error signal, e(t).

- When the reference input is applied to the given system then the information given about the level of desired output is observed.
- The actual output is feed back to the input side and it is compared with the input signal.
- Thus steady state error can also be defined as the difference between the reference input and the feedback signal.

There are two types of error coefficient.

1) static error coefficient

2) Dynamic error coefficient

Dynamic error coefficient:

- Use to express dynamic error
- Provides error signal as function of time
- Used for determining any type of input
- The dynamic error coefficient provides a simple way of estimating error signal to arbitrary inputs and the steady sate error without solving the system differential equation.

Static error coefficient:

- The response that remain after the transient response has died out is called steady state response.
- The steady sate response is important to find the accuracy of the output.
- The difference between steady state response and desired response gives the steady state error.
- The control system has following steady state errors for change in positions, velocity and acceleration.

Kp = Positional error constant

Kv = Velocity error constant

Ka = Acceleration error constant

- These constants are called static error coefficient. They have the ability to minimize the steady error.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=_p6w7oztrwQ
https://www.youtube.com/watch?v=_p6w7oztrwQ

Important Books/Journals for further learning including the page nos.:

M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:165)

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LECTURE HANDOUTS

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III/V

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : II-TIME RESPONSE ANALYSIS Date of Lecture:

Topic of Lecture: Steady state errors

Introduction :

- The drawback in static error coefficients is that it does not show the variation of error with time and input should be a standard value.
- The generalized error coefficients gives the steady state error as a function of time.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Error in system

2.Steady state error

Detailed content of the Lecture:

- The deviation of the output of control system from desired response during steady state is known as steady state error. It is represented as essess. We can find steady state error using the final value theorem as follows.

  ess=limt→∞e(t)=lims→0sE(s)

  Where,E(s) is the Laplace transform of the error signal, e(t).

- When the reference input is applied to the given system then the information given about the level of desired output is observed.

- The actual output is feed back to the input side and it is compared with the input signal.

The error signal in s-domain ,E(s)can be expressed as a product of two s-domain functions

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

$$E(s)= F(s)R(s)$$

Where e(t)= error signal in time domain

f(t)=Inverse laplace transform of F(s)

r(t)=input signal in time domain

- The response that remain after the transient response has died out is called steady state response.
- The steady sate response is important to find the accuracy of the output.
- The difference between steady state response and desired response gives the steady state error.
- The control system has following steady state errors for change in positions, velocity and acceleration.

  Kp = Positional error constant

  Kv = Velocity error constant

  Ka = Acceleration error constant

- These constants are called static error coefficient. They have the ability to minimize the steady error.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=gvo-ejTROP0
https://www.youtube.com/watch?v=91a-yvzDIzo

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:309)

Course faculty

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LECTURE HANDOUTS

EEE

III/V

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : II-TIME RESPONSE ANALYSIS Date of Lecture:

Topic of Lecture: P, PI, PD and PID Compensation

Introduction :

- In feedback control system a controller may be introduced to modify the error signal and to achieve better control action.
- The introduction of controllers will modify the transient response and steady state error of the system.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Controller

2.Gain

Detailed content of the Lecture:

Proportional:

- The motor current is set in proportion to the existing error.
- However, this method fails if, for instance, the arm has to lift different weights: a greater weight needs a greater force applied for a same error on the down side, but a smaller force if the error is on the upside.

Integral:

- An integral term increases action in relation not only to the error but also the time for which it has persisted.
- So, if applied force is not enough to bring the error to zero, this force will be increased as time passes.
- A pure "I" controller could bring the error to zero, but it would be both slow reacting at the start (because action would be small at the beginning, needing time to get significant) and brutal (the action increases as long as the error is positive, even if the error has started to approach zero).

Derivative:

- A derivative term does not consider the error (meaning it cannot bring it to zero: a pure D controller cannot bring the system to its setpoint), but the rate of change of error, trying to bring this rate to zero.

Effects of proportional controller:

- The proportional controller produces an output signal which is proportional to error signal.
- The transfer function of proportional controller is K_p.The term K_p is called the gain of the cotroller.
- Hence the proportional controller amplifies the error signal and increases the loop gain of the system.
- The following aspects of system bahaviour are improved by increasing loop gain.

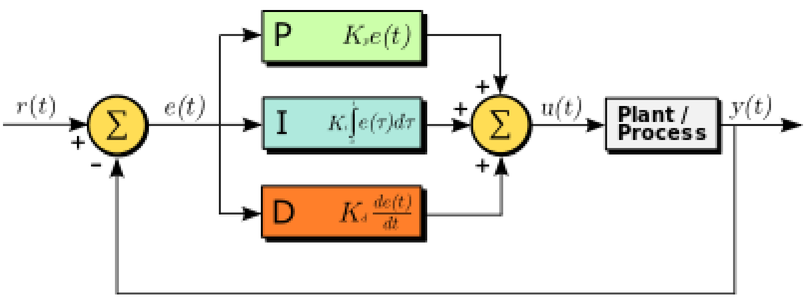
  i)Steady state tracking accuracy

  ii)Disturbance signal rejection

  iii)Relative Stability

Proportional–integral–derivative controller:

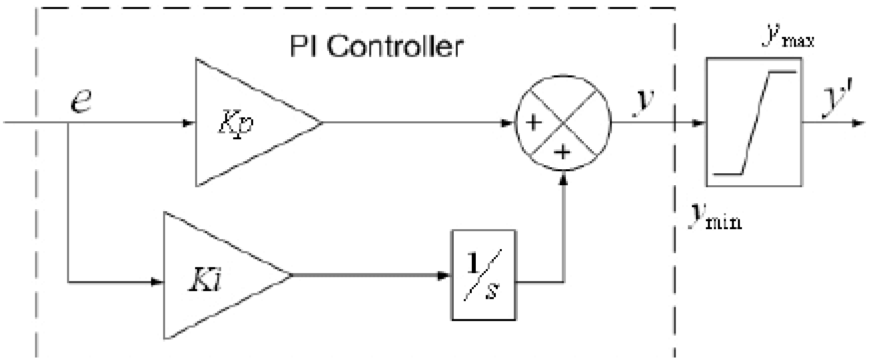
- A proportional–integral–derivative controller (PID controller. or three-term controller) is a control loop mechanism employing feedback that is widely used in industrial control systems and a variety of other applications requiring continuously modulated control.



- The distinguishing feature of the PID controller is the ability to use the three control terms of proportional, integral and derivative influence on the controller output to apply accurate and optimal control.
- The block diagram on the right shows the principles of how these terms are generated and applied.
- Term P is proportional to the current value of the SP − PV error e(t).
- Term I accounts for past values of the SP − PV error and integrates them over time to produce the I term.
- Term D is a best estimate of the future trend of the SP − PV error, based on its current rate of change.

P.I Controller:

➤ A P.I Controller is a feedback control loop that calculates an error signal by taking the difference between the output of a system, which in this case is the power being drawn from the battery, and the set point.



➤ The integral mode of the controller is the last term of the equation. Its function is to integrate or continually sum the controller error, e(t), over time.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=lVQxEwxVqgk

https://www.youtube.com/watch?v=Z0BcL8UVNBI

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:310)

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LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : II-TIME RESPONSE ANALYSIS Date of Lecture:

Topic of Lecture: Analysis using MATLAB

Introduction :

- Time-domain and frequency-domain analysis commands let you compute and visualize SISO and MIMO system responses such as Bode plots, Nichols plots, step responses, and impulse responses.
- You can also extract system characteristics such as rise time and settling time, overshoot, and stability margins. Most linear analysis commands can either return response data or generate response plots.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Time domain

2.Frequency domain

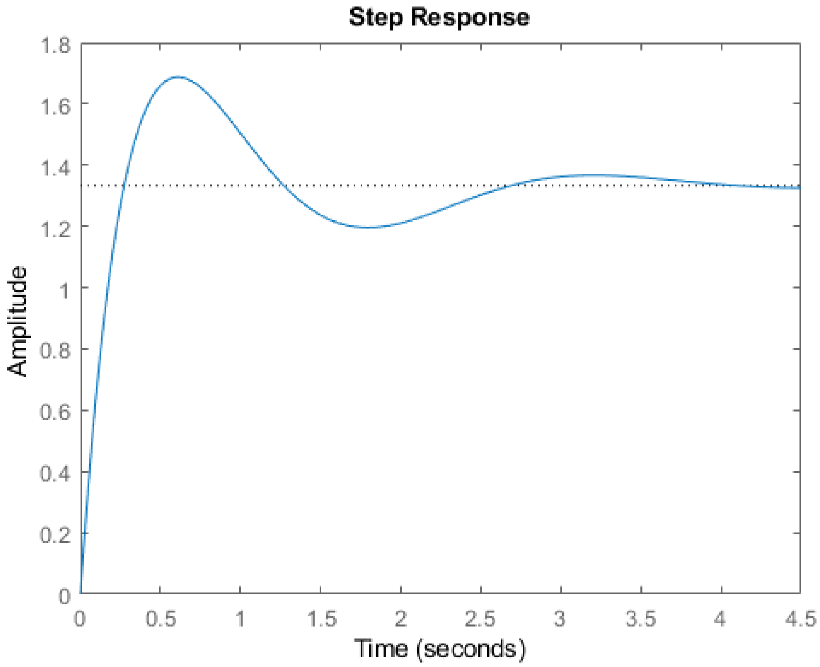
Detailed content of the Lecture:

<u>Time domain analysis:</u>

- Stability is a standard requirement for control systems to avoid loss of control and damage to equipment.
- For linear feedback systems, stability can be assessed by looking at the poles of the closed-loop transfer function.
- Gain and phase margins measure how much gain or phase variation at the gain crossover frequency will cause a loss of stability.
- Together, these two quantities give an estimate of the *safety margin* for closed-loop stability. The smaller the stability margins, the more fragile stability.

step	Step response plot of dynamic system; step response data
stepinfo	Rise time, settling time, and other step-response characteristics

impulse	Impulse response plot of dynamic system; impulse response data
initial	Initial condition response of state-space model
lsim	Simulate time response of dynamic system to arbitrary inputs
lsiminfo	Compute linear response characteristics
gensig	Generate test input signals for lsim
covar	Output and state covariance of system driven by white noise
stepDataOptions	Options set for step



Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=z-yqMQTCIYI
https://www.youtube.com/watch?v=JmSWrw2hDHA

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:260)

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LECTURE HANDOUTS

L 19

EEE

III/V

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : III- FREQUENCY RESPONSE ANALYSIS **Date of Lecture:**

Topic of Lecture:

Frequency Response

Introduction :

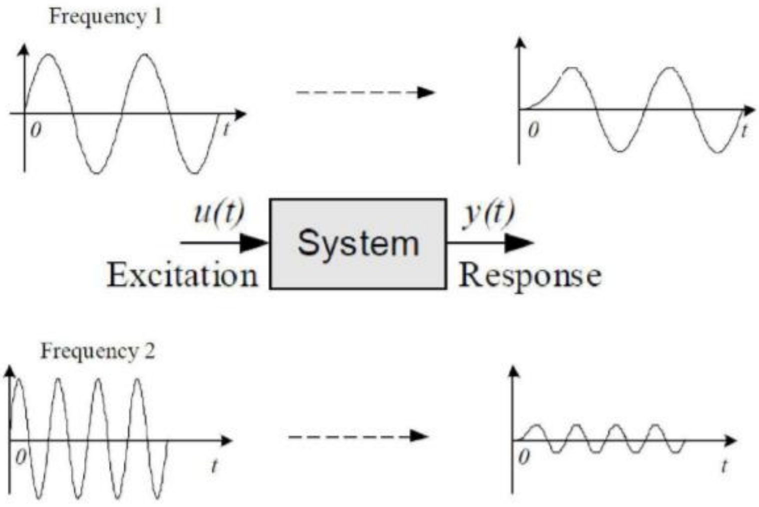
- The frequency response of a system is a frequency dependent function which expresses how a sinusoidal signal of a given frequency on the system input is transferred through the system.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Signals and Systems
- Amplifier

Detailed content of the Lecture:

- Time-varying signals at least periodical signals —which excite systems, as the reference (set point) signal or a disturbance in a control system or measurement signals which are inputs signals to signal filters, can be regarded as consisting of a sum of frequency components.



- Each frequency component is a sinusoidal signal having certain amplitude and a certain frequency. (The Fourier series expansion or the Fourier transform can be used to express these frequency components quantitatively.)

- The frequency response expresses how each of these frequency components is transferred through the system.

- Some components may be amplified, others may be attenuated, and there will be some phase lag through the system.
- The frequency response is an important tool for analysis and design of signal filters (as low pass filters and high pass filters), and for analysis, and to some extent, design, of control systems.
-

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=BsF0EkfEAxc

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:470-472)

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LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : III-FREQUENCY RESPONSE ANALYSIS Date of Lecture:

Topic of Lecture: Bode plot

Introduction :

- Plots of the magnitude and phase characteristics are used to fully describe the frequency response
- A Bode plot is a (semilog) plot of the transfer function magnitude and phase angle as a function of frequency. The gain magnitude is many times expressed in terms of decibels (dB)

db = 20 log 10 A

Prerequisite knowledge for Complete understanding and learning of Topic:

- Signals and Systems

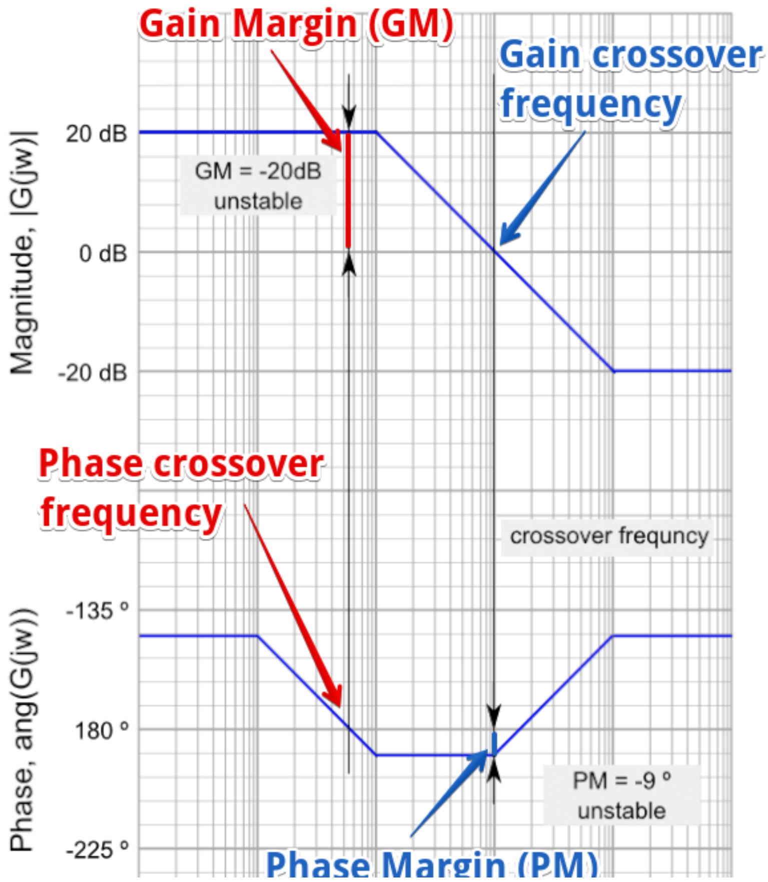
Detailed content of the Lecture:

- A **Bode plot** is a graph commonly used in control system engineering to determine the stability of a control system.
- A Bode plot maps the frequency response of the system through two graphs – the Bode magnitude plot (expressing the magnitude in decibels) and the Bode phase plot (expressing the phase shift in degrees)
- Bode plots offer a relatively simple method to calculate system stability, they can not handle transfer functions with right half plane singularities (unlike Nyquist stability criterion).

Gain Margin

- The greater the Gain Margin (GM), the greater the stability of the system. The gain margin refers to the amount of gain, which can be increased or decreased without making the system unstable. It is usually expressed as a magnitude in dB.

- We can usually read the gain margin directly from the Bode plot (as shown in the diagram below). This is done by calculating the vertical distance between the magnitude curve (on the Bode magnitude plot) and the x-axis at the frequency where the Bode phase plot = 180°. This point is known as the phase crossover frequency.



Phase Margin

- The greater the Phase Margin (PM), the greater will be the stability of the system. The phase margin refers to the amount of phase, which can be increased or decreased without making the system unstable. It is usually expressed as a phase in degrees.
- We can usually read the phase margin directly from the Bode plot (as shown in the diagram above).
- This is done by calculating the vertical distance between the phase curve (on the Bode phase plot) and the x-axis at the frequency where the Bode magnitude plot = 0 dB. This point is known as the gain crossover frequency.
-

Bode Plot Stability

- Below are a summarised list of criterion relevant to drawing Bode plots (and calculating their stability):
- **Gain Margin:** Greater will the gain margin greater will be the stability of the system. It refers to the amount of gain, which can be increased or decreased without making the system unstable. It is usually expressed in dB.
- **Phase Margin**: Greater will the **phase margin** greater will be the stability of the system. It refers to the phase which can be increased or decreased without making the system unstable. It is usually expressed in phase.
- **Gain Crossover Frequency**: It refers to the frequency at which magnitude curve cuts the zero dB axis in the bode plot.
- **Phase Crossover Frequency**: It refers to the frequency at which phase curve cuts the negative times the 180o axis in this plot.

- **Corner Frequency:** The frequency at which the two asymptotes cuts or meet each other is known as break frequency or corner frequency.
- **Resonant Frequency:** The value of frequency at which the modulus of G (jω) has a peak value is known as the resonant frequency.
- **Factors:** Every loop transfer function {i.e. G(s) × H(s)} product of various factors like constant term K, Integral factors (jω), first-order factors (1 + jωT)(± n) where n is an integer, second order or quadratic factors.
- **Slope:** There is a slope corresponding to each factor and slope for each factor is expressed in the dB per decade.
- **Angle:** There is an angle corresponding to each factor and angle for each factor is expressed in the degrees.

How to Draw Bode Plot

- Keeping all the above points in mind, we are able to draw a Bode plot for any kind of control system. Now let us discuss the procedure of drawing a Bode plot:
- Substitute the s = jω in the open loop transfer function G(s) × H(s).
- Find the corresponding corner frequencies and tabulate them.
- Now we are required one semi-log graph chooses a frequency range such that the plot should start with the frequency which is lower than the lowest corner frequency.
- Mark angular frequencies on the x-axis, mark slopes on the left hand side of the y-axis by marking a zero slope in the middle and on the right hand side mark phase angle by taking -180o in the middle.
- Calculate the gain factor and the type or order of the system.
- Now calculate slope corresponding to each factor.

For drawing the Bode magnitude plot:

- Mark the corner frequency on the semi-log graph paper.
- Tabulate these factors moving from top to bottom in the given sequence.
  1. Constant term K.
  2. Integral factor $\frac{1}{j\omega^n}$
  3. First order factor $\frac{1}{1+j\omega T}$
  4. First order factor (1+jωT).
  5. Second order or quadratic factor: $\left[\frac{1}{1+(2\zeta/\omega)} \times (j\omega) + \left(\frac{1}{\omega^2}\right) \times (j\omega)^2\right]$

- Now sketch the line with the help of the corresponding slope of the given factor. Change the slope at every corner frequency by adding the slope of the next factor. You will get the magnitude plot.
- Calculate the gain margin.

For drawing the Bode phase plot:

- Calculate the phase function adding all the phases of factors.
- Substitute various values to the above function in order to find out the phase at different points and plot a curve. You will get a phase curve.
- Calculate the phase margin.

Bode Stability Criterion

- Stability conditions are given below:
- For Stable System: Both the margins should be positive or phase margin should be greater than the gain margin.
- For Marginal Stable System: Both the margins should be zero or phase margin should be equal to the gain margin.
- For Unstable System: If any of them is negative or **phase margin** should be less than the gain margin.

Advantages of Bode Plot

- It is based on the asymptotic approximation, which provides a simple method to plot the logarithmic magnitude curve.
- The multiplication of various magnitude appears in the transfer function can be treated as an addition, while division can be treated as subtraction as we are using a logarithmic scale.
- With the help of this plot only we can directly comment on the stability of the system without doing any calculations.
- **Bode plots** provides relative stability in terms of **gain margin** and **phase margin**.
- It also covers from low frequency to high frequency range.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=_eh1conN6YM

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:478-494)

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LECTURE HANDOUTS

EEE

III/V

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : III- FREQUENCY RESPONSE ANALYSIS Date of Lecture:

Topic of Lecture: Bode plot

Introduction :

- **A Bode plot** is a (semilog) plot of the transfer function magnitude and phase angle as a function of frequency. The gain magnitude is many times expressed in terms of decibels (dB)
- **The Polar plot** is a plot, which can be drawn between the magnitude and the phase angle of G(jω)H(jω) by varying ω from zero to ∞.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Signals and Systems

Detailed content of the Lecture:

Bode Plot –

Example For the following T.F draw the Bode plot and obtain Gain cross over frequency (wgc) , Phase cross over frequency , Gain Margin and Phase Margin.

G(s) = 20 / [s (1+3s) (1+4s)]

Solution: The sinusoidal T.F of G(s) is obtained by replacing s by jw in the given T.F

G(jw) = 20 / [jw (1+j3w) (1+j4w)]

Corner frequencies: wc1= 1/4 = 0.25 rad /sec ;

wc2 = 1/3 = 0.33 rad /sec

Choose a lower corner frequency and a higher Corner frequency

wl= 0.025 rad/sec ;

wh = 3.3 rad / sec

Calculation of Gain (A) (MAGNITUDE PLOT)

A @ wl ; A= 20 log [20 / 0.025] = 58 .06 dB

A @ wc1 ; A = [Slope from wl to wc1 x log (wc1 / wl] + Gain (A)@wl = - 20 log [0.25 / 0.025] + 58.06 = 38.06 dB

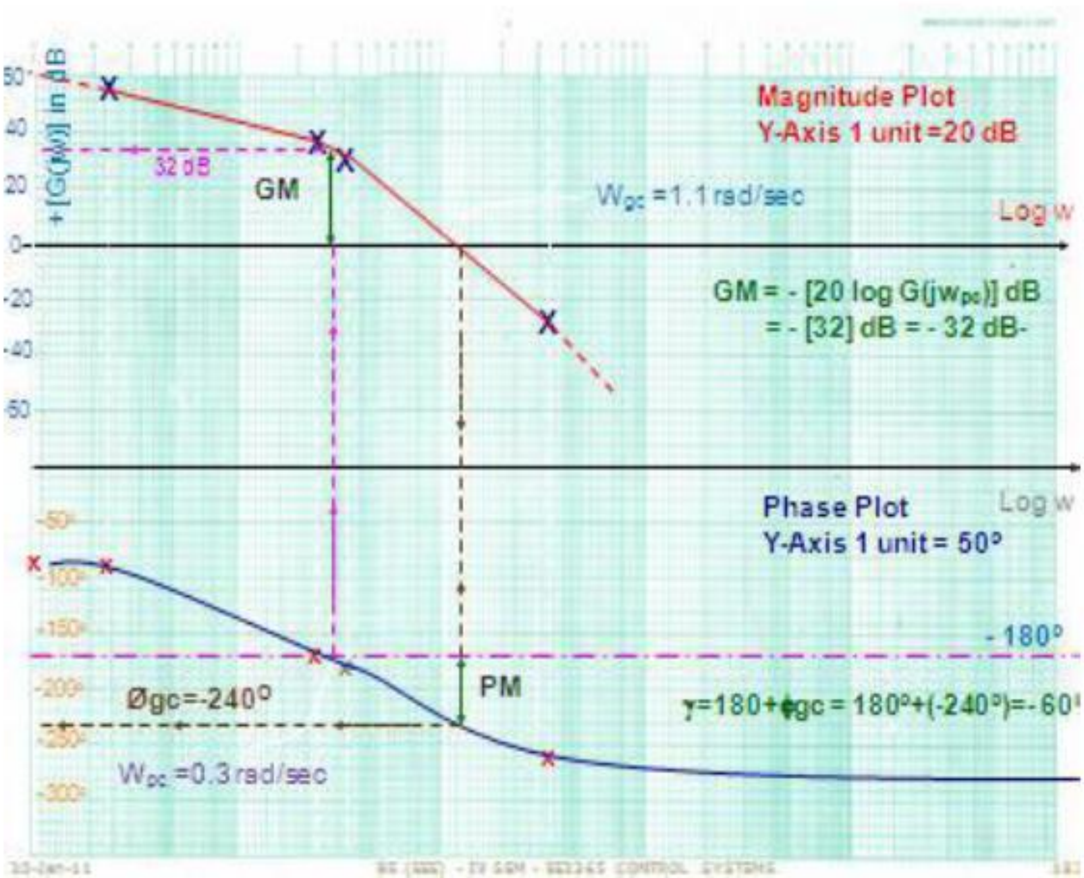
A @ wc2 ; A = [Slope from wc1 to wc2 x log (wc2 / wc1] + Gain (A)@ wc1 = - 40 log [0.33 / 0.25] + 38 = 33 dB

A @ wh ; A = [Slope from wc2 to wh x log (wh / wc2] + Gain (A) @ wc2 = - 60 log [3.3 / 0.33] + 33 =-27 dB

Calculation of Phase angle for different values of frequencies [PHASE PLOT]

Ø = -90O- tan -1 3w – tan -1 4w
When

Frequency in rad / sec	Phase angles in Degree
w=0	Ø= -90 0
w = 0.025	Ø= -990
w = 0.25	Ø= -1720
w = 0.33	Ø= -1880
w =3.3	Ø= -2590
w =∞	Ø= -2700



Calculations of Gain cross over frequency

The frequency at which the dB magnitude is Zero wgc = 1.1 rad / sec

Calculations of Phase cross over frequency

The frequency at which the Phase of the system is - 180o wpc = 0.3 rad / sec

Gain Margin

The gain margin in dB is given by the negative of dB magnitude of G(jw) at phase cross over frequency GM = - { 20 log [G(jwpc)] = - { 32 } = -32 dB

Phase Margin

Γ = 1800+ Øgc= 1800 + (- 2400o) = -600

Conclusion

For this system GM and PM are negative in values. Therefore the system is unstable in nature.

Polar plot

- Polar plot is a plot which can be drawn between magnitude and phase. Here, the magnitudes are represented by normal values only.
- The Polar plot is a plot, which can be drawn between the magnitude and the phase angle of $G(j\omega)H(j\omega)$ by varying ω from zero to ∞.

To sketch the polar plot of $G(j\omega)$ for the entire range of frequency ω, i.e., from 0 to infinity, there are four key points that usually need to be known:
(1) the start of plot where $\omega = 0$,
(2) the end of plot where $\omega = \infty$,
(3) where the plot crosses the real axis, i.e., $Im(G(j\omega)) = 0$, and
(4) where the plot crosses the imaginary axis, i.e., $Re(G(j\omega)) = 0$.

Basics of Polar Plot:

- The polar plot of a sinusoidal transfer function $G(j\omega)$ is a plot of the magnitude of $G(j\omega)$ Vs the phase of $G(j\omega)$ on polar co-ordinates as ω is varied from 0 to ∞.(ie) $|G(j\omega)|$ Vs angle $G(j\omega)$ as $\omega \rightarrow 0$ to ∞.
- Polar graph sheet has concentric circles and radial lines.
- Concentric circles represents the magnitude.
- Radial lines represents the phase angles.
- In polar sheet
  +ve phase angle is measured in ACW from 0^o
  - ve phase angle is measured in CW from 0^o

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=GdK2CLNnGAM

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:465)

Course Faculty

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Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : III- FREQUENCY RESPONSE ANALYSIS Date of Lecture:

Topic of Lecture: Polar plot

Introduction :

- Polar plot is a plot which can be drawn between magnitude and phase. Here, the magnitudes are represented by normal values only.
- **The Polar plot** is a plot, which can be drawn between the magnitude and the phase angle of G(jω)H(jω) by varying ω from zero to ∞.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Signals and Systems

Detailed content of the Lecture:

PROCEDURE

- Express the given expression of OLTF in (1+sT) form.
- Substitute s = jω in the expression for G(s)H(s) and get G(jω)H(jω).
- Get the expressions for | G(jω)H(jω)| & angle G(jω)H(jω).
- Tabulate various values of magnitude and phase angles for different values of ω ranging from 0 to ∞.
- Usually the choice of frequencies will be the corner frequency and around corner frequencies
- Choose proper scale for the magnitude circles.
- Fix all the points in the polar graph sheet and join the points by a smooth curve.
- Write the frequency corresponding to each of the point of the plot.

MINIMUM PHASE SYSTEMS:

- Systems with all poles & zeros in the Left half of the s-plane – Minimum Phase Systems.
- For Minimum Phase Systems with only poles
- Type No. determines at what quadrant the polar plot starts.
- Order determines at what quadrant the polar plot ends.
- Type No. → No. of poles lying at the origin
- Order → Max power of‗s' in the denominator polynomial of the transfer function.

GAIN MARGIN

- Gain Margin is defined as ―the factor by which the system gain can be increased to drive the system to the verge of instability‖.

For stable systems, ωgc< ωpc Magnitude of G(j)H(j) at ω=ωpc < 1

GM = in positive dB

More positive the GM, more stable is the system.

For marginally stable systems,

ωgc = ωpc

magnitude of G(j)H(j) at ω=ωpc = 1

GM = 0 dB

For Unstable systems, ωgc> ωpc , magnitude of G(j)H(j) at ω=ωpc > 1

GM = in negative dB

Gain is to be reduced to make the system stable

PHASE MARGIN

- Phase Margin is defined as ― the additional phase lag that can be introduced before the system becomes unstable‖ .
- A‘ be the point of intersection of G(j)H(j) plot and a unit circle centered at the origin.
- Draw a line connecting the points ‗O‘ & ‗A‘ and measure the phase angle between the line OA and +ve real axis.
- This angle is the phase angle of the system at the gain cross over frequency.
  Angle of G(jwgc)H(jw gc) =θ gc

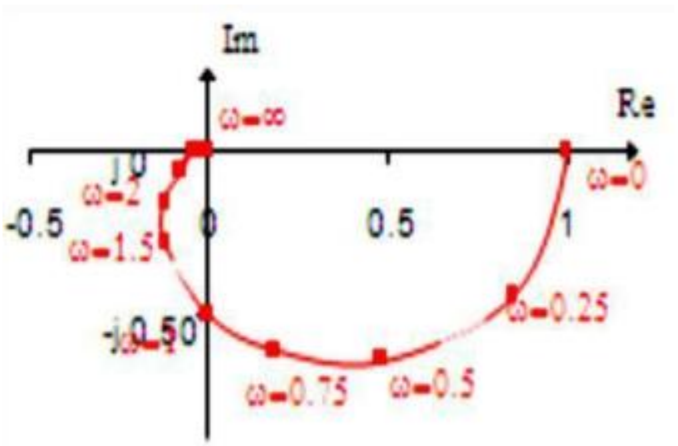
If an additional phase lag of θ PM is introduced at this frequency, then the phase angle G(jwgc)H(jw gc) will become 180 and the point ‗A‗ coincides with (-1+j0) driving the system to the verge of instability.

This additional phase lag is known as the Phase Margin. γ= 1800+ angle of G(jwgc)H(jw gc)

γ= 1800 + θ gc

[Since θ gc is measured in CW direction, it is taken as negative] For a stable system, the phase margin is positive.

A Phase margin close to zero corresponds to highly oscillatory system



A polar plot may be constructed from experimental data or from a system transfer function

- If the values of w are marked along the contour, a polar plot has the same information as a bode plot.
- Usually, the shape of a polar plot is of most interest.

Advantage

- It can capture the system behavior over the entire frequency range in a single plot

Disadvantage

- It can't tell the impact of individual component of open loop transfer function.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=OKo3GSeB3hU

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:496)

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LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : III- FREQUENCY RESPONSE ANALYSIS Date of Lecture:

Topic of Lecture:
Nyquist stability

Introduction :
The Nyquist stability criterion works on the **principle of argument**. It states that if there are P poles and Z zeros are enclosed by the 's' plane closed path, then the corresponding G(s)H(s)G(s)H(s) plane must encircle the origin P−ZP−Z times.

Prerequisite knowledge for Complete understanding and learning of Topic:
- Partial differential equation

Detailed content of the Lecture:

Nyquist Stability Criterion:

The Nyquist stability criterion works on the **principle of argument**. It states that if there are P poles and Z zeros are enclosed by the 's' plane closed path, then the corresponding $G(s)H(s)$G(s)H(s) plane must encircle the origin $P-Z$P−Z times. So, we can write the number of encirclements N as,

$$N=P-Z$$ N=P−Z

- If the enclosed 's' plane closed path contains only poles, then the direction of the encirclement in the G(s)H(s)G(s)H(s) plane will be opposite to the direction of the enclosed closed path in the 's' plane.
- If the enclosed 's' plane closed path contains only zeros, then the direction of the encirclement in the G(s)H(s)G(s)H(s) plane will be in the same direction as that of the enclosed closed path in the 's' plane.

Let us now apply the principle of argument to the entire right half of the 's' plane by selecting it as a closed path. This selected path is called the **Nyquist** contour.

We know that the closed loop control system is stable if all the poles of the closed loop transfer function are in the left half of the 's' plane. So, the poles of the closed loop transfer function are nothing but the roots of the characteristic equation. As the order of the characteristic equation increases, it is difficult to find the roots. So, let us correlate these roots of the characteristic equation as follows.

- The Poles of the characteristic equation are same as that of the poles of the open loop transfer function.
- The zeros of the characteristic equation are same as that of the poles of the closed loop transfer function.

We know that the open loop control system is stable if there is no open loop pole in the the right half of the 's' plane.

i.e.,$P=0\Rightarrow N=-Z$P=0⇒N=−Z

We know that the closed loop control system is stable if there is no closed loop pole in the right half of the 's' plane.

i.e.,$Z=0\Rightarrow N=P$Z=0⇒N=P

Nyquist stability criterion states the number of encirclements about the critical point (1+j0) must be equal to the poles of characteristic equation, which is nothing but the poles of the open loop transfer function in the right half of the 's' plane. The shift in origin to (1+j0) gives the characteristic equation plane.

Rules for Drawing Nyquist Plots:

Follow these rules for plotting the Nyquist plots.

- Locate the poles and zeros of open loop transfer function G(s)H(s)G(s)H(s) in 's' plane.
- Draw the polar plot by varying ωω from zero to infinity. If pole or zero present at s = 0, then varying ωω from 0+ to infinity for drawing polar plot.
- Draw the mirror image of above polar plot for values of ωω ranging from −∞ to zero (0^- if any pole or zero present at s=0).
- The number of infinite radius half circles will be equal to the number of poles or zeros at origin. The infinite radius half circle will start at the point where the mirror image of the polar plot ends. And this infinite radius half circle will end at the point where the polar plot starts.

After drawing the Nyquist plot, we can find the stability of the closed loop control system using the Nyquist stability criterion. If the critical point (-1+j0) lies outside the encirclement, then the closed loop control system is absolutely stable.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=sof3meN96MA

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:463)

Course Faculty

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Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : III- FREQUENCY RESPONSE ANALYSIS Date of Lecture:

Topic of Lecture:
Frequency Domain specifications from the plots

Introduction :
The correlation between time and frequency response has an explicit from only for first and second order systems.

Prerequisite knowledge for Complete understanding and learning of Topic:
- Signals and Systems

Detailed content of the Lecture:

time-domain specifications

(i) Delay time, td
(ii) Rise time, tr
(iii) Peak time, tp
(iv) Peak overshoot, Mp
(v) Settling time For unity step input,

(i)Delay time, td: It is the time required to reach 50% of output.
(ii) Rise time, tr : The time taken for response to raise from 0% to 100% for the very first time
(iii) Peak time, tp:The time required by the system response to reach the first maximum value.
(iv) Peak overshoot, Mp: It is the time required to reach 50% of output.
(iv) Settling time, ts: It is the time taken by the system response to settle down and stay with in ± 2% or ±5% its final value.

frequency domain specifications

i. Resonant peak (Mr)
ii. Resonant frequency (ω_r)
iii. Cut-off frequency(ω_c)
iv. Band-width(ω_b)
v. Phase cross-over frequency
vi. Gain margin (GM)
vii. Gain cross-over frequency
viii. Phase margin (PM)

(i)Resonant peak: Maximum value of M(jω) whenω is varied from 0 to Mr
(ii)Resonant peak : The frequency at which Mr occurs
(iii)Cut-off frequency: The frequency at which M(jω) has a value of 1/√2. It is the frequency at which the magnitude is 3dB below its zero frequency value

(iv) Band-width: It is the range of frequencies in which the magnitude of a closed-loop system is 1/√2times of Mr
(v) Phase cross-over frequency: The frequency at which phase plot crosses -180^0

(vi)Gain margin : It is the increase in open-loop gain in dB required to drive the closed-loop system to the verge of instability

(vii) Gain cross-over frequency: The frequency at which gain or magnitude plot crosses 0dB line

(viii) Phase margin : It is the increase in open-loop phase shift in degree required to drive the closed-loop system to the verge of instability

Correlation between time and frequency response

For a second order system

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

Putting $s = j\omega$

$$\frac{C(j\omega)}{R(j\omega)} = \frac{\omega_n^2}{\omega_n^2 - \omega^2 + j2\zeta\omega_n\omega}$$

$$\Rightarrow \frac{C(j\omega)}{R(j\omega)} = \frac{1}{\left(1 - \frac{\omega^2}{\omega_n^2}\right) + j2\zeta\left(\frac{\omega}{\omega_n}\right)}$$

Let, $u = \frac{\omega}{\omega_n}$, then

$$\frac{C(j\omega)}{R(j\omega)} = \frac{1}{\left(1 - u^2\right) + j2\zeta u}$$

Now,

$$M(j\omega) = |M(j\omega)| \angle M(j\omega)$$

Where,

$$|M(j\omega)| = \frac{1}{\sqrt{\left(1 - u^2\right)^2 + (2\zeta u)^2}}$$

$$\theta = -\tan^{-1}\left(\frac{2\zeta u}{1 - u^2}\right)$$

Now,

$$M_r = \frac{1}{2\zeta\sqrt{1 - \zeta^2}}$$

$$\omega_r = \omega_n\sqrt{1 - 2\zeta^2}$$

$$\omega_b = \omega_n \sqrt{1 - 2\zeta^2 + \sqrt{4\zeta^4 - 4\zeta^2 + 2}}$$

$$PM = -180^0 + \varphi$$

Where, $\varphi = \tan^{-1} \dfrac{2\zeta}{\sqrt{\sqrt{4\zeta^2 + 1} - 2\zeta^2}}$

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=s6PsiMA4qm4

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:578-585)

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LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : III- FREQUENCY RESPONSE ANALYSIS **Date of Lecture:**

Topic of Lecture: Constant M and N Circles

Introduction :

- Two graphical methods are available to determine the closed loop response from open loop frequency response. they are,
    1. M and N circles
    2. Nichols chart

Prerequisite knowledge for Complete understanding and learning of Topic:

- Signals and Systems

Detailed content of the Lecture:

Constant M and N circles

- Hall circles (also known as M-circles and N-circles) are a graphical tool in control theory used to obtain values of a closed-loop transfer function from the Nyquist plot (or the Nichols plot) of the associated open-loop transfer function.

Peak Magnitude

$$M_r = 20\log\left|\frac{C(j\omega)}{R(j\omega)}\right| \text{dB}$$

3 dB is considered good

Constant M-circles for unity feedback systems

- The magnitude of closed loop transfer function with unit feedback can be shown to be in the form of circle for every value of M. these circles are called M-Circles.

$$M(j\omega) = \frac{G(j\omega)}{1+G(j\omega)}$$

$$G(j\omega) = x + jy$$

$$|M(j\omega)| = \frac{\sqrt{x^2+y^2}}{\sqrt{(1+x)^2+y^2}}$$

$$M^2(1+x)^2 + M^2y^2 = x^2 + y^2$$

$$x^2(1-M^2) + (1-M^2)y^2 - 2M^2x = M^2$$

$$x^2 + y^2 - 2\frac{M^2}{1-M^2}x = \frac{M^2}{1-M^2}$$

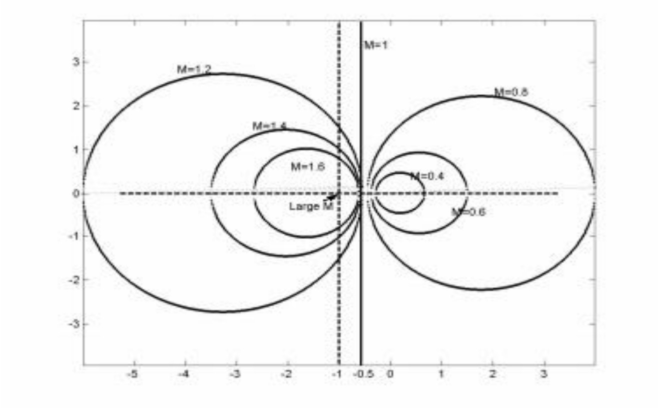
Adding $\left(\frac{M^2}{1-M^2}\right)^2$ in both sides, we get

$$\left(x - \frac{M^2}{1-M^2}\right)^2 + y^2 = \left(\frac{M}{1-M^2}\right)^2$$

The above equation represents a family of circles with its center at $\left(\frac{M^2}{1-M^2}, 0\right)$ and radius $\left|\frac{M}{1-M^2}\right|$.

Family of M-circles

Family of M-circles corresponding to the close loop magnitudes (M) of a unit feedback system
Constant M-circles for unity feedback systems



Constant N-circles

- If the phase of closed loop transfer function with unity feedback is α, then it can be shown that than α will be in the form of circle for every value of α. these circles are called N-Circles

$$\angle M = \alpha = \frac{\angle G(j\omega)}{\angle 1 + G(j\omega)}$$

$$\alpha = \tan^{-1}\frac{y}{x} - \tan^{-1}\frac{y}{1+x}$$

$$N = \tan\left(\tan^{-1}\frac{y}{x} - \tan^{-1}\frac{y}{1+x}\right)$$

$$\tan(A-B) = \frac{\tan A - \tan B}{1 + \tan A \tan B}$$

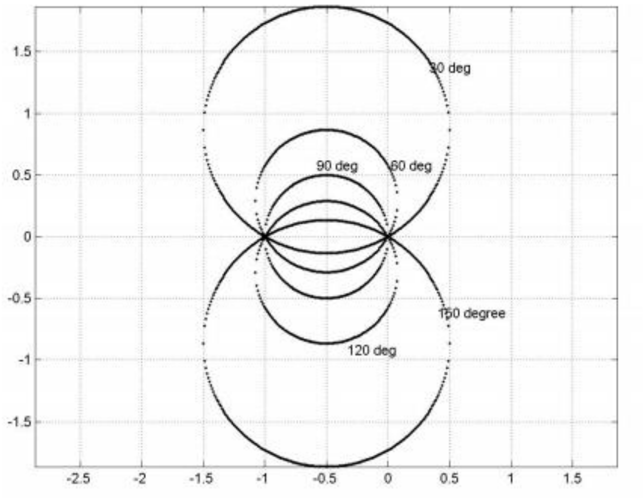
Here, tan(α)=N

$$N = \frac{y}{x^2 + x + y^2}$$

$$\left(x+\frac{1}{2}\right)^2 + \left(y - \frac{1}{2N}\right)^2 = \frac{1}{4} + \left(\frac{1}{2N}\right)^2$$

The above equation represents a family of circles with its center at $(-\frac{1}{2}, \frac{1}{2N})$ and radius

$$\sqrt{\frac{1}{4} + \left(\frac{1}{2N}\right)^2}$$



Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=wXGw_FXr2mk

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:521)

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LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : III- FREQUENCY RESPONSE ANALYSIS **Date of Lecture:**

Topic of Lecture: Nichols chart

Introduction :

- Two graphical methods are available to determine the closed loop response from open loop frequency response. they are,
  3. M and N circles
  4. Nichols chart

Prerequisite knowledge for Complete understanding and learning of Topic:

- Signals and Systems

Detailed content of the Lecture:

Nichols chart of frequency response

Syntax

nichols(sys)

nichols(sys,w)

nichols(sys1,sys2,...,sysN)

nichols(sys1,sys2,...,sysN,w)

nichols(sys1,'PlotStyle1',...,sysN,'PlotStyleN')

[mag,phase,w] = nichols(sys)

[mag,phase] = nichols(sys,w)

Description

- ✓ Nichols creates a Nichols chart of the frequency response.
- ✓ A Nichols chart displays the magnitude (in dB) plotted against the phase (in degrees) of the system response. Nichols charts are useful to analyze open- and closed-loop properties of SISO systems, but offer little insight into MIMO control loops.
- ✓ Use ngrid to superimpose a Nichols chart on an existing SISO Nichols chart.
- ✓ nichols(sys) creates a Nichols chart of the dynamic system sys.
- ✓ This model can be continuous or discrete, SISO or MIMO. In the MIMO case, nichols produces an array of Nichols charts, each plot showing the response of one particular I/O channel.
- ✓ The frequency range and gridding are determined automatically based on the system poles and zeros.
- ✓ nichols(sys,w) specifies the frequency range or frequency points to be used for the chart.
- ✓ To focus on a particular frequency interval [wmin,wmax], set w = {wmin,wmax}. To use particular frequency points, set w to the vector of desired frequencies.
- ✓ Use logspace to generate logarithmically spaced frequency vectors.
- ✓ Frequencies must be in rad/TimeUnit, where TimeUnit is the time units of the input dynamic system, specified in the TimeUnit property
  of sys.nichols(sys1,sys2,...,sysN) or nichols(sys1,sys2,...,sysN,w) superimposes the Nichols charts of several models on a single figure. All systems must have the same number of inputs and outputs, but may otherwise be a mix of continuous- and discrete-time systems. You can also specify a distinctive color, linestyle, and/or marker for each system plot with the
  syntax nichols(sys1,'PlotStyle1',...,sysN,'PlotStyleN').

See bode for an example.

[mag,phase,w] = nichols(sys) or [mag,phase] = nichols(sys,w) returns the magnitude and phase (in degrees) of the frequency response at the frequencies w (in rad/TimeUnit). The outputs mag and phase are 3-D arrays similar to those produced by bode (see the bode reference page). They have dimensions

(number of outputs) × (number of inputs) × (length of w)

Examples

Nichols Response with Nichols Grid Lines

Example

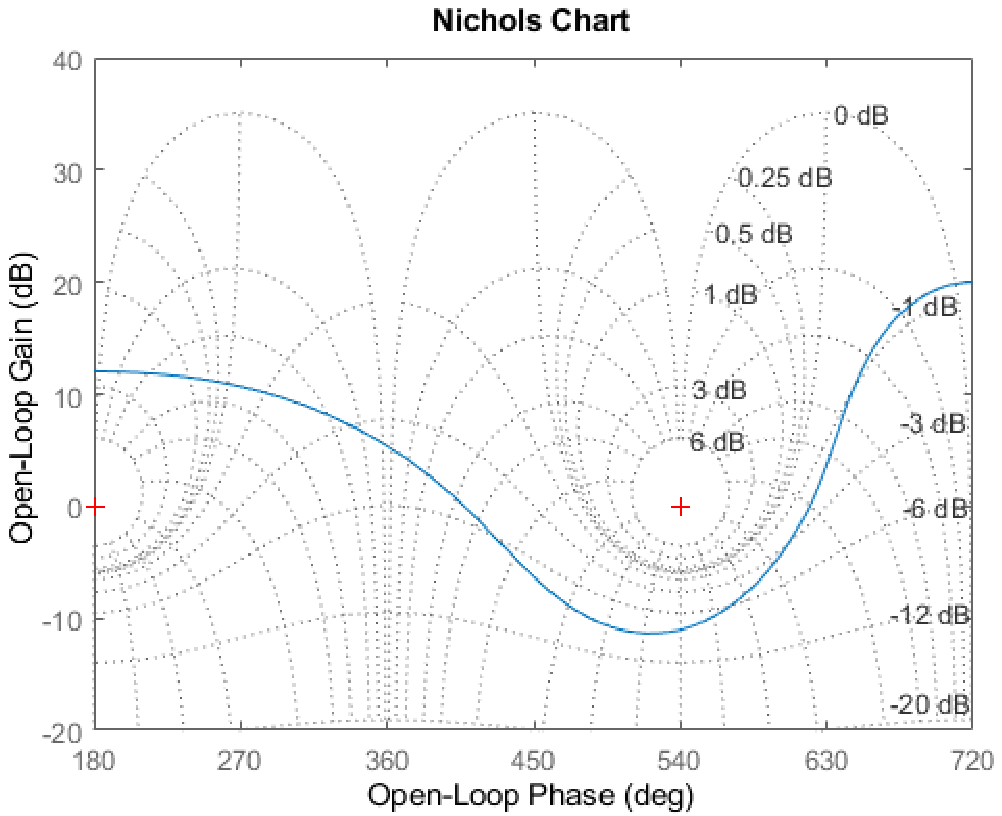
Plot the Nichols response with Nichols grid lines for the following system:

$$H(s)= -4s^4 +48s^3 -18s^2 +250s+600s^4 +30s^3 +282s^2 +525s+60.$$

H = tf([-4 48 -18 250 600],[1 30 282 525 60]);

nichols(H)

ngrid



The context menu for Nichols charts includes the **Tight** option under **Zoom**. You can use this option to clip unbounded branches of the Nichols chart.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=wXGw_FXr2mk

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:521)

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LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : III- FREQUENCY RESPONSE ANALYSIS **Date of Lecture:**

Topic of Lecture: Use of Nichol"s Chart in Control System Analysis

Introduction :

- The Nichols chart is a very useful technique for determining stability and the closed-loop frequency response of a feedback system. Stability is determined from a plot of the open-loop gain versus phase characteristics. At the same time, the closed-loop frequency response of the system is determined by utilizing contours of constant closed-loop amplitude and phase shift which are overlaid on the gain-phase plot.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Signals and Systems

Detailed content of the Lecture:

✓ In order to derive the basic Nichols chart relationships, let us consider the unity-feedback system illustrated in Figure. The closed-loop transfer function is given by

$$\frac{C(j\omega)}{R(j\omega)} = \frac{G(j\omega)}{1+G(j\omega)}, \qquad (6.112)$$

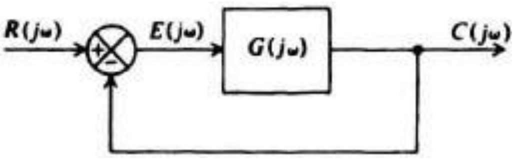

Figure. Block diagram of a simple feedback control system.

or

$$\frac{C(j\omega)}{R(j\omega)} = M(\omega)e^{j\alpha(\omega)}, \qquad (6.113)$$

- ✓ where $M(\omega)$ represents the amplitude component of the transfer function and $\alpha(\omega)$ the phase component of the transfer function.
- ✓ The radian frequency at which the maximum value of $C(j\omega)/R(j\omega)$ occurs is called the resonant frequency of the system, ω_p, and the maximum value of $C(j\omega)/R(j\omega)$ is denoted by M_p. For the system illustrated in , we would expect a typical closed-loop frequency response to have the general form shown in FIG.
- ✓ In feedback control design, the plot is useful for assessing the stability and robustness of a linear system. This application of the Nichols plot is central to the quantitative feedback theory (QFT) of Horowitz and Sidi, which is a well known method for robust control system design.
- ✓ In most cases, refers to the phase of the system's response. Although similar to a Nyquist plot, a Nichols plot is plotted in a Cartesian coordinate system while a Nyquist plot is plotted in a Polar coordinate system.
- ✓ Nichols recognized the shortcomings of the Nyquist and Bode plots and performed the logical step further. It is hard to understand why Bode Plots are strongly advertised in most textbooks while the superior Nichols Chart is rarely mentioned. It is derived from the Nyquist plot by conformal mapping into rectangular real coordinates. It combines the advantages of the Nyquist plot and the Bode plot pair. The frequency is the parameter along the curve from right to left. The list of advantages is impressive:

- ✓ The whole information is concentrated in one curve as in the Nyquist plot, but on a real rectangular coordinate system with dB and degree axes as in the Bode plots, so that measurement results can be entered directly; no calculations necessary, no knowledge of higher mathematics.
- ✓ Every full revolution of the Nyquist plot is mapped onto another 360-degree wide half-plane in parallel to the vertical axis such that it can be extended on the left as needed. Nyquist plots of complicated circuits are almost impossible to interpret, in the Nichols representation the interwoven Nyquist curve is so to speak unfolded into the left half-planes and easy to interpret.
- ✓ Gain and phase margins can be read directly, and, like in the Nyquist plot, the closest distances to the critical frequencies. Necessary changes to the circuit in order to stabilize or improve stability margins are immediately and clearly obvious.
- ✓ Due to the logarithmic vertical scale, any gain change just needs a vertical shift.
- ✓ Nichols Charts are powerful tools for determining closed-loop response from open-loop measurements. On the other hand, open-loop measurements are often impossible because the gain and the offset drift of the amplifier may be so high that no input signal can be applied without saturating it. In such cases, Nichols Charts can be used to convert closed-loop measurements to open-loop responses. Open-loop measurements are entered into the rectangular grid, a second grid of contour lines for gain and phase is overlaid from which the closed-loop response can be read;

closed-loop gain is obtained from the gain contour which the curve touches, and the phase from the phase contour which it intersects.

- ✓ Example of a Nichols Plot, showing in Figure 1 how the gain and phase margins can be directly read from the diagram: the phase margin is the distance from the intersection of the curve with the 0 dB axis and the critical - 180-degree point, here 35 degrees. The gain margin is the vertical distance between the - 180 degree - point and the intersection between a vertical line through the - 180 degree - point and the curve, here 15 dB. The frequency is the parameter along the curve from right to left. The minimum distance between the - 180 degree. point and the curve indicates the critical frequency.

Further information about the Nichols Chart can be found in older literature.

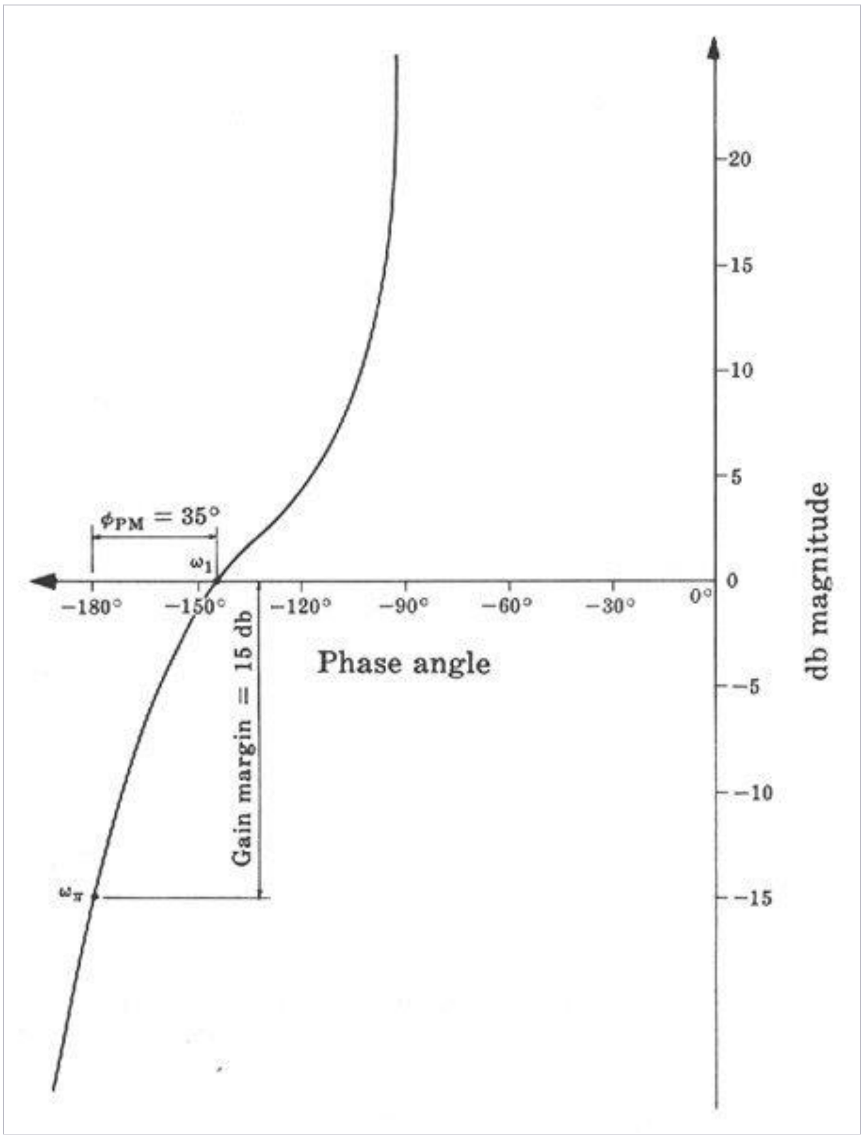

Figure 1: Example of a Nichols Plot

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=wXGw_FXr2mk

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:521)

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LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : IV- STABILITY ANALYSIS **Date of Lecture:**

Topic of Lecture:
Stability

Introduction : (Maximum 5 sentences)

- The stability of a system relates to its response to inputs or disturbances. A system which remains in a constant state unless affected by an external action and which returns to a constant state when the external action is removed can be considered to be stable.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Partial differential equation

Detailed content of the Lecture:

- The local behaviour of a system of differential equations,

$$\frac{dX_i}{dt} = f_i(X_1,\ldots,X_n) \qquad (i=1,\ldots,n)$$

near an equilibrium point depends on the roots (eigenvalues) of the characteristic equation

$$|A - \lambda I| = 0 \qquad (4.1)$$

where $A = (a_{ij})$ is the matrix of first partial derivatives $\frac{\partial f_i}{\partial X_j}$ evaluated at the equilibrium point.

- If the real parts of all the roots are negative, the system returns to equilibrium after a small perturbation. If the real parts of all the roots are positive, the system moves away from equilibrium (is locally unstable).

- If some roots have positive and some negative real parts, the behaviour of the system depends on how it is perturbed; it sometimes returns to equilibrium but for other displacements moves away.
- In biological systems we usually assume the perturbations to be unconstrained so that eventually the system will be displaced in a direction which allows the positive root to lead the system away from equilibrium.
- A single zero real part gives a neutral or passive equilibrium, but multiple zero roots can give unbounded solutions (unstable equilibrium).
- If a root is complex the system oscillates at a frequency given by the imaginary part while the amplitude behaves according to the real part of the root.

Video Content / Details of website for further learning (if any):

-

Important Books/Journals for further learning including the page nos.:

- M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:683)

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LECTURE HANDOUTS

EEE

III/V

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : IV- STABILITY ANALYSIS **Date of Lecture:**

Topic of Lecture:
Routh Hurwitz criterion.

Introduction : (Maximum 5 sentences)

Any pole of the system lies on the right hand side of the origin of the s plane, it makes the system unstable. On the basis of this condition A. Hurwitz and E.J. Routh started investigating the necessary and sufficient conditions of stability of a system.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Partial differential equation

Detailed content of the Lecture:

Routh-Hurwitz Stability Criterion

- Routh-Hurwitz stability criterion is having one necessary condition and one sufficient condition for stability. If any control system doesn't satisfy the necessary condition, then we can say that the control system is unstable.
- But, if the control system satisfies the necessary condition, then it may or may not be stable. So, the sufficient condition is helpful for knowing whether the control system is stable or not.

Necessary Condition for Routh-Hurwitz Stability

- The necessary condition is that the coefficients of the characteristic polynomial should be positive. This implies that all the roots of the characteristic equation should have negative real parts.
- Consider the characteristic equation of the order 'n' is -

a0sn+a1sn−1+a2sn−2+...+an−1s1+ans0=0a0sn+a1sn−1+a2sn−2+...+an−1s1+ans0=0

- Note that, there should not be any term missing in the **n^{th}** order characteristic equation. This means that the **n^{th}** order characteristic equation should not have any coefficient that is of zero value.

Sufficient Condition for Routh-Hurwitz Stability

- The sufficient condition is that all the elements of the first column of the Routh array should have the same sign. This means that all the elements of the first column of the Routh array should be either positive or negative.

Routh Array Method

- If all the roots of the characteristic equation exist to the left half of the 's' plane, then the control system is stable. If at least one root of the characteristic equation exists to the right half of the 's' plane, then the control system is unstable.
- So, we have to find the roots of the characteristic equation to know whether the control system is stable or unstable. But, it is difficult to find the roots of the characteristic equation as order increases.
- So, to overcome this problem there we have the Routh array method. In this method, there is no need to calculate the roots of the characteristic equation.
- First formulate the Routh table and find the number of the sign changes in the first column of the Routh table.
- The number of sign changes in the first column of the Routh table gives the number of roots of characteristic equation that exist in the right half of the 's' plane and the control system is unstable.

Follow this procedure for forming the Routh table.

- Fill the first two rows of the Routh array with the coefficients of the characteristic polynomial as mentioned in the table below. Start with the coefficient of Snsn and continue up to the coefficient of s0s0.
- Fill the remaining rows of the Routh array with the elements as mentioned in the table below. Continue this process till you get the first column element of **row** s0s0 is anan. Here, anan is the coefficient of s0s0 in the characteristic polynomial.

Note − If any row elements of the Routh table have some common factor, then you can divide the row elements with that factor for the simplification will be easy.

The following table shows the Routh array of the n^{th} order characteristic polynomial.

a0Sn+a1Sn−1+a2Sn−2+...+an−1S1+anS0

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=WBCZBOB3LCA

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:223)

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LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19BMC06 & BIO CONTROL SYSTEM

Course Faculty : Mr.C.S.SATHEESH

Unit : IV- STABILITY ANALYSIS **Date of Lecture:**

Topic of Lecture:
Root Locus Technique

Introduction :

The root locus is a graphical representation in s-domain and it is symmetrical about the real axis. Because the open loop poles and zeros exist in the s-domain having the values either as real or as complex conjugate pairs. In this chapter, let us discuss how to construct (draw) the root locus.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Characteristics equation

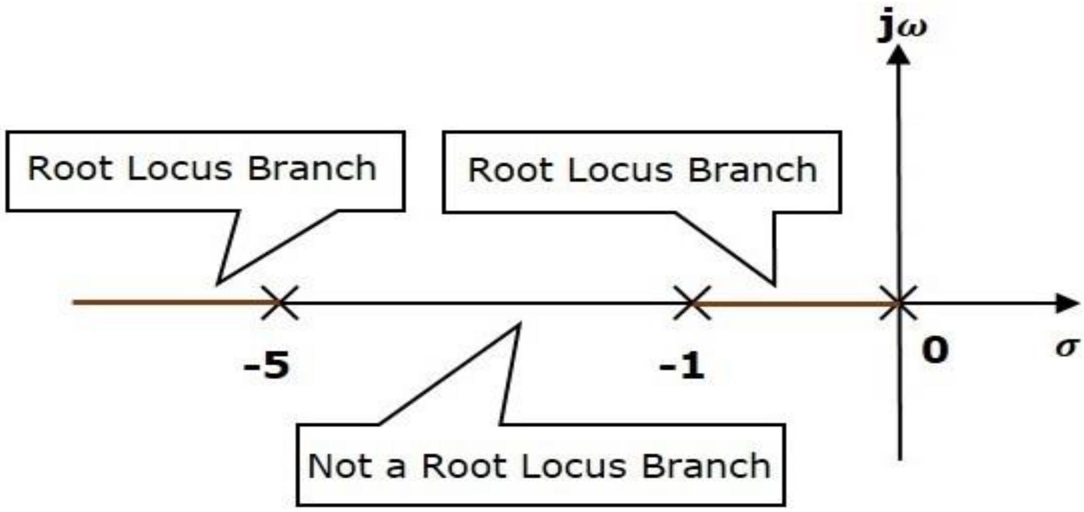
Detailed content of the Lecture:

Let us now draw the root locus of the control system having open loop transfer function,

G(s)H(s)=Ks(s+1)(s+5)G(s)H(s)=Ks(s+1)(s+5)

Step 1 − The given open loop transfer function has three poles at s=0,s=−1s=0,s=−1 and s=−5s=−5. It doesn't have any zero. Therefore, the number of root locus branches is equal to the number of poles of the open loop transfer function.

N=P=3N=P=3



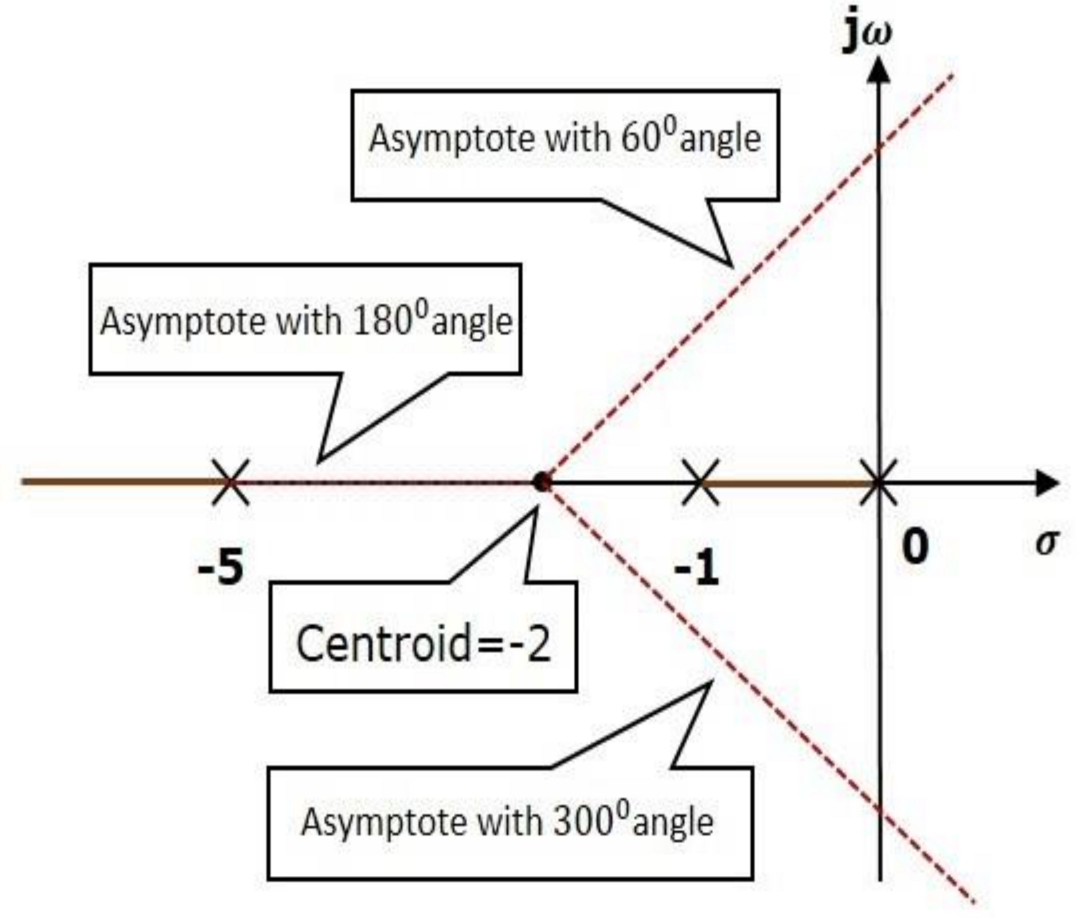
The three poles are located are shown in the above figure. The line segment between s=−1s=−1 and s=0s=0 is one branch of root locus on real axis. And the other branch of the root locus on the real axis is the line segment to the left of s=−5s=−5.

Step 2 − We will get the values of the centroid and the angle of asymptotes by using the given formulae.

Centroid α=−2α=−2

The angle of asymptotes are θ=600,1800θ=600,1800 and 30003000.

The centroid and three asymptotes are shown in the following figure.

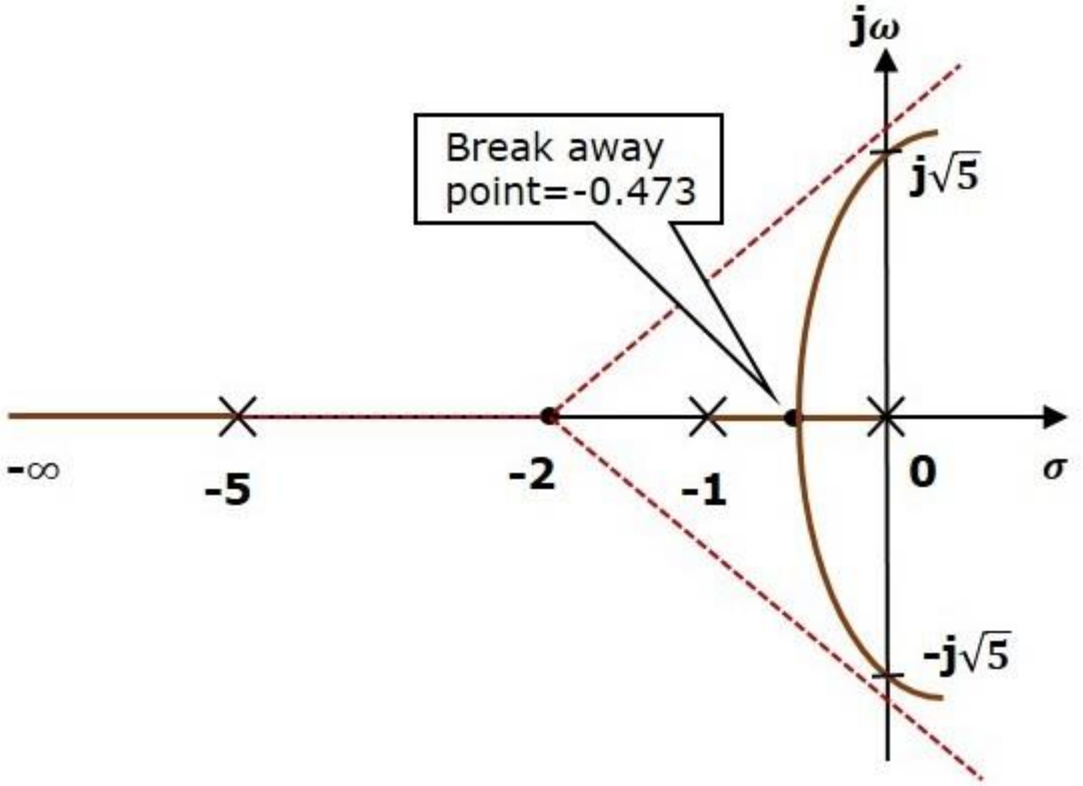


Step 3 –

Since two asymptotes have the angles of 600600 and 30003000, two root locus branches intersect the imaginary axis. By using the Routh array method and special case(ii), the root locus branches intersects the imaginary axis at j5–√j5 and −j5–√−j5.

There will be one break-away point on the real axis root locus branch between the poles s=−1s=−1 and s=0s=0. By following the procedure given for the calculation of break-away point, we will get it as s=−0.473s=−0.473.

The root locus diagram for the given control system is shown in the following figure.



In this way, you can draw the root locus diagram of any control system and observe the movement of poles of the closed loop transfer function.

From the root locus diagrams, we can know the range of K values for different types of damping.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=CRvVDoQJjYI.

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:369)

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LECTURE HANDOUTS

EEE

III/V

Course Name with Code : 16BMD07 & BIO CONTROL SYSTEM

Course Faculty : Mrs.M.SWATHISRIRANJANI

Unit : V- STATE VARIABLE ANALYSIS AND BIOMEDICAL APPLICATIONS

Date of Lecture:

Topic of Lecture:
Concepts of Controllability and Observability

Introduction :

- The concept of controllability refers to the ability of a controller to arbitrarily alter the functionality of the system plant.
- The state-variable of a system, x, represents the internal workings of the system that can be separate from the regular input-output relationship of the system.

Prerequisite knowledge for Complete understanding and learning of Topic:

- State variable
- State functions

Detailed content of the Lecture:

Controllability:

- In the world of control engineering, there are a slew of systems available that need to be controlled.
- The task of a control engineer is to design controller and compensator units to interact with these pre-existing systems.
- However, some systems simply cannot be controlled (or, more often, cannot be controlled in specific ways).
- The concept of controllability refers to the ability of a controller to arbitrarily alter the functionality of the system plant.
- Complete state controllability (or simply controllability if no other context is given) describes the ability of an external input to move the internal state of a system from any initial state to any other final state in a finite time interval.
- Controllability A system with internal state vector x is called controllable if and only if the system states can be changed by changing the system input.

Reachability:

A particular state x1 is called reachable if there exists an input that transfers the state of the system from the initial state x0 to x1 in some finite time interval [t0, t).

Controllability Matrix :

- For LTI (linear time-invariant) systems, a system is reachable if and only if its controllability matrix, ζ, has a full row rank of p, where p is the dimension of the matrix A, and $p \times q$ is the dimension of matrix B.
- A system is controllable or "Controllable to the origin" when any state x1 can be driven to the zero state $x = 0$ in a finite number of steps. A system is controllable when the rank of the system matrix A is p, and the rank of the controllability matrix is equal.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=ibhwKT6l_Os
https://www.youtube.com/watch?v=g9G8b7FxEHc

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.(Page No:617-620)

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EEE

III/V

Course Name with Code : 16BMD07 & BIO CONTROL SYSTEM

Course Faculty : Mrs.M.SWATHISRIRANJANI

Unit : V- STATE VARIABLE ANALYSIS AND BIOMEDICAL APPLICATIONS

Date of Lecture:

Topic of Lecture:
Sampling Theorem

Introduction :

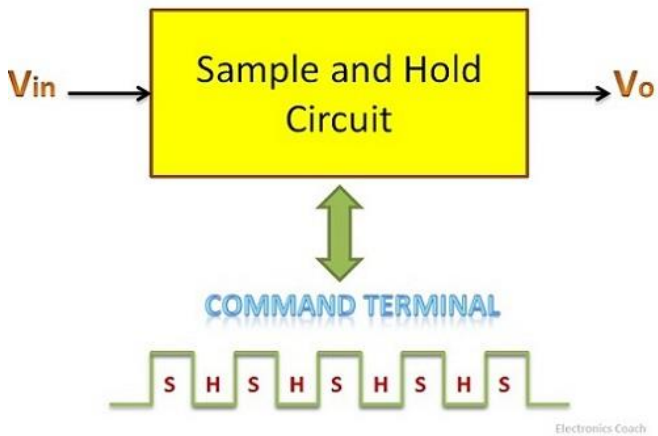
- The Sample and Hold circuit is an electronic circuit which creates the samples of voltage given to it as input, and after that, it holds these samples for the definite time.
- The time during which sample and hold circuit generates the sample of the input signal is called sampling time.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Sampling time
- Holding time

Detailed content of the Lecture:

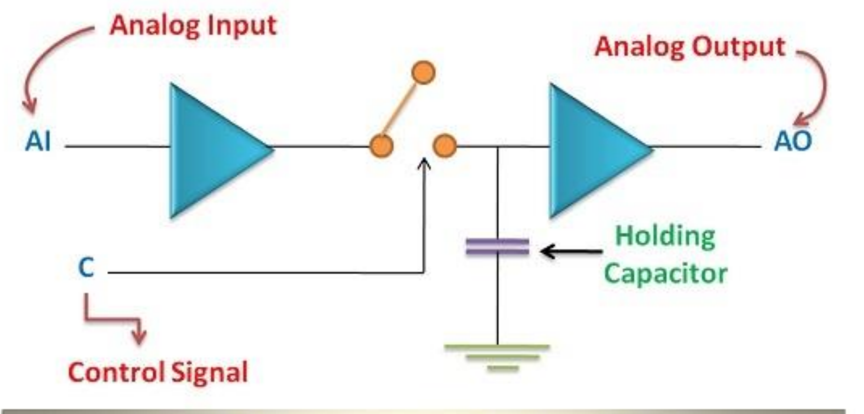
- The Sample and Hold **circuit** is an electronic circuit which creates the samples of voltage given to it as input, and after that, it holds these samples for the definite time.
- The time during which sample and hold circuit generates the sample of the input signal is called sampling time.
- Similarly, the time duration of the circuit during which it holds the sampled value is called holding time.



- Sampling time is generally between **1μs to 14 μs** while the holding time can assume any value as required in the application.
- It will not be wrong to say that capacitor is the heart of sample and hold circuit.
- This is because the capacitor present in it charges to its peak value when the switch is opened, i.e. during sampling and holds the sampled voltage when the switch is closed.

Circuit Diagram of Sample and Hold Circuit:

- The diagram below shows the circuit of the sample and hold circuit with the help of an Operational Amplifier.
- It is evident from the circuit diagram that two OP-AMPS are connected via a switch.
- When the switch is closed sampling process will come into the picture and when the switch is opened holding effect will be there.

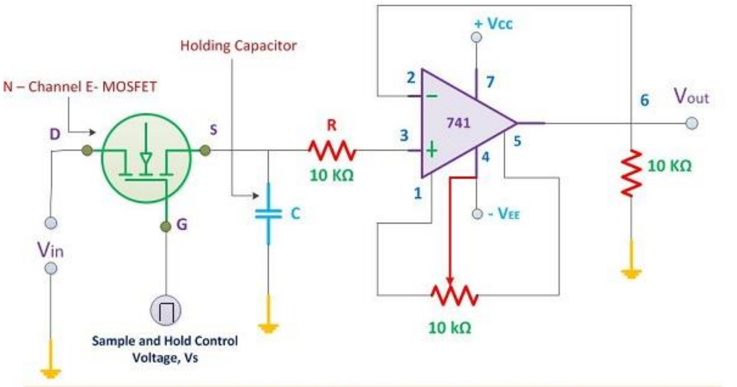


Circuit diagram of Sample and Hold Circuit

- The capacitor connected to the second operational amplifier is nothing but a holding capacitor.

Working of Sample and Hold Circuit:

- The working of sample and hold circuit can be easily understood with the help of working of its components.
- The main components which a sample and hold circuit involves is an N-channel Enhancement type MOSFET, a capacitor to store and hold the electric charge and a high precision operational amplifier.



Practical Circuit of Sample and Hold Circuit

- When the MOSFET acts as a closed switch, then the analogue signal applied to it through the drain terminal will be fed to the capacitor.
- The capacitor will then charge to its peak value. When the MOSFET switch is opened, then the capacitor stops charging.
- Due to the high impedance operational amplifier connected at the end of the circuit, the capacitor will experience high impedance due to this it cannot get discharged.
- This leads to the holding of the charge by the capacitor for the definite amount of time. This time can be referred as holding period. And the time in which samples of the input voltage is generated is called sampling period.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=za-Y2mT8zLg
https://www.youtube.com/watch?v=kXK3fpqeapU

Important Books/Journals for further learning including the page nos.:
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EEE **III/V**

Course Name with Code : 16BMD07 & BIO CONTROL SYSTEM

Course Faculty : Mrs.M.SWATHISRIRANJANI

Unit : V- STATE VARIABLE ANALYSIS AND BIOMEDICAL APPLICATIONS

Date of Lecture:

Topic of Lecture:
Sampler & Hold

Introduction :

- The Sample and Hold circuit is an electronic circuit which creates the samples of voltage given to it as input, and after that, it holds these samples for the definite time.
- The time during which sample and hold circuit generates the sample of the input signal is called sampling time.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Sampling time
- Holding time

Detailed content of the Lecture:

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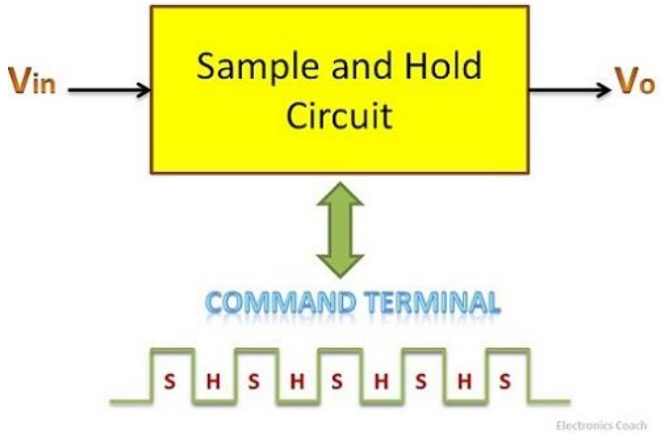

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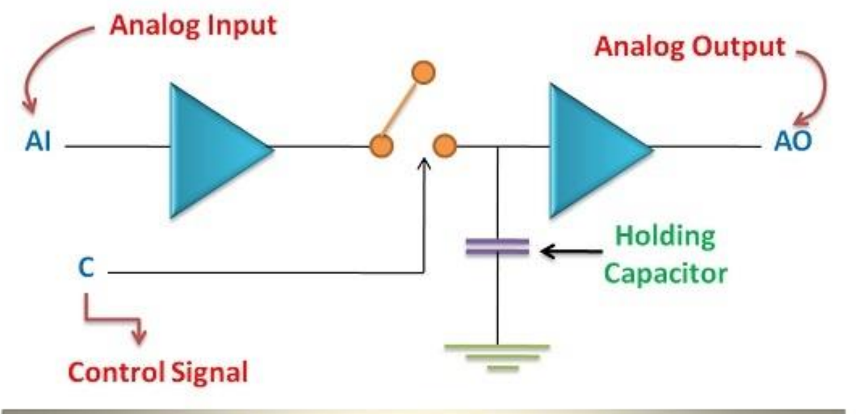

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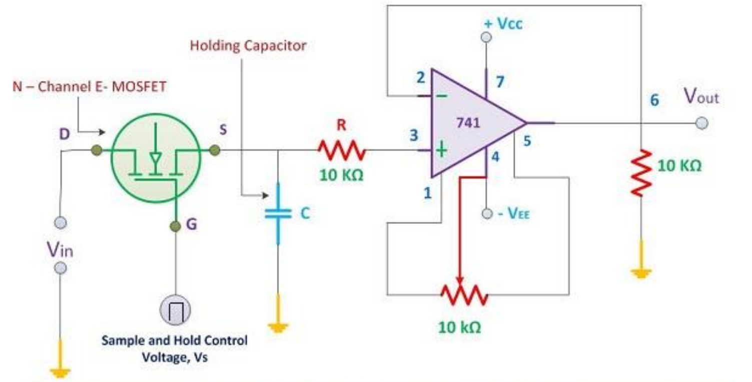

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Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=za-Y2mT8zLg
https://www.youtube.com/watch?v=kXK3fpqeapU

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M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.
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LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 16BMD07 & BIO CONTROL SYSTEM

Course Faculty : Mrs.M.SWATHISRIRANJANI

Unit : V- STATE VARIABLE ANALYSIS AND BIOMEDICAL APPLICATIONS

Date of Lecture:

Topic of Lecture:
Open loop & Closed loop sampled data systems

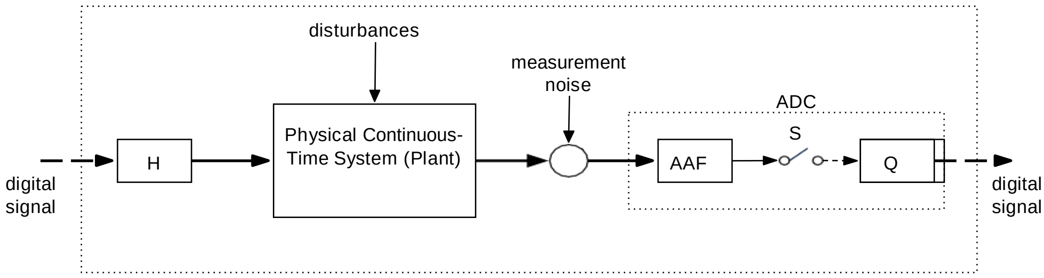
Introduction :

- The state model having minimum number of non-zero elements are called as canonical forms.
- So, we will find that in this particular form, the number of non-zero elements are minimum other elements are maximum 0's.

Prerequisite knowledge for Complete understanding and learning of Topic:

- State space
- Matrix

Detailed content of the Lecture:



Organization of Sampled-Data Systems

- ✓ The input signals of a digital controller consist of discrete sequences of finite precision numbers. We call such a sequence a digital signal. Often we ignore quantization (i.e., finite precision) issues and still call the discrete sequence a digital signal.
- ✓ In sampled-data systems, the plant to be controlled is an ana- log system (continuous-time, and usually continuous-state), and measurements about the state of this plant that are initially in the analog domain need to be converted to digital signals.
- ✓ This conversion process from analog to digital signals is generally called sampling, although sampling can also refer to a par- ticular part of this process, as we discuss below. Similarly, the

digital controller produces digital signals, which need to be transformed to analog signals to ac- tuate the plant.

- ✓ In control systems, this transformation is typically done by a form of signal holding device, most commonly a zero-order hold (ZOH) pro- ducing piecewise constant signals. Fig.shows a sampled-data model, i.e. the continuous plant together with the DAC and ADC devices, which takes digital input signals and produces digital output sig- nals and can be connected directly to a digital controller.
- ✓ The convention used throughout these notes is that continuous-time signals are represented with full lines and sampled or digital signals are represented with dashed lines. Note that the DAC and ADC can be integrated for example on the microcontroller where the digital controller is implemented, and so the diagram does not nec- essarily represents the spatial configuration of the system. We will revisit this point later as we discuss more complex models including latency and commu- nication networks. The various parts of the system represented on Fig. are discussed in more detail in this chapter.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=LKPErUCCnPA
https://www.youtube.com/watch?v=WHC9DUucAis

Important Books/Journals for further learning including the page nos.:
M. Gopal, Control Systems, Principles and Design, Tata McGraw Hill, 2012.
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III/V

Course Name with Code : 16BMD07 & BIO CONTROL SYSTEM

Course Faculty : Mrs.M.SWATHISRIRANJANI

Unit : V- STATE VARIABLE ANALYSIS AND BIOMEDICAL APPLICATIONS

Date of Lecture:

Topic of Lecture:
Lung mechanics model with proportional control

Introduction :

- Lung mechanics are abnormal in infants and children with large left-to-right shunts due to increased extravascular lung water resulting in decreased lung compliance and increased resistance to expiratory flow.
- Therefore we advocate using volume-controlled mode of ventilation to maintain a tight control of minute ventilation and acid-base status.

Prerequisite knowledge for Complete understanding and learning of Topic:

- State space
- Transfer function

Detailed content of the Lecture:

Lung Mechanics

- Lung mechanics are abnormal in infants and children with large left-to-right shunts due to increased extravascular lung water resulting in decreased lung compliance and increased resistance to expiratory flow.
- Therefore we advocate using volume-controlled mode of ventilation to maintain a tight control of minute ventilation and acid-base status.

Pulmonary Mechanics and Weaning From Mechanical Ventilation:

- Pulmonary mechanics are most commonly abnormal in these infants because of changes in airway resistance, lung compliance, or bellows function.
- Increased airway resistance usually results from luminal narrowing related either to intrinsic accumulation of secretions or to extrinsic compression from interstitial edema or dilated neighboring vessels or both in the bronchovascular pedicle associated with pulmonary venous hypertension. Although many pathologic processes culminate in reduced lung compliance, the most common mechanism in these neonates is the

perioperative accumulation of interstitial lung water.92 DiCarlo and colleagues93 demonstrated reduced mean lung compliance in all of 28 neonates (17 with HLHS) after cardiac surgical procedures.

- Patients are commonly managed with pressure-regulated volume control ventilation to deliver a set tidal volume, limiting airway pressure below a selected high-pressure threshold. The ventilator is adjusted to maintain normal ventilation with the patient at functional residual capacity to minimize increases in PVR due to acidosis or alveolar collapse/distention. Because confirmation of sufficient cardiac reserve and manageable abnormalities in pulmonary mechanics is difficult to quantify in neonates, mechanical ventilatory support can be empirically tapered on the first or second postoperative day once hemodynamics are satisfactory.
- Minimal support is maintained to offset the resistance to breathing imposed by the endotracheal tube. The infant is evaluated at each step, with particular attention to the effort expended in spontaneous breaths and cardiovascular evidence of excessive sympathetic response to the increased metabolic demand (i.e., increased heart rate, systemic arterial pressure, atrial pressure).
- Tracheal extubation is performed if the neonate exhibits minimal effort with spontaneous respiration and no evidence is noted of sympathetic response to the metabolic demand posed by the threshold level of support.
- When either of these criteria is not met, an attempt is made to identify and treat the underlying cause while continuing an appropriate level of ventilatory support.
- A decision to proceed with a trial of extubation may be made in the absence of a clearly identified cardiopulmonary cause (e.g., inadequate cardiac reserve, abnormal pulmonary mechanics, increased work imposed by spontaneous respiration through a tracheal tube), recognizing the potential for immediate respiratory failure.
- Reintubation is as frequently based on cardiovascular signs as on blood gas–tension abnormalities. In a 1988 series of 56 neonates extubated after stage I, the 30% who were ultimately reintubated manifested significant increases in heart rate, systemic arterial pressure, and atrial pressure during the period of spontaneous ventilation.
- These changes probably reflected sympathetic discharge and diminished ventricular compliance. Analysis of arterial blood in these infants before and after extubation demonstrated reduced arterial pH (diminished metabolic alkalemia), but gas tensions were no different compared with those in patients successfully weaned.
- Recent data indicate that the median duration of mechanical ventilation after stage I is approximately 5 days

Volume Control: Initial Ventilator Settings and Adjustments for Patients with Normal to Moderately Abnormal Mechanics

Normal lung mechanics:

- TV: 8 mL/kg IBW
- Rate: 15 breaths/min
- Fio_2: start with 50% Fio_2
- PEEP: 5 cm H_2O
- Mild to moderate increase in airway resistance:
- TV: 8 mL/kg IBW
- Rate: 8–15 breaths/min
- Fio_2: start with ≥ 100% Fio_2
- PEEP: 5 cm H_2O
- Mild to moderate decrease in lung compliance:
- TV: 6 ml/kg IBW
- Rate: 20–25 breaths/min
- Fio_2: start with 100% Fio_2
- PEEP: 5–10 cm H_2O

Video Content / Details of website for further learning (if any):
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