QUESTIONS

UNIT- 1

Q. Compare mechatronics systems with electromechanical systems.

Q. Discuss and explain with neat diagram the mechatronics constituents.

Q. Mechatronics key elements

Q. Short note on modelling & simulation.

Q. State the importance of sensors in mechatronics.

Q. Classify various actuators use in mechatronics design.

Q. State the importance of hardware in the loop simulation in mechatronics system design. Discuss various configuration for hardware in the loop simulation.

Q. Compare the internal bus system with external bus system used for real time interfacing in mechatronics.

Q. Discuss with neat diagram the scheme for hardware & software integrated in Mechatronics.

Q. Discuss in detail the steps involved in Mechatronics Design process (not constituents, the bigger flow chart)

Q. Write short note on model-based monitoring. (discuss with neat diagram)

Q. Advanced approaches in mechatronics (1 comes for sure)

UNIT - 2

Q. Discuss the 3 basic functions which the visual simulation environment must perform. (Pg. 70)

Q. Write short notes on Analogy approach for block diagram modelling (Pg. 85)

Q. Compare modified analogy approach with Analogy approach of block diagram modelling.

Q. Discuss the steps involved in creating the block diagram model using the modified analogy approach.

Q. Compare the modified analogy of block diagram modelling with direct method of block diagram modelling.

UNIT - 3

Q. CISS sensors

Q. Benefits of CISS

M2 Syllabus :- UNIT 3 (Sensors) & UNIT 5 (Controllers) (till where we study)

Q. Classification of Sensors

Q. Sensors selection criteria

Q. State the need of signal conditioning circuit in mechatronics system design

Q. Discuss with examples the working of smart sensor in process control applications (diagram)

Q. Explain with relevant examples the fuzzy logic based system.

Q. State the architecture of intelligent sensor and state its capabilities

Q. List the problems with conventional sensors.

Q. Write short note on feed-forward neural network

Q. Discuss with neat diagram the operation of a pattern recognition system.

or

Explain with relevant examples the steps involved in design or implementation of pattern recognition system

Q. Discuss with relevant example the design cycle of pattern recognition system.

Q. Sketch the architecture of fingerprint scanner and discuss its working.

Q. Discuss with neat diagram the working of capacitive fingerprint scanner. Compare capacitive fingerprint scanner with photo-electric fingerprint scanner.

Q. Write short note on retina scanner.

Q. Compare retina scanner with iris scanner.

Q. Compare retina scanner with fingerprint scanner.

Q. Write a short note on nanosensors

Q. Compare the transmittes type and reflectance type biosensor on pulse oximeter.

Q. Discuss with neat diagram the working of oximeter.

Q. Write short note on ON - OFF Controller.
or
Discuss with neat diagram the working of ON-OFF and design an ON-OFF controller using op-amps

Q. Implement electronic ON - OFF controller with op - Amps with deadband

Q. Write short note on time proportional control.

Q. Compare time proportional control with amplitude proportional control

Q. Compare open loop with closed loop

Q. Discuss with neat diagram control systems

Q. Classify different controller modes

Q. Classify control system

Q. Compare feedback system with feed forward system.

Q. State the limitations of derivative controller. Discuss various techniques to remove this limitations.

Q. Write short note on inverse derivative controller. Compare the derivative controller with inverse derivative controller.

Q. Integral & Derivative controller mathematical eqⁿ and characteristics.

Q. Design PI / PD / PID Controller with op amps.

Q. Design parallel controllers (PI / PD / PID) using op Amps.

Q. Design non-interacting (ideal) controllers (PI / PD / PID) using op Amps

Q. Design / Implement a parallel PID controller using op Amps. Discuss it's working using characteristics and equations. → same as analog parallel PID controller.

Q. Same as above for ideal / non-interacting.

Q. Same for PI & PD

Q. State the equation for digital PID controller. Compare the velocity form with position form implementation with PID.

Q. Discuss different methods for tuning PID controllers

Q. Numericals on tuning

Q. Discuss the working of model predictive controller with reference to industrial application. Sketch the architecture of model predictive controller.

Q. Discuss the principle of operation of adaptive controller. State different techniques of adaptation used for adaptive controller design.

Q. Write short note on model reference adaptive controller.
(Construction, Working)

UNIT - 1

MECHATRONICS DESIGN PROCESS

(Mechatronics System Design - Devdas Shetty & Richard Kolk)

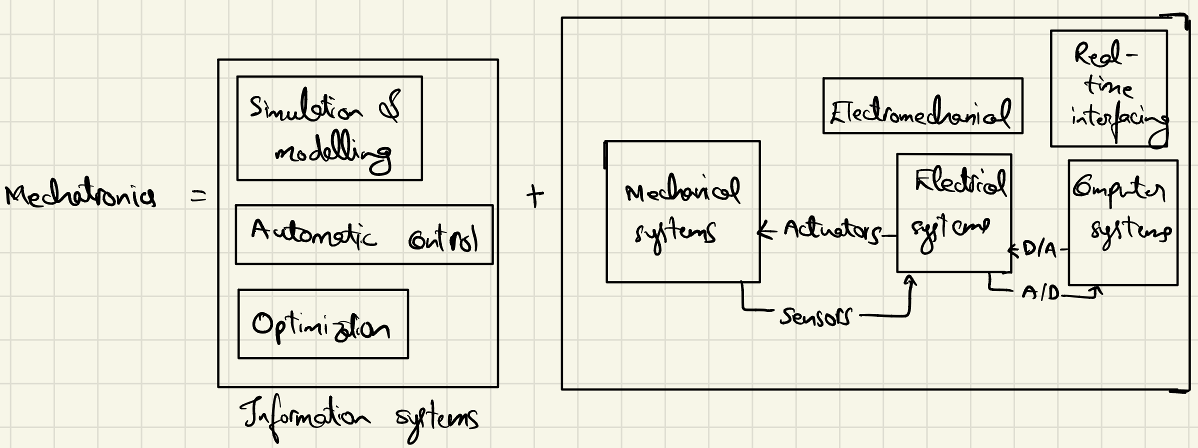
Mechatronics

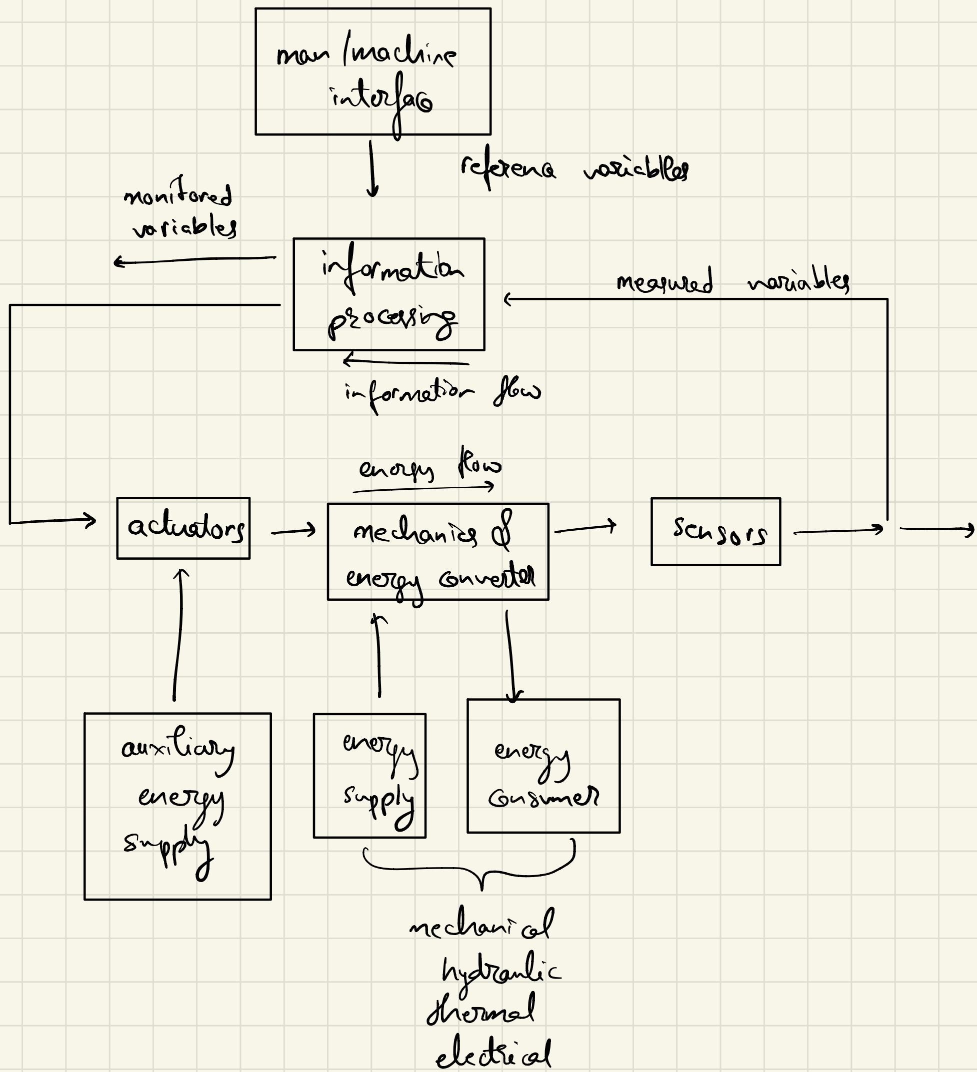
is a methodology used for the optimal design of electromechanical products.

Mechatronics design methodology is based on concurrent, instead of sequential approach to discipline design, resulting in products with more synergy approach.

information system → data from previous systems

Mechatronics Constituents





man /machine interface
reference variables
monitored variables
information processing
measured variables
information flow
energy flow
actuators
mechanics & energy converter
sensors
auxiliary energy supply
energy supply
energy consumer
mechanical
hydraulic
thermal
electrical

Mechatronics key Elements

1) Information Systems

a) Modeling & Simulation

Modeling is the mathematical representation (equations & logic) of an physical system.

models →
- static model (no energy transfer)
- dynamic model (energy transfer)

Simulation is the process of solving the model and it is performed on a computer.

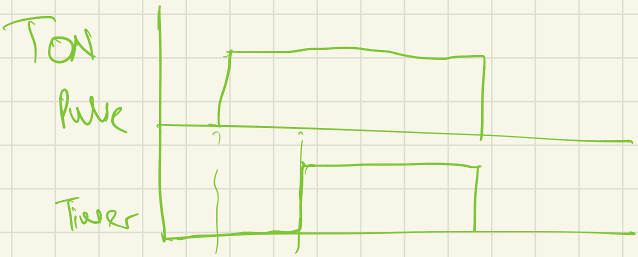
simulation →
- initialization
- iteration
- termination

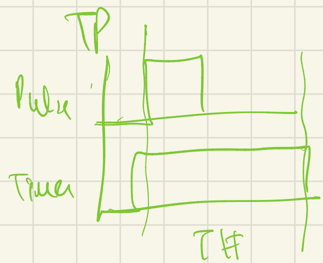
b) Automatic Controls

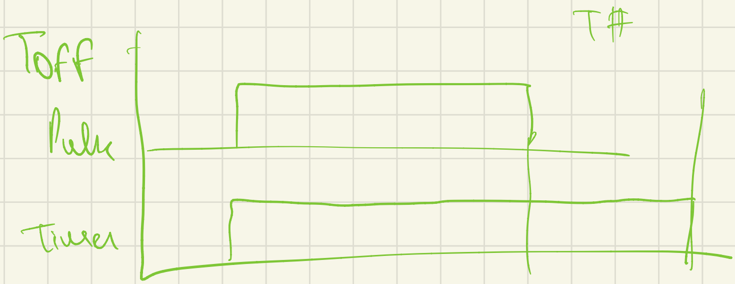
Concurrent approach is used in Mechatronics instead of a series of design steps.

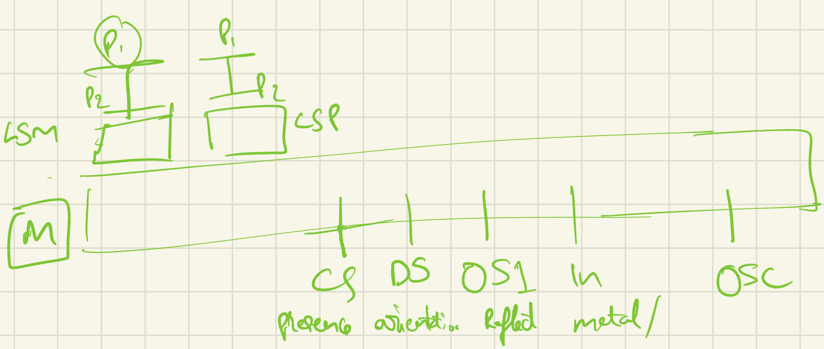
c) Optimization

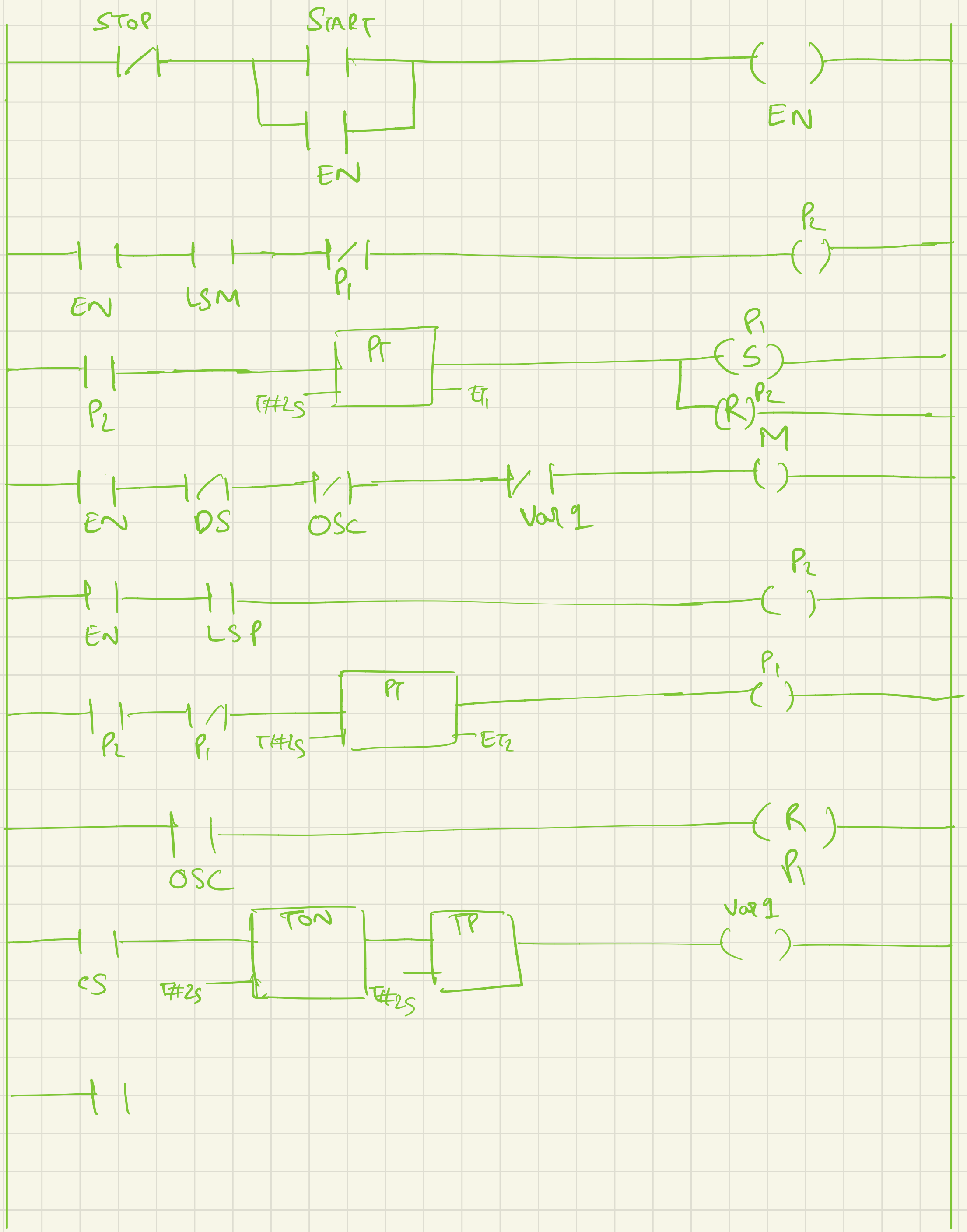
2) Mechanical Systems










STOP
START
EN
EN
P2
EN
LSM
P1
P1
PT
S
P2
T#2S
ET1
R
M
EN
DS
OSC
Var 1
P2
EN
LSP
P1
PT
P2
P1
T#1S
ET2
R
OSC
P1
Var 1
TON
TP
CS
T#2S
T#2S

Internal bus

→ Used for transmission in very short distance.
→ computer specific
→ Less cost
→ Drawback :- i) version error (compatibility)
→ Connected via ribbon cable & printed boards

External Bus System

→ IEEE 1451 protocol for making connection b/w smart devices.
→ Connected to host computer using RS232 ports.
→ Relatively long distance transmission.
→ Costlier compare to internal bus system.

Signals

1. Analog Signals

Low voltage or current , ±5V , ±10V , 0-10V , 4-20mA

2. Discrete Signals

Binary in nature , either high or low value.

3. Frequency Signals

→ Periodic Signals.
→ Frequency based ADC

COMPUTER SYSTEMS

Hardware :- → computer-specific circuits and devices.
→ logic networks, flip flops, counters, timers, triggers, integrated circuits, microprocessors.

Software :- → High level programming languages like BASIC, FORTRAN, C, PASCAL use compilers.
→ Visual programming language (Block diagram)

Mechatronics Design Process

Explanation :-

→ 3 categories → Modelling & Simulation (more steps)
→ Prototyping
→ Deployment / Life cycle

modelling & simulation

→ recognition of the need

there should be some requirement of the system.

↳ either does not exist

↳ or modification of existing system

→ conceptual design & functional specification

functional specification (load, space & work)

→ physical specification

↳ size, shape, structure

→ technical specification

→ motor torque

→ voltage consumption

→ battery life

→ 3P to 1P conversion

Conceptual design

↳ product affordable

↳ sol^n should be simple, marketable

→ first principle modular mathematical modeling

modular → easy assemble - disassemble

↳ not done in isolation

↳ easy maintainance (remove only the defective part & not the whole thing)

→ sensor and actuator selection

selection of sensor
- → what type of motor
- → what type of movement
- → need to have their mathematical eq^n's for simulation
- → readily available

customized sensors
- → time taken to complete project increases (time taken overshoots)
- → for sensors that are not readily available

→ Detailed Modular mathematical modeling

After selection of sensors & actuators, the design needs to be refined and updated according to the specification

→ Control System Design

- → Signal wired or wireless
- → control manual or automatic
- → sometimes semi-automatic (controller & robot)
- → when deadlock situation occurs, system should enter in self destruction mode (surveillance system)

→ Design optimization

can be
- → mechanical structure
- → sensors & actuators

done till satisfactory results achieved in simulation (closed loop to first principle modeling)

prototyping

→ **Hardware – in – the – Loop Simulation**

- → compare the real word signals to those obtained in simulation.
- → implement model in the real life scenario
- → sometimes prototyping not possible like space missions (unpredictable situations)
- → have safety incorporated

→ **Design optimization**

Deployment / Life Cycle

→ **Deployment of embedded software**

- ↳ implement everything in real life.
- ↳ all the mechanical components, sensors, actuators assembled according to prototyping results

→ **Life cycle optimization**

- ↳ continuous monitoring after system is deployed
- ↳ take the information for future modules / upgrades

Advanced approaches in Mechatronics

Model - based monitoring

- Compare the real life behaviour to simulation behaviour.
- controller is responsible for changes to match the simulation behaviour

- Maintainance
  - Periodic
  - Preventive
  - Predictive

Mechatronic System with open Architecture Platform

- one system getting connected to another
- open architecture = decentrialization (if one fails, all won't fail together)
- all systems are closed loop

- vendor neutral (google's android used by many phone companies)

Intelligent Supervisory Control

- SCADA
- layers → lowest :- servo control

UNIT - 2

MODELLING & SIMULATION OF PHYSICAL SYSTEMS

(Mechatronics System Design — Devdas Shetty)

Simulation → Hardware in the loop
Simulation → Normal Simulation

Mechanical	Electrical
force	Voltage
Displacement	current

Modelling → Direct method
- Direct method → Transfer fun^n (synthesis)
- Direct method → FBD (clockwise -ve anticlockwise +ve)

Modelling → Analogy method

System Representation

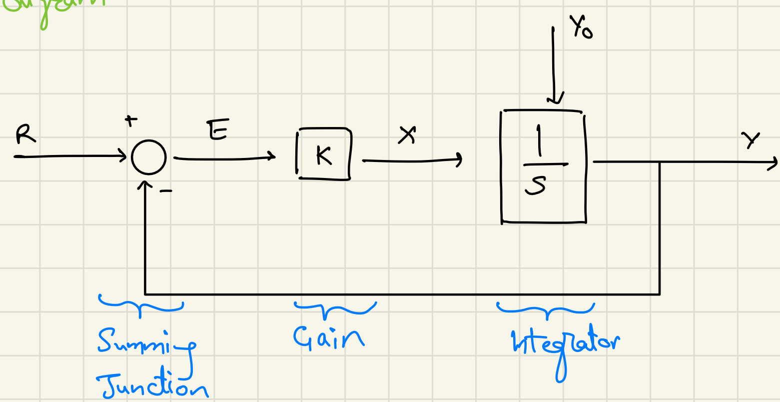
Transfer function is used in LTI systems.

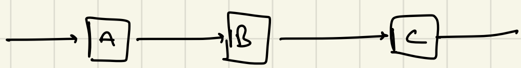
In transfer fun^n, Numerator → zeroes
Denominator → poles

Dominant → poles

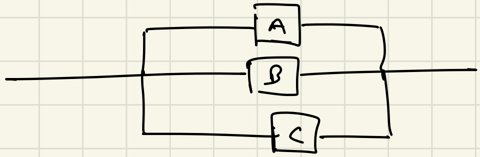
Simulation :- process of solving a block diagram model on a computer

Block diagram





$= A \cdot B \cdot C$



$= A + B + C$

Simulation

3 basic functions :-

Simulation →
- i) Graphical Editing
- ii) Analysis
- iii) Simulation

→ frequency response (Bode Plot :- frequency overshoot, Phase margin, gain...)

Simulation Process :-

Simulation →
- Initialization
- Iteration
- Termination

BLOCK DIAGRAM MODELLING

i) DIRECT METHOD

ODE → Ordinary Differential Equations $\left(\frac{d}{dt}\right)$

* Transfer Function ⟶ Block Diagram

CP – I

Q. The following eqⁿ represents TF for a mechatronic system. Develop the block diagram model for the system using direct method.

$$T(s) = \frac{Y(s)}{R(s)} = \frac{s^2 - 3s + 4}{s^4 + 2s^3 - 5s^2 + 2s - 9}$$

$y(0) = 1$ $\qquad$ $\ddot{y}(0) = 6$

$\dot{y}(0) = -2$ $\qquad$ $\dddot{y}(0) = 3$

A. Step 1 :- Create the state variable $x(t)$, by 'sliding' the numerator part of the transfer function into a new block which is located to the right of the denominator part of the transfer function.

$$r(t) \longrightarrow \boxed{\frac{1}{s^4 + 2s^3 - 5s^2 + 2s - 9}} \xrightarrow{x(t)} \boxed{s^2 - 3s + 4} \xrightarrow{y(t)}$$

The order of transfer function is 4.

Step II :- The state eqⁿ (SE) b/w input $r(t)$ to $x(t)$

$$SE = \frac{x(t)}{r(t)} = \frac{1}{s^4 + 2s^3 - 5s^2 + 2s - 9}$$

$$s^4 x(t) + 2s^3 x(t) - 5s^2 x(t) + 2s\, x(t) - 9x(t) = r(t)$$

$$\frac{d^4}{dt^4} x(t) + 2\frac{d^3}{dt^3} x(t) - 5\frac{d^2}{dt^2} x(t) + 2\frac{d}{dt} x(t) - 9x(t) = r(t)$$

Step III :- From the eq^n we can construct the primary block diagram by connecting the integrator blocks in series from left to right. The input to the left most integrator block will be the highest derivative of $x(t)$

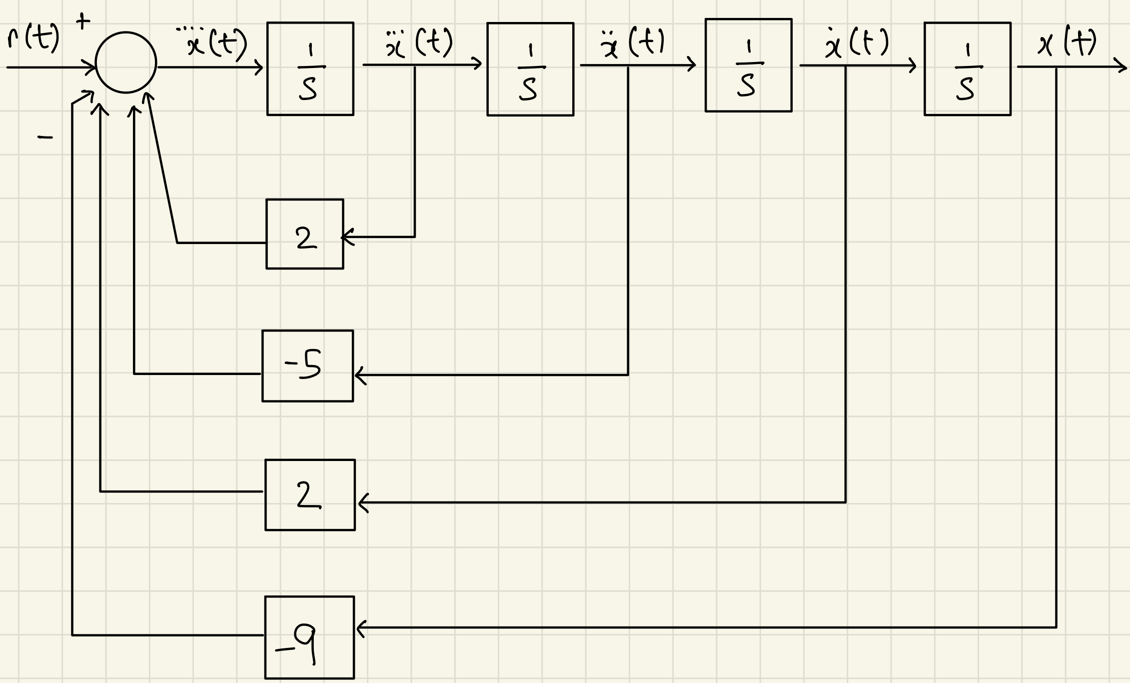
$$\xrightarrow{\frac{d^4}{dt^4}x(t)} \boxed{\frac{1}{s}} \xrightarrow{\dddot{x}(t)} \boxed{\frac{1}{s}} \xrightarrow{\ddot{x}(t)} \boxed{\frac{1}{s}} \xrightarrow{\dot{x}(t)} \boxed{\frac{1}{s}} \xrightarrow{x(t)}$$

In this step we are ignoring the initial condition which will be added during the final block diagram representation.

Step IV :- Re arranging the eq^n to get the highest derivative of the state variable.

$$\frac{d^4}{dt^4} x(t) = -2\frac{d^3}{dt^3} x(t) + 5\frac{d^2}{dt^2} x(t) - 2\frac{d}{dt} x(t) + 9x(t) + r(t)$$

From this we can add summing junction to the block diagram along with required gain blocks.



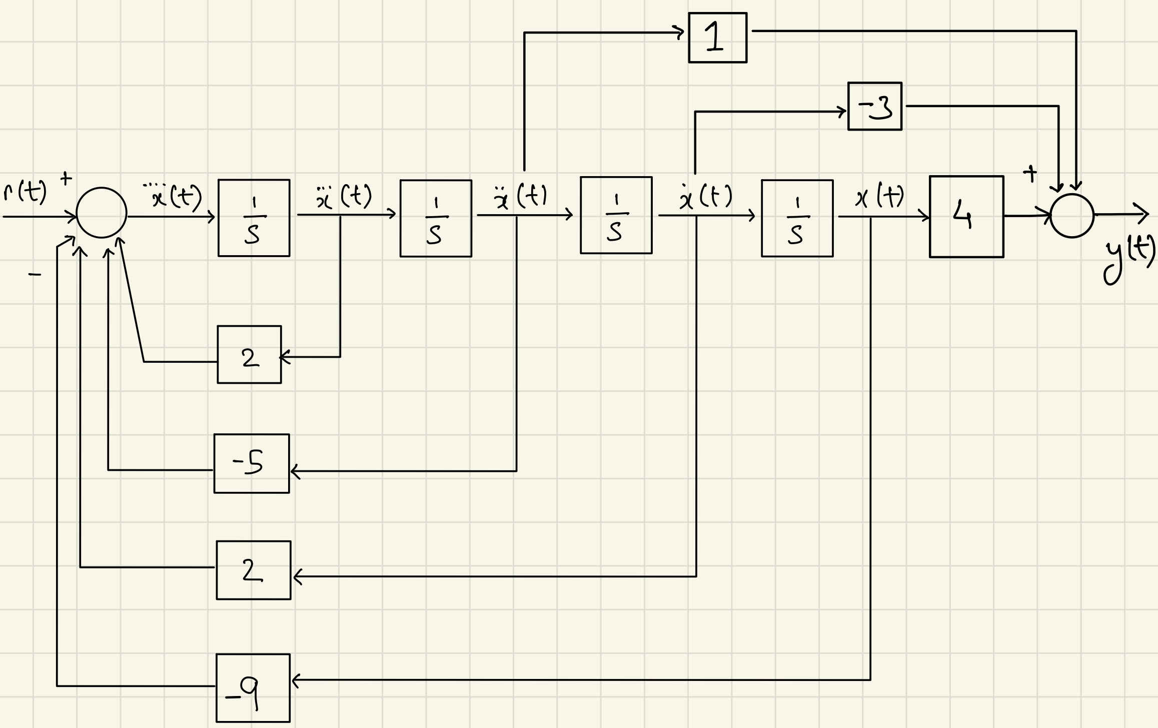
Step V :- The relationship b/w state variable $x(t)$ and $y(t)$ is given by

$$OE = \frac{y(t)}{x(t)} = s^2 - 3s + 4$$

From this we get

$$\ddot{x}(t) - 3\dot{x}(t) + 4x(t) = y(t)$$

By using the relation we can add the gain & summing blocks to get $y(t)$.



Step VI :- We need to add the initial conditions to the block diagram created in step V. This we'll do using the relationship b/w $y(t)$ & $x(t)$

We have :- $\ddot{x}(t) - 3\dot{x}(t) + 4x(t) = y(t)$

From this,

$$\ddot{x}(0) - 3\dot{x}(0) + 4x(0) = y(0) = 1 \longrightarrow (1)$$

$$\dddot{x}(0) - 3\ddot{x}(0) + 4\dot{x}(0) = \dot{y}(0) = -2 \longrightarrow (2)$$

$$\ddddot{x}(0) - 3\dddot{x}(0) + 4\ddot{x}(0) = \ddot{y}(0) = 6 \longrightarrow (3)$$

Substituting the value of $\frac{d^4}{dt^4}x(0)$ in eq^n (3),

$$\left[-2\dddot{x}(0) + 5\ddot{x}(0) - 2\dot{x}(0) + 9x(0) + r(0)\right] - 3\dddot{x}(0) + 4\ddot{x}(0) = \ddot{y}(0) = 6$$

$$-5\dddot{x}(0) + 9\ddot{x}(0) - 2\dot{x}(0) + 9x(0) + r(0) = 6$$

$$-5\ddddot{x}(0) + 9\dddot{x}(0) - 2\ddot{x}(0) + 9\dot{x}(0) + \dot{r}(0) = 6$$

Consider $r(0) = 0$, $\dot{r}(0) = 0$

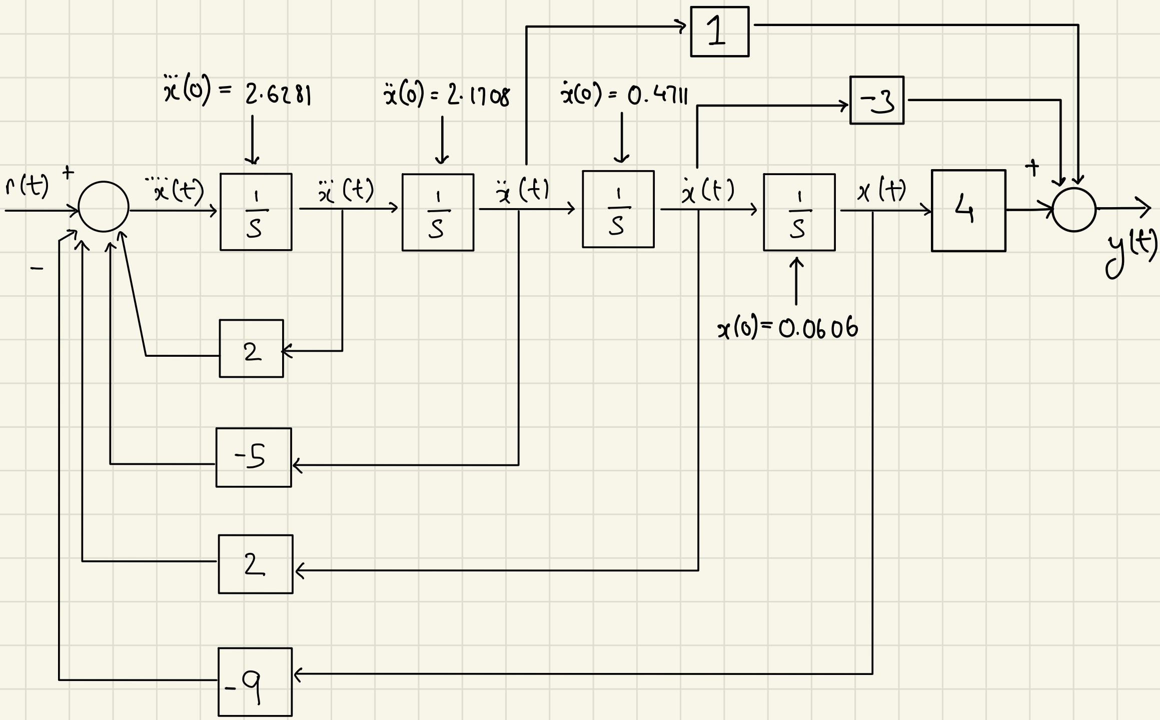
Normally the input & derivative are assumed to be zero

$$\begin{bmatrix} 0 & 1 & -3 & 4 \\ 1 & -3 & 4 & 0 \\ -5 & 9 & -2 & 9 \\ 19 & -27 & 19 & 45 \end{bmatrix} \begin{bmatrix} \dddot{x}(0) \\ \ddot{x}(0) \\ \dot{x}(0) \\ x(0) \end{bmatrix} = \begin{bmatrix} y(0) = 1 \\ \dot{y}(0) = -2 \\ \ddot{y}(0) = 6 \\ \dddot{y}(0) = 3 \end{bmatrix}$$

solving the eq^{n}s we get values,

$$\begin{bmatrix} \dddot{x}(0) \\ \ddot{x}(0) \\ \dot{x}(0) \\ x(0) \end{bmatrix} = \begin{bmatrix} 2.6281 \\ 2.1708 \\ 0.4711 \\ 0.0606 \end{bmatrix}$$

The final block diagram after adding the initial conditions,



r(t)
+
−
x⃛(t)
ẍ(t)
ẍ(t)
ẋ(t)
x(t)
x⃛(0) = 2.6281
ẍ(0) = 2.1708
ẋ(0) = 0.4711
x(0) = 0.0606
1/s
1/s
1/s
1/s
1
-3
4
+
y(t)
2
-5
2
-9

CP - II

Q. The following eqⁿ represents TF for a mechatronic system. Develop the block diagram model for the system using direct method.

$$T(s) = \frac{Y(s)}{R(s)} = \frac{3}{5s^2 + 8s + 13}$$

$y(0) = 2$

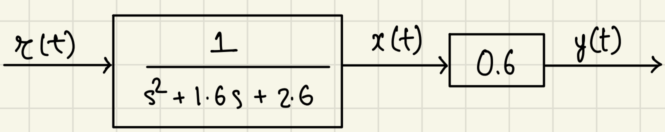
$\dot{y}(0) = -2$

A. Step I :- Monic form

$$T(s) = \frac{Y(s)}{R(s)} = \frac{3}{5} \frac{1}{s^2 + \frac{8}{5}s + \frac{13}{5}}$$

$$= 0.6 \frac{1}{s^2 + 1.6s + 2.6}$$

Create State Variable $x(t)$



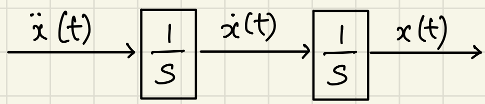
Order of Transfer function = 2

Step 2 :- Write state Equation (SE)

$$\frac{x(t)}{r(t)} = \frac{1}{s^2 + 1.6s + 2.6}$$

$$\frac{d^2}{dt^2}x(t) + 1.6\frac{d\,x(t)}{d(t)} + 2.6\,x(t) = r(t)$$

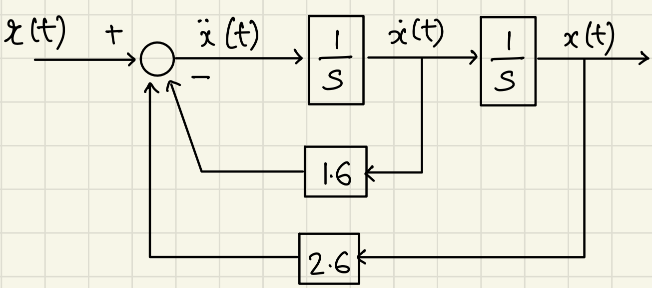
Step 3 :- Construct primary block diagram



Step 4 :- Solve for $\frac{d^2}{dt^2}x(t)$

$$\frac{d^2}{dt^2}x(t) = -1.6\frac{d}{dt}x(t) - 2.6\,x(t) + r(t)$$

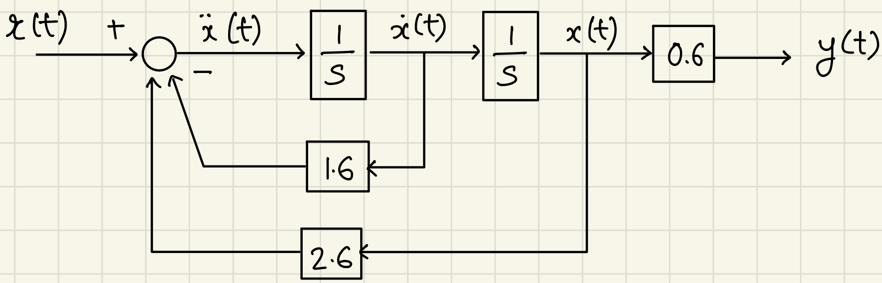
Add summing junctions with required gain blocks.



Step 5 :- Relationship b/w state variable $x(t)$ and $y(t)$ is given by

$$OE = \frac{y(t)}{x(t)} = 0.6$$

$$0.6\,x(t) = y(t)$$



Step 6 :- Add initial conditions

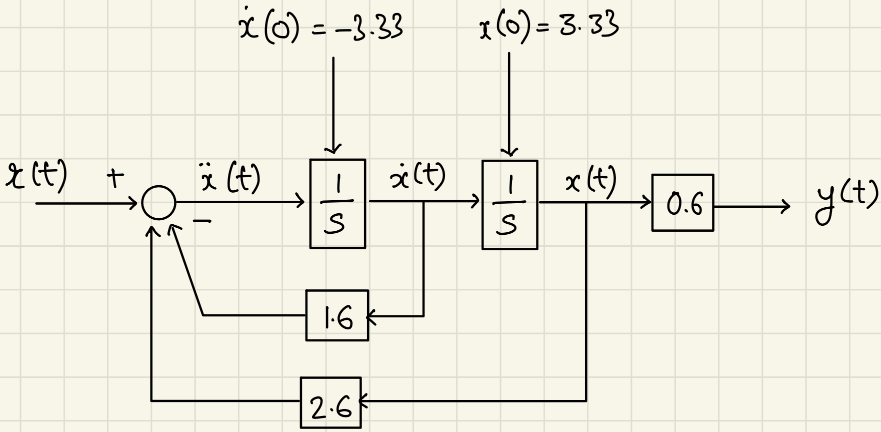
$$0.6\;x(t) = y(t)$$

Given, $y(0) = 2$, $\dot{y}(0) = -2$

i) $0.6\,x(0) = y(0) = 2$
$x(0) = 3.33$

ii) $0.6\,\dot{x}(0) = \dot{y}(0) = -2$
$\dot{x}(0) = -3.33$

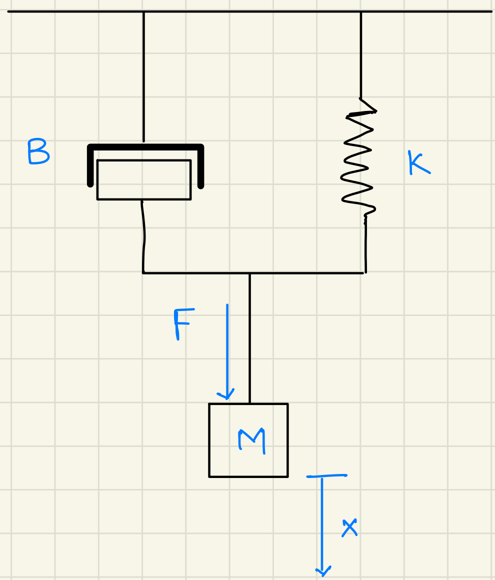
Final block diagram :-



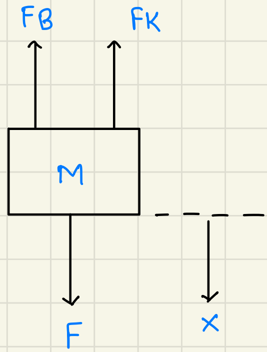
Force - Voltage Analogy

Force $\rightarrow$ Voltage
Displacement $\rightarrow$ Current
Resistance $\rightarrow$ Damper
Inductance $\rightarrow$ Mass
Capacitance $\rightarrow$ Spring

Direct Method (Method I)



Free body diagram



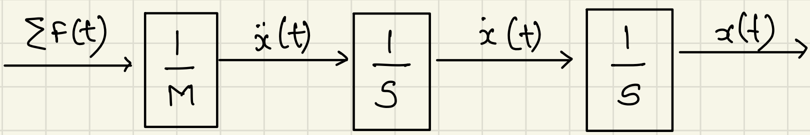
Step 1 :- For each mass you have as per Newton's laws,

$$\sum F(t) = M\ddot{x}(t)$$

By rearranging we get,

$$\ddot{x}(t) = \frac{1}{M}\sum F(t)$$

From this we can develop the primary block diagram.



($\because$ 2^{nd} order)

Step II :- Write $\Sigma F(t)$ from the Free body diagram.

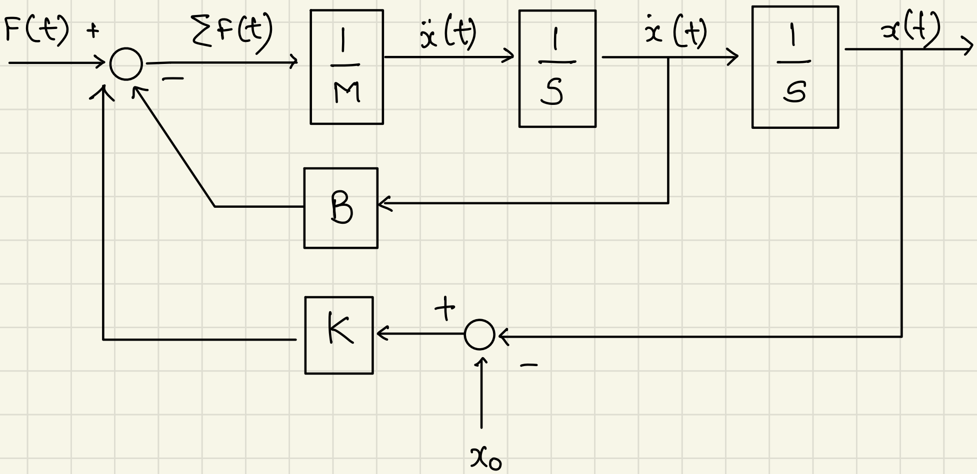
$$\Sigma F(t) = F(t) - F_K(t) - F_B(t)$$

WKT,

$$F_K(t) = K(x(t) - x_0)$$

$$F_B(t) = B\dot{x}(t)$$

Step III :- Considering these eqⁿ the final block diagram is created adding the gain block & the summing blocks



For simulation, we will consider the initial displacement, $x_0 = 0$

$F(t) =$ unit step

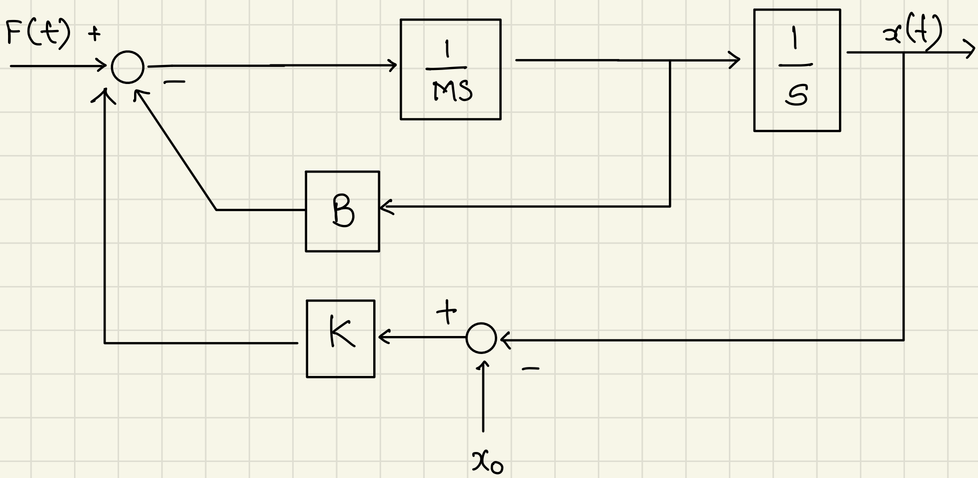
Case – I	Case – II	Case – III
$M = 10$	$M = 10$	$M = 10$
$B = 5$	$B = 0$	$B = 50$
$K = 10$	$K = 10$	$K = 10$
underdamped	undamped	overdamped

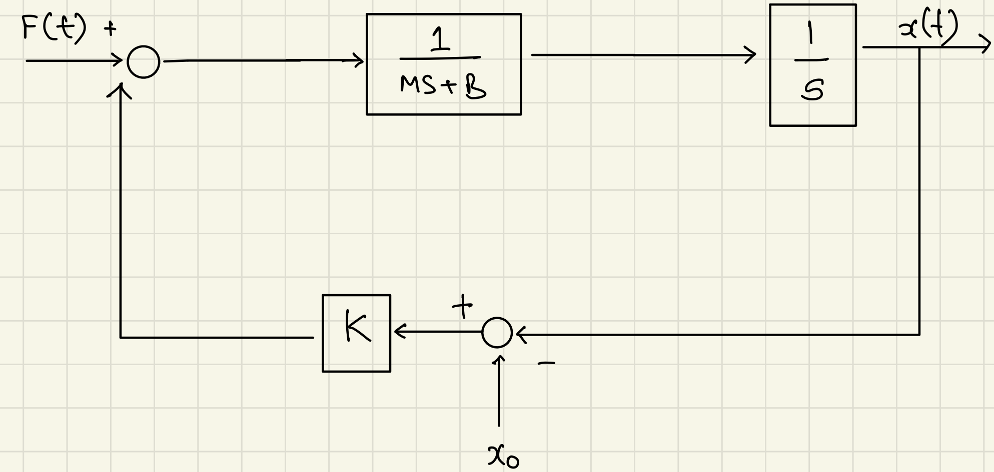
Case - $\underline{IV}$

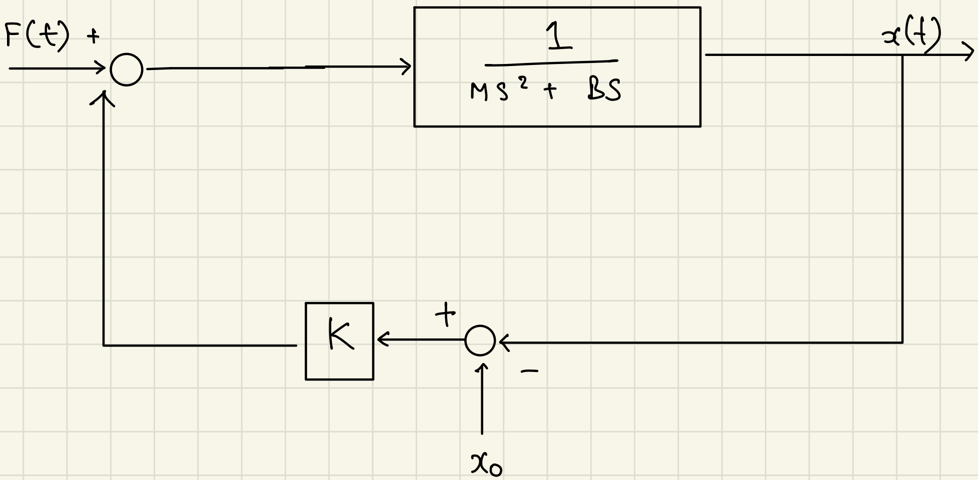
$M = 10$
$B = 18$
$K = 10$

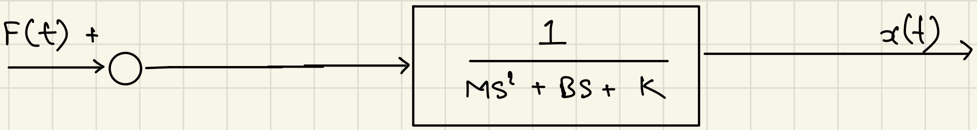
Critically Damped

Transfer function :-




F(t) +
1
MS+B
1
S
x(t)
+
K
−
x0


F(t) +
1
MS 2 + BS
x(t)
+
K
−
x0


F(t) +
1
MS2 + BS + K
x(t)

Zeta Values :-

$$T.F. = \frac{1}{Ms^2 + Bs + K}$$

$$= \frac{1}{M\left(s^2 + \frac{B}{M}s + \frac{K}{M}\right)}$$

$$2\zeta\omega_n = \frac{B}{M} \qquad \omega_n = \sqrt{\frac{K}{M}}$$

$$\zeta = \frac{B}{2M}\sqrt{\frac{M}{K}}$$

Case - 1 :- $M = 10$
$B = 5$
$K = 10$

$$\zeta = \frac{1}{4} = 0.25 \quad \text{(underdamped)}$$

Case - 2 :- $M = 10$
$B = 0$
$K = 10$

$$\zeta = 0 \quad \text{(undamped)}$$

Case - 3 :- $M = 10$
$B = 50$
$K = 10$

$$\zeta = \frac{50}{20} = 2.5$$

(overdamped)

Case 4 :-

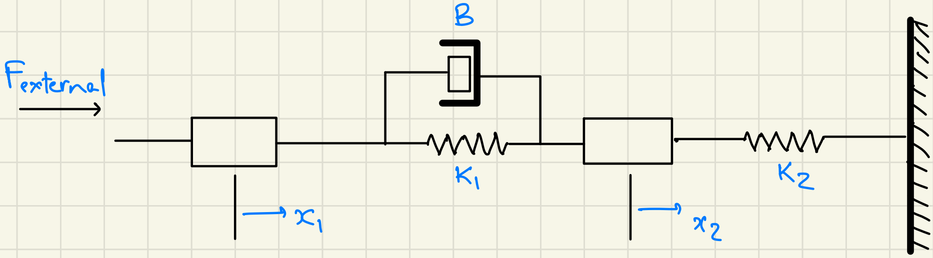
$$M = 10$$
$$B = 18$$
$$K = 10$$

$$\zeta = \frac{18}{20} = \frac{9}{10} = 0.9$$

(critically damped aprox.)

Method - II

Q. Develop a block diagram for the following two - mass mechanical translation system using direct method.



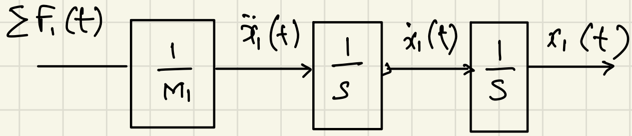
A. Step - I :- For each mass we will write down the eq^n using the relationship

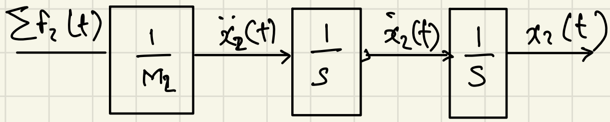
$$\sum F(t) = M\ddot{x}(t)$$

$\therefore$ Mass 1 : $\ddot{x}_1(t) = \frac{1}{M_1} \sum F_1(t)$

$\therefore$ Mass 2 : $\ddot{x}_2(t) = \frac{1}{M_2} \sum F_2(t)$

Step - II :- From these 2 eq^ns we can create a primary block diagram.





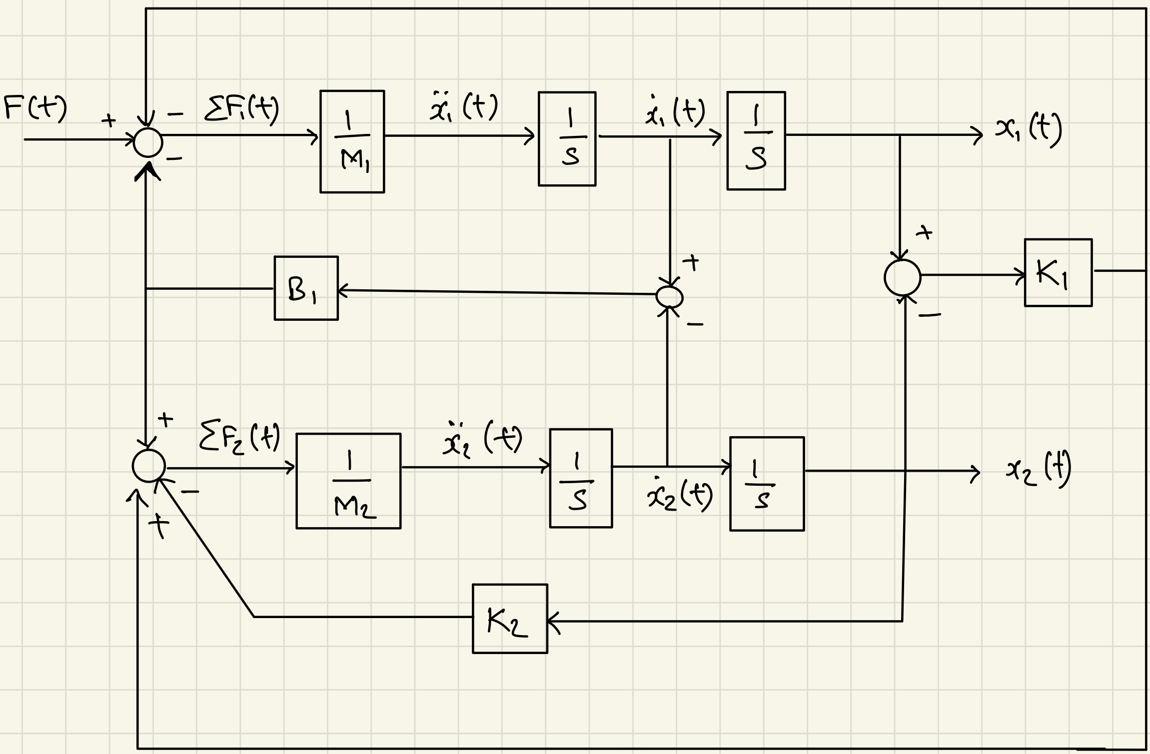
For each of these 2 masses, we can write down the eq^{n}s for $\sum f(t)$ using the different forces acting on the mass (we can also get this from FBD).

(assume initial displacement 0)

$$\sum F_1(t) = f_1(t) - K_1(x_1(t) - x_2(t)) - B(\dot{x}_1(t) - \dot{x}_2(t))$$

$$\sum f_2(t) = K_1(x_1(t) - x_2(t)) + B(\dot{x}_1(t) - \dot{x}_2(t)) - K_2 x_2(t)$$

Step III :- Considering the primary block diagram & the eq^{n}s in Step II, the final block diagram is constructed as follows



Solve more @ page 83

Modified Analogy Approach

Convert diagram (physical, heat, thermal) to block diagram.

Step - I :- Creating Impedance Diagram

Step - II :- Identify PV (Loop) & FV (Branching)
(forces to move forward) $\boxed{KVL}$ (flowing in system) $\boxed{KCL}$

Step - III :- Construction of block diagram by representing PV & FV as summing junctions.

$\left(\frac{1}{s} = \frac{1}{D} = \text{integrator}\right)$ (Rearrange eqⁿ such that output should result in integrator or gain blocks)

Step - IV :- Completion of block diagram.

→ Connecting signals from summing junctions or impedances.

Note :-
(always look at C & L elements, do multiplication with capacitor & division with Inductor)

Resistance $\longrightarrow$ Impedance

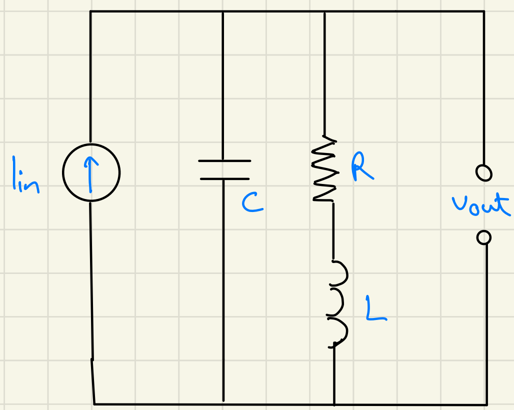
$$Z = R + jX$$

$$\phi = \tan^{-1}\left(\frac{X}{R}\right)$$

(phase)

Component	impedance	
Capacitor	$Z_C = \frac{1}{j\omega C}$	$\frac{-j}{\omega C}$
inductor	$Z_L = j\omega L$	$j\omega L$
resistor	$Z_R = R$	R (real)

Q. Construct the block diagram model for the parallel resonant circuit using modified analogy approach.



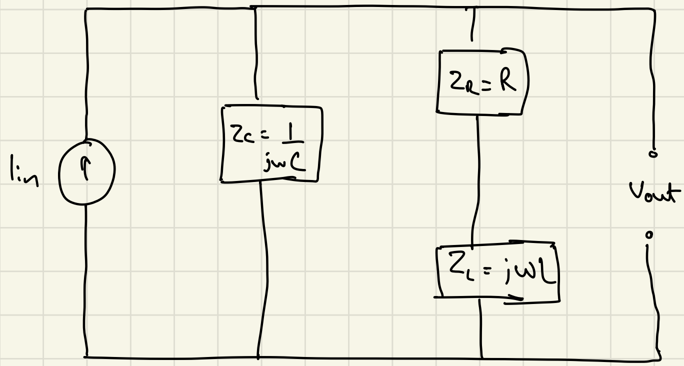
A. In this diagram we will consider,

(current) $I = Fv$
(voltage) $V = Pv$

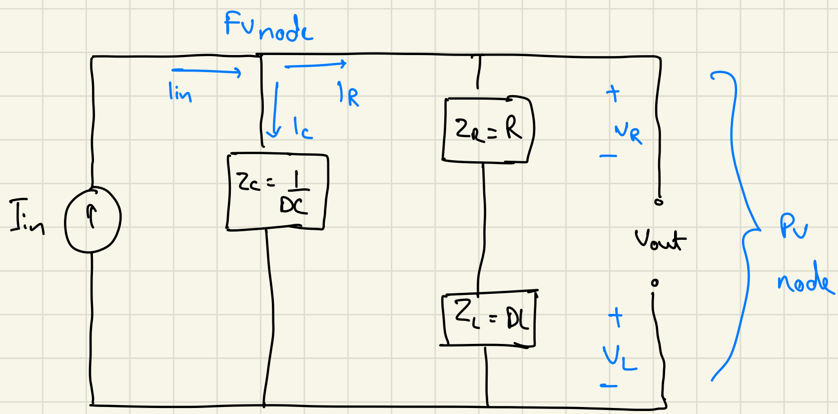
The impedances of the components is given as :-

Resistor : $Z_R = R$
Inductor : $Z_L = j\omega L = DL$
Capacitance : $Z_C = \frac{1}{j\omega C} = \frac{1}{DC}$

Step I :- Creating the impedance diagram



Step II :- Identifying FV & PV nodes in the impedance diagram



Here we have 1 FV node,

$$I_{in} = I_C + I_R$$

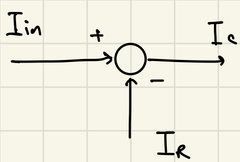
Here $I_R = I_L$ (∵ series)

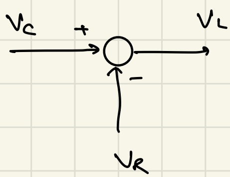
& 1 PV node,

$$V_{out} = V_R + V_L$$

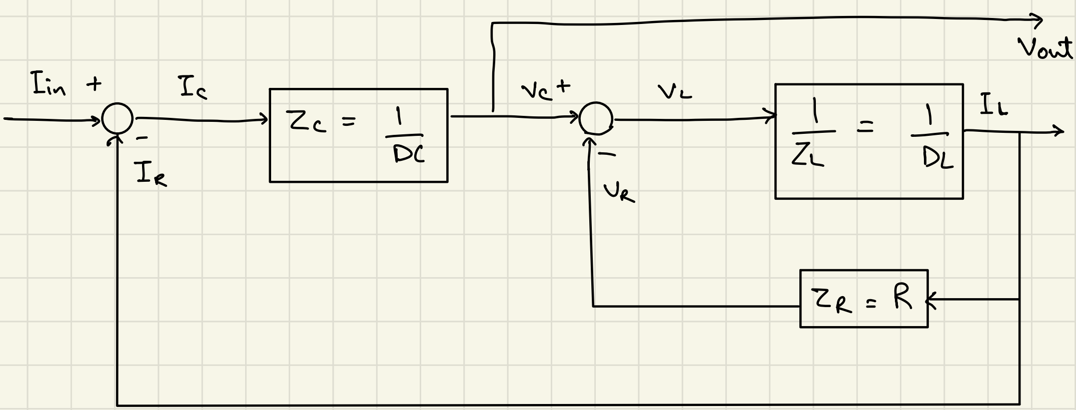
$$V_{out} = V_C$$

Step III :- Representing FV & PV nodes as summing junction so that either gain or integral causality results.





Step IV :- → Adding all impedance block.
→ Connecting & creating the intermediate & output signals to get the complete block diagram.



Equivalent TF :-

$$V_{out} = \frac{DL + R}{D^2LC + DRC + 1} I_{in}$$

$$\ddot{V}_{out} LC + \dot{V}_{out} RL + V_{out} = \dot{I}_{in} L + I_{in} R$$

Checking of zeta values :-

$$s^2LC + sRC + 1 \qquad \text{(From TF)}$$

$$\Rightarrow \quad s^2 + s\frac{R}{L} + \frac{1}{LC}$$

which is equivalent to,

$$s^2 + 2\zeta\omega_n s + \omega_n^2$$

$$\therefore \quad \omega_n = \sqrt{\frac{1}{LC}}$$

$$2\zeta\omega_n = \frac{R}{L}$$

$$\zeta = \frac{R}{2L}\sqrt{LC}$$

Case 1 :-

$R = 10$
$L = 10$
$C = 10$

$$\zeta = \frac{R}{2L}\sqrt{LC} = \frac{10}{20} \times 10 = 5$$

$\zeta > 1$ (overdamped)

Case 2 :-

$R = 0$
$L = 10$
$C = 10$

$$\zeta = \frac{R}{2L}\sqrt{LC} = 0$$

$\zeta = 0$ (undamped)

Case 3 :-

$R = 20$
$L = 5$
$C = 5$

$$\zeta = \frac{R}{2L}\sqrt{LC} = 10$$

$\zeta > 1$ (overdamped)

Case 4 :-

$R = 1$
$L = 10$
$C = 10$

$$\zeta = \frac{R}{2L}\sqrt{LC} = \frac{1}{20} \times 10 = 0.5$$

$\zeta < 1$ (underdamped)

Case 5 :-

$R = 2$
$L = 5$
$C = 5$

$$\zeta = \frac{R}{2L}\sqrt{LC} = \frac{2}{10} \times 5$$

$\zeta = 1$ (critically damped)

M-1

Q. Develop block diagram model for the system using Direct Method.

$$T(s) = \frac{Y(s)}{R(s)} = \frac{s^2 - 3s + 4}{s^4 + 2s^3 - 5s^2 + 2s - 9}$$

$$y(0) = 1 \qquad \ddot{y}(0) = 6$$
$$\dot{y}(0) = -2 \qquad \dddot{y}(0) = 3$$

A. Step 1 :- Create state variable $x(t)$

$$r(t) \longrightarrow \boxed{\frac{1}{s^4 + 2s^3 - 5s^2 + 2s - 9}} \xrightarrow{x(t)} \boxed{s^2 - 3s + 4} \xrightarrow{y(t)}$$

order of TF = 4

Step 2 : State Eq^n (SE) b/w $r(t)$ & $x(t)$

$$SE = \frac{x(t)}{r(t)} = \frac{1}{s^4 + 2s^3 - 5s^2 + 2s - 9}$$

$$s^4 x(t) + 2s^3 x(t) - 5s^2 x(t) + 2s\, x(t) - 9\, x(t) = r(t)$$

$$\frac{d^4}{dt^4}x(t) + 2\frac{d^3}{dt^3}x(t) - 5\frac{d^2}{dt^2}x(t) + 2\frac{d}{dt}x(t) - 9x(t) = r(t)$$

Step 3 :- Construct primary block diagram by connecting integrator blocks in series. input = highest derivative of $x(t)$

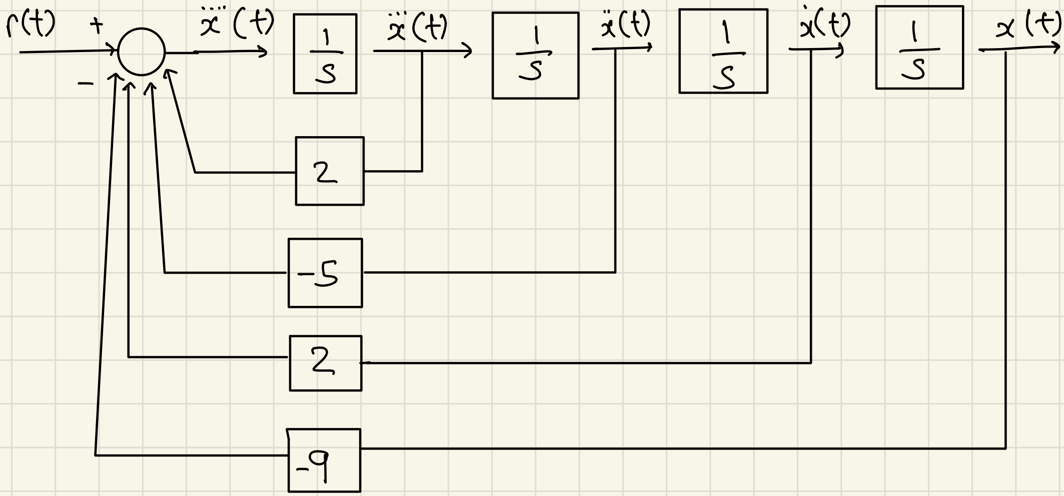
$$\frac{d^4}{dt^4}x(t) \longrightarrow \boxed{\frac{1}{s}} \xrightarrow{\dddot{x}(t)} \boxed{\frac{1}{s}} \xrightarrow{\ddot{x}(t)} \boxed{\frac{1}{s}} \xrightarrow{\dot{x}(t)} \boxed{\frac{1}{s}} \xrightarrow{x(t)}$$

ignore initial conditions. They will be added in last step

Step 4 :- Rearranging eq^n to get highest derivative of SE

$$\frac{d^4}{dt^4}x(t) = -2\frac{d^3}{dt^3}x(t) + 5\frac{d^2}{dt^2}x(t) - 2\frac{d}{dt}x(t) + 9x(t) + r(t)$$

From this, add summing junctions

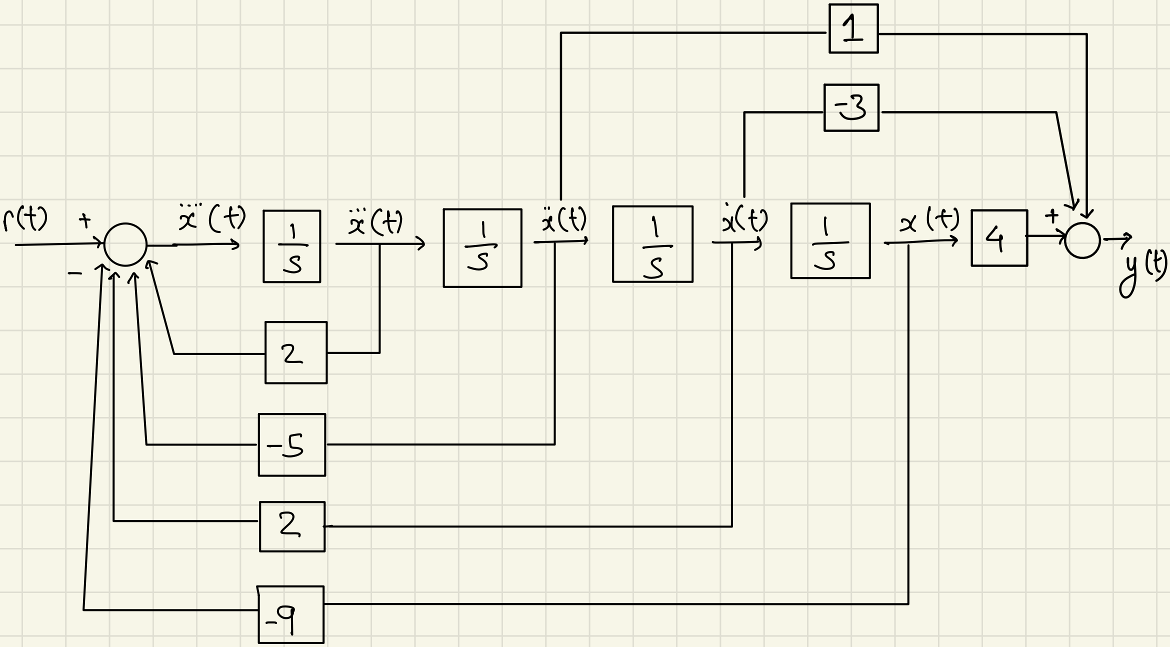


Step 5 :- Relationship b/w $x(t)$ & $y(t)$

$$OE = \frac{y(t)}{x(t)} = s^2 - 3s + 4$$

$$\ddot{x}(t) - 3\dot{x}(t) + 4x(t) = y(t)$$

By using this relation we can add gain & summing blocks to get $y(t)$



Step 6 :- Add initial conditions using relationship b/w $y(t)$ & $x(t)$

$$\ddot{x}(t) - 3\dot{x}(t) + 4x(t) = y(t)$$

From this,

$$\ddot{x}(0) - 3\dot{x}(0) + 4x(0) = y(0) = 1 \longrightarrow (1)$$

$$\dddot{x}(0) - 3\ddot{x}(0) + 4\dot{x}(0) = \dot{y}(0) = -2 \longrightarrow (2)$$

$$\ddddot{x}(0) - 3\dddot{x}(0) + 4\ddot{x}(0) = \ddot{y}(0) = 6 \longrightarrow (3)$$

Substituting the value of $\frac{d^4}{dt^4}x(t)$ in (3),

$$\left[-2\dddot{x}(0) + 5\ddot{x}(0) - 2\dot{x}(0) + 9x(0) + r(0)\right] - 3\dddot{x}(0) + 4\ddot{x}(0) = \ddot{y}(0) = 6$$

$$-5\dddot{x}(0) + 9\ddot{x}(0) - 2\dot{x}(0) + 9x(0) + r(0) = \ddot{y}(0) = 6$$

$\to$ 4

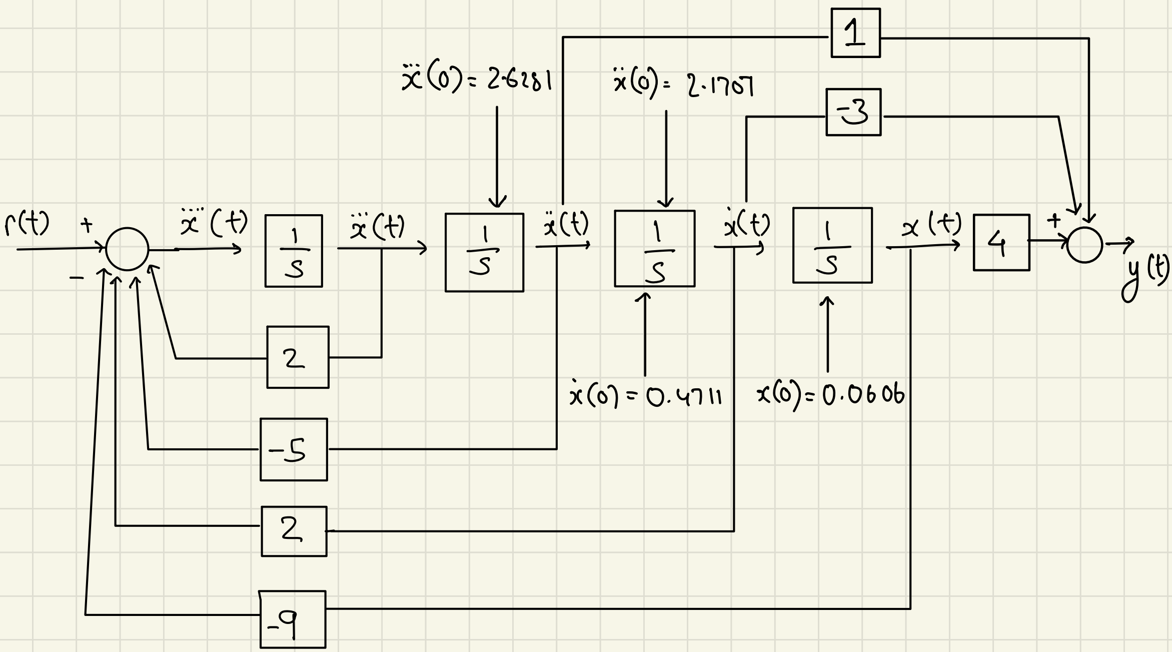
$$-5\ddddot{x}(0) + 9\dddot{x}(0) - 2\ddot{x}(0) + 9\dot{x}(0) + \dot{r}(0) = \dddot{y}(0) = 3$$

$$-5\left[-2\dddot{x}(0) + 5\ddot{x}(0) - 2\dot{x}(0) + 9x(0) + r(0)\right] + 9\dddot{x}(0) - 2\ddot{x}(0) + 9\dot{x}(0) + \dot{r}(0) = 3$$

$$19\dddot{x}(0) - 27\ddot{x}(0) + 19\dot{x}(0) + 45x(0) + \dot{r}(0) - 5r(0) = 3$$

$$\begin{bmatrix} 0 & 1 & -3 & 4 \\ 1 & -3 & 4 & 0 \\ -5 & 9 & -2 & 9 \\ 19 & -27 & 19 & 45 \end{bmatrix} \begin{bmatrix} \dddot{x}(0) \\ \ddot{x}(0) \\ \dot{x}(0) \\ x(0) \end{bmatrix} = \begin{bmatrix} y(0) = 1 \\ \dot{y}(0) = -2 \\ \ddot{y}(0) = 6 \\ \dddot{y}(0) = 3 \end{bmatrix}$$

$$\begin{bmatrix} \dddot{x}(0) \\ \ddot{x}(0) \\ \dot{x}(0) \\ x(0) \end{bmatrix} = \begin{bmatrix} 2.6281 \\ 2.1707 \\ 0.471 \\ 0.0606 \end{bmatrix}$$

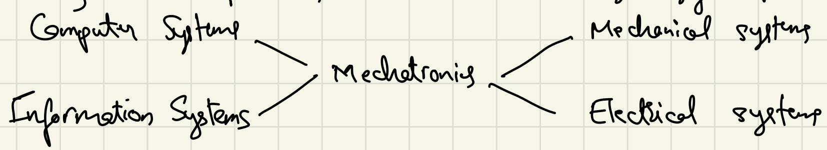


Q. Mechatronics

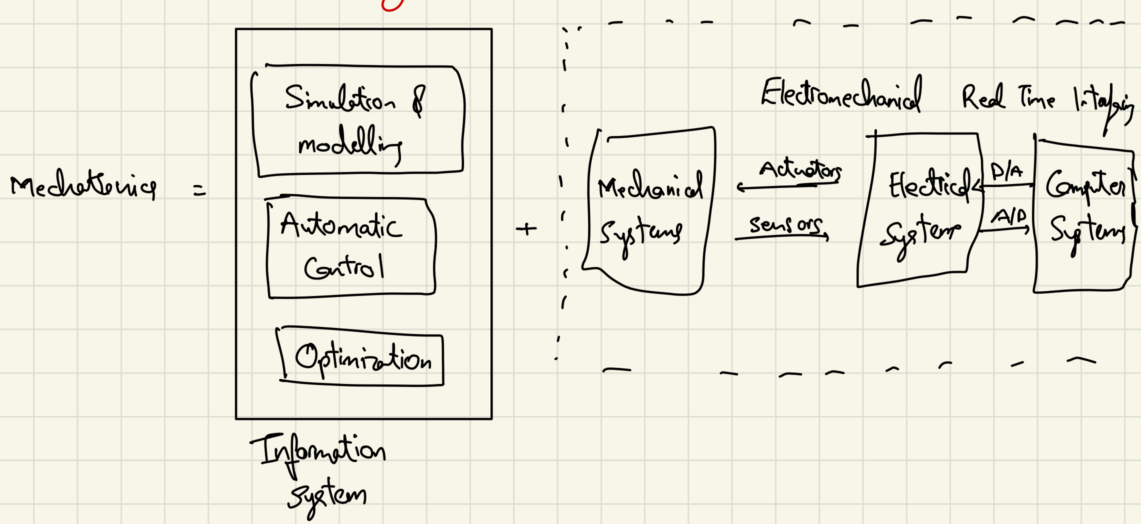
→ methodology for optimal design of electromechanical products

→ multidisciplinary field that combines elements of mechanical systems, electrical systems, computer systems and information systems to create intelligent systems & products that can perform complex tasks with high precision

→ mechatronics design methodology is based on concurrent (instead of sequential) approach to discipline design, resulting in products with more synergy approach.



Q. Mechatronics Key elements



Q. Mechatronics v/s Electromechanical

Mechatronics	Electromechanical
→ combines mechanical, electrical, computer, information system components.	→ interaction b/w electrical & mechanical components.
→ more complex. require sophisticated algorithms & software to coordinate interaction.	→ simple to moderately complex. like speed regulation, position control
→ Concurrent approach to discipline design	→ Sequential approach to discipline design
→ Example :- CNC, autonomous cleaner, industrial robots	→ Example :- motors, Conveyer belts, elevators

Q. Modelling & Simulation

A. Modelling :- → process of representing behaviour of real system by a collection of mathematical eqn & logic

→ static (no energy transfer) or dynamic (energy)

→ are cause effect structures : except external info & process it with their logic & eqns to produce one or more outputs.

→ visually intuitive → block diagram

Simulation :-
- → process of solving a model & performed on computer.
- → divided in 3 sections :

  initialization

  eq^{ns} of each block must be sorted according to pattern in which blocks are connected

  iteration

  solve any differential eq^{n}s present in model using integration and/or differentiation

  termination

  used to present & post process the output.

Q. Sensors

A.
- → monitor performance of machines & processes
- → monitoring devices located near manufacturing processes
- → provide real time information that assist controllers in identifying potential bottlenecks, breakdowns and other problems
- → measurement variables : temp, speed, pos, force, torque & acceleration.
- → intelligent sensors not only sense info but process it as well
- →

Quantity being measured → Sensors → Signal Conditioner → Display → Value of Quantity

Q. Actuators

A. → Actuators are devices or components that convert electrical signals, fluid pressure, or other controlled inputs into mechanical motion, force, or some form of physical action.

→ Ex :- ejection of work piece from a conveyer system initiated by sensor.

→ 3 general groups :-

<u>Electromagnetic</u> (AC/DC motors, stepper motors)

<u>Fluid Power Actuators</u> (hydraulics & pneumatic)

<u>Unconventional Actuators</u> (piezoelectric, magnetostrictive, memory metal)

Q. Hardware in the loop simulation

A. → prototyping, non-computer subsystems replaced with actual hardware.

→ Sensors & actuators provide interface signals necessary to connect hardware back to model

→ resulting model is part mathematical & part real

→ real part evolves in real time & mathematical part evolves in simulated time, essential two parts be synchronised

→ Process of fusing & synchronizing model, sensor and actuator info is called real time interfacing or hardware in the loop simulation.

C P CSAP CSAP

SAP
SAC
P
S

Real hardware components	Mathematically modelled component	Description
Sensors, Actuators, Process	Control Algo	Modify control system design
Sensors, Actuators, Control	Process	Evaluate validity of process model
Protocol	Control Algo, Sensors, Actuators, Process	Evaluate effects of data transmission on design
Signal Processing hardware	Control Algo, Sensors, Actuators, Process	Evaluate effect of actual signal processing hardware

Q. Visual Simulation Environment

A. → <u>Graphical Editing</u> creating, editing, storage & retreieval of models. Also create model inputs, orchestrate simulation & present model results.

→ <u>Analysis</u> obtain TF, compute frequency response

→ <u>Simulation</u> numerical sol^n of block diagram model

Q. Internal & External bus systems

A. Internal :- → computer specific & consists of board or card connected to internal computer bus & an external screw terminal, board connected to the internal card via ribbon cable.

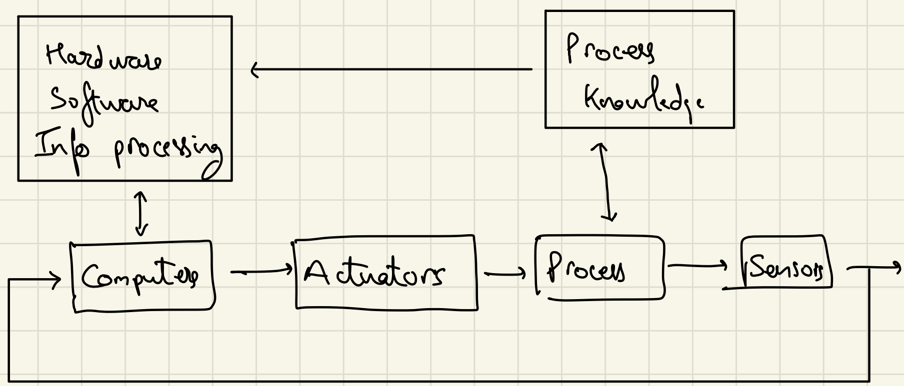
→ high speed, low cost & small size

External :- → computer independent & normally connected to the host computer through its serial port, which is responsible for slow data rates.

→ Ex : Rs - 232 is limited to 9600 bauds

Q. Scheme of hardware & software

A.



Q. Mechatronics Design Process

RCFSDCD

Modelling & Simulation

Recog of need

↓

Conceptual design & functional specification

↓

First principle modular mathematical modelling

↓

Sensor & actuator selection

↓

Detailed modular mathematical modelling

↓

Control System Design

↓

Design optimization

HD

Prototyping

Hardware in the loop simulation

↓

Design Optimization

DL

Deployment / Life Cycle

Deployment of embedded software

↓

Life cycle optimization

i) $$\Sigma F(t) = M\ddot{x}(t)$$

$$\ddot{x}(t) = \frac{1}{M}\Sigma F(t)$$

$$\Sigma F(t) \longrightarrow \boxed{\frac{1}{M}} \xrightarrow{\ddot{x}(t)} \boxed{\frac{1}{s}} \xrightarrow{\dot{x}(t)} \boxed{\frac{1}{s}} \xrightarrow{x(t)}$$

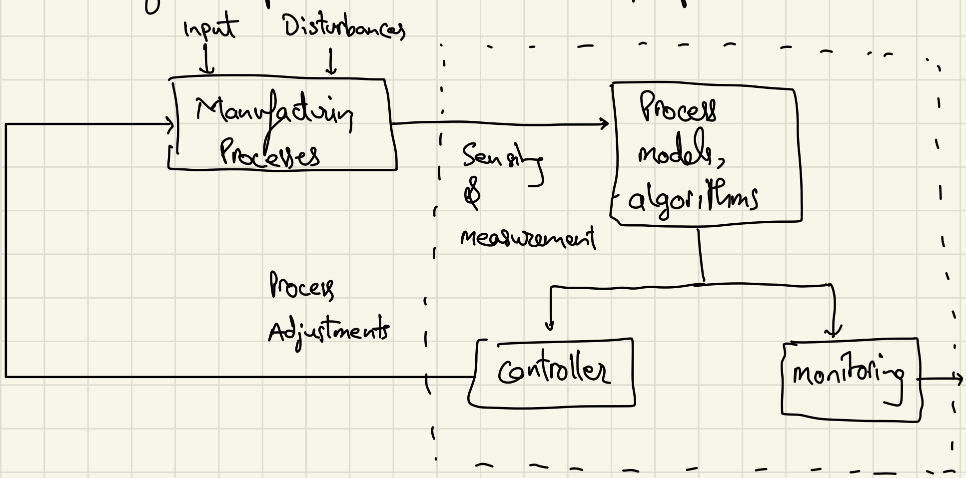
ii) $$\Sigma F(t) = F(t) - F_K(t) - F_B(t)$$

iii) $$F_K(t) = K\,(x(t) - x_0)$$
$$F_B(t) = B\,\dot{x}(t)$$

Q. Advanced approaches

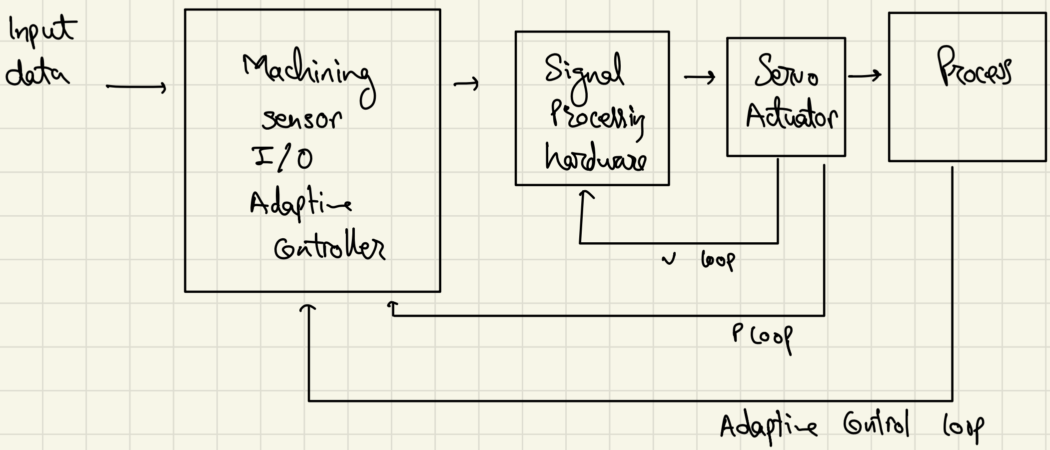
A. i) Model - based monitoring

Use set of modeling eqn^s & estimation algo (state observer) to estimate the signal important to machine performance



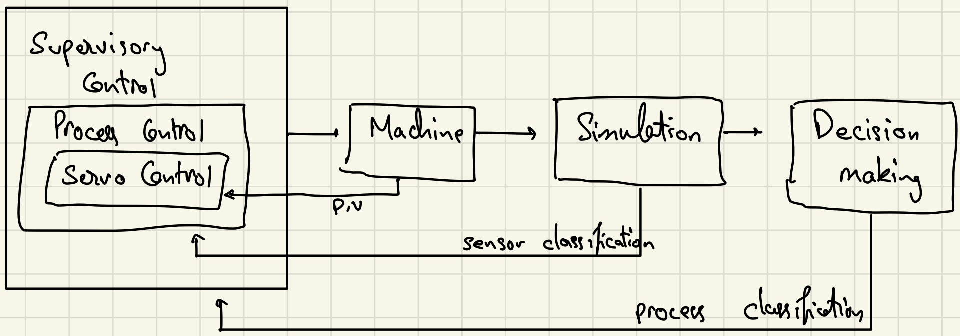
ii) Open Architecture

The development of modular, open architecture machine controllers, have provided vendor neutral open real-time interfacing for the integration of monitoring functionality into the controller.



iii) Intelligent supervisory Control

In this, the controller elects position & velocity at machine level, force & wear at the process level & quality control issues at the product level.



Supervisory Control
Process Control
Servo Control
Machine
Simulation
Decision making
P,V
sensor classification
process classification

Figure 2-50 pg. 97 (modified analogy approach)

→ 1 FV

CP IV

Q. Develop the block diagram model for the transformer system shown in the following circuit using modified analogy approach.

(page 100) figure 2-55

CP - V

Q. Develop the block diagram model for automobile suspension system using modified analogy approach.

(page 106 fig 2-64)

Rotational Systems (avoid for exam)

$$f = ma$$

$$T = J\ddot{\theta}$$

Electrical - Mechanical Coupling

$$T = K_T \, i$$

Torque

current

Torque constant

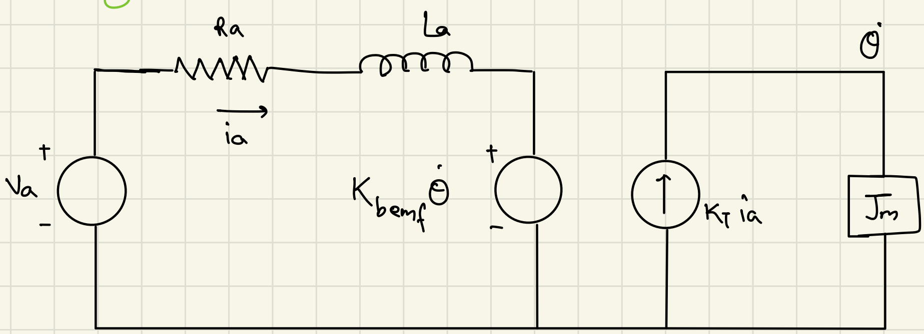
$$V = K_b \dot{\theta}$$

angular velocity

back emf constant

Q. DC Motor Model Circuit diagram

Only Armature



Fluid System

Tank = Capacitor
valve = resistor

∴ RC circuit

Pressure = PV
Volume Flow / Flow rate = FV

Q. Water tank block diagram model

H_0 = initial height of water in tank

q = flow rate

$$\text{Impedance} = \frac{PV}{FV}$$

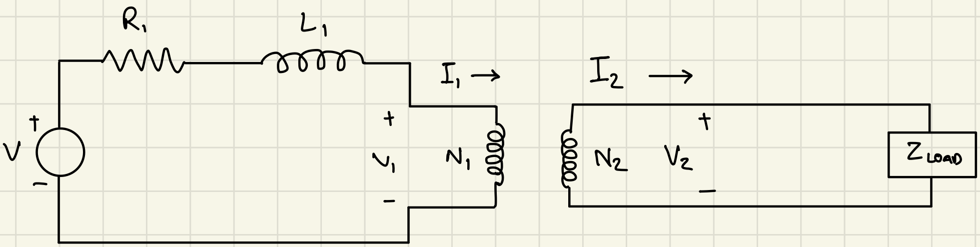
here, PV = height = $H - H_0$
FV = q = flow rate

q = input

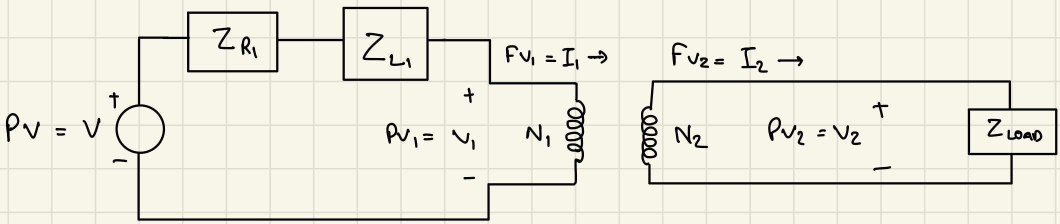
Q. Three tank system

CP - 4

Q. Develop the block diagram model for the transformer system shown in the following circuit using modified analogy approach.



A. Step 1 :- Create Impedance diagram



Step 2 :- Identify PV and FV nodes

Primary winding loop eqⁿ :-

$PV - PV_{R_1} - PV_{L_1} - PV_1$

Secondary winding loop eq^n :

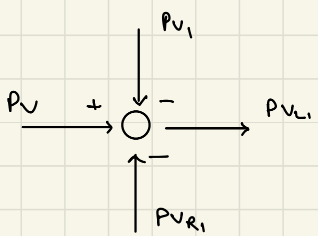
$$PV_2 - Z_{Load} \cdot FV_2$$

Loop eq^{n}s :-

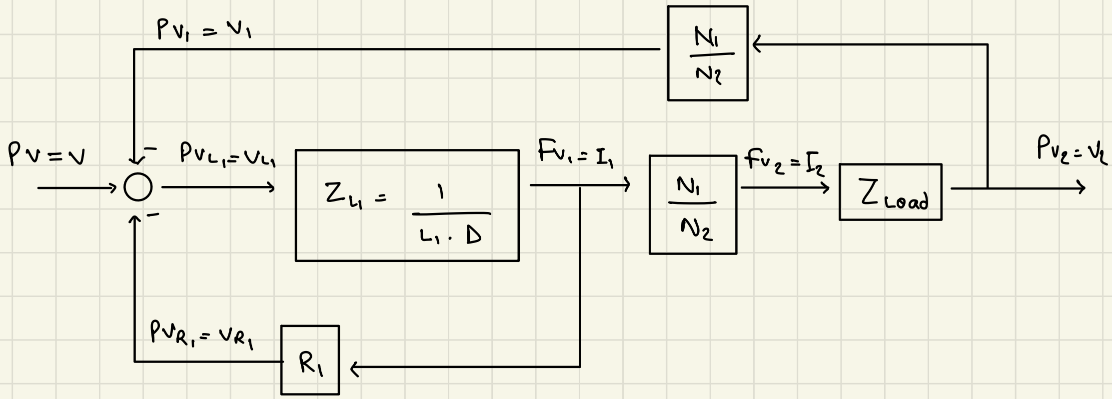
$$PV_1 = \frac{N_1}{N_2} PV_2$$

$$FV_1 = \frac{N_2}{N_1} FV_2$$

Step 3 :- Represent Fv & Pv nodes as summing junction so that either gain or causality results



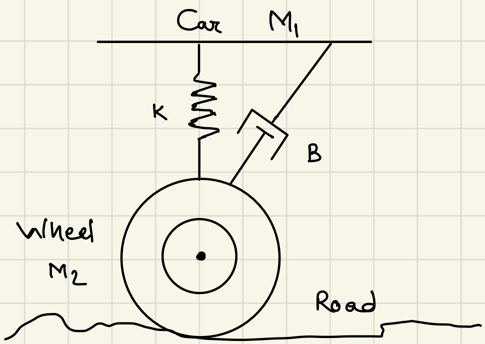
Step 4 :- → Add all impedance blocks
→ Connecting & creating the intermediate & output signals to get the complete block diagram.



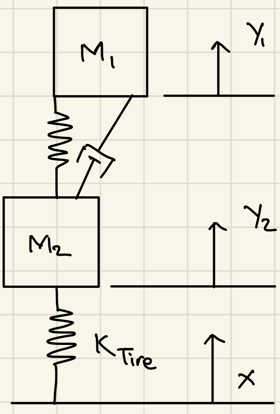
PV = V
PV1 = V1
PVL1 = VL1
ZL1 = 1 / L1 · D
FV1 = I1
N1 / N2
FV2 = I2
ZLoad
PV2 = V2
N1 / N2
PVR1 = VR1
R1

CP - 5

Q. Develop the block diagram model for automobile suspension system using modified analogy approach.



A. Suspension Mechanical Diagram :-



Step 1 :- Create Impedance diagram

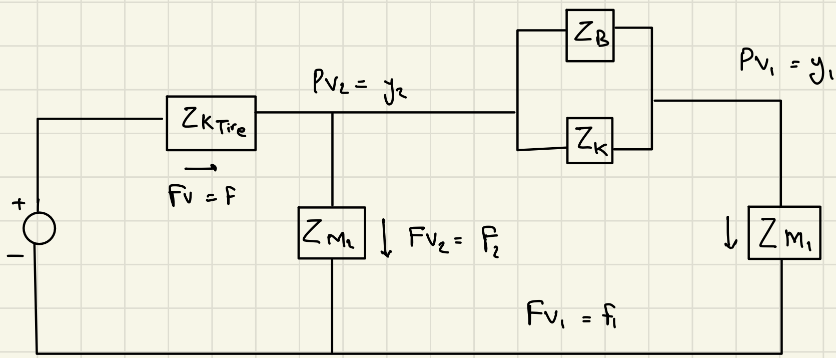
$$Z_{K_{Tire}} = \frac{1}{K_{Tire}}$$

$$Z_{M_1} = \frac{1}{M_1 D^2} \quad Z_{M_2} = \frac{1}{M_2 D^2}$$

$$Z_B = \frac{1}{BD} \quad Z_K = \frac{1}{K}$$

$$\frac{1}{Z_{KB}} = BD + K$$

Impedance diagram :-



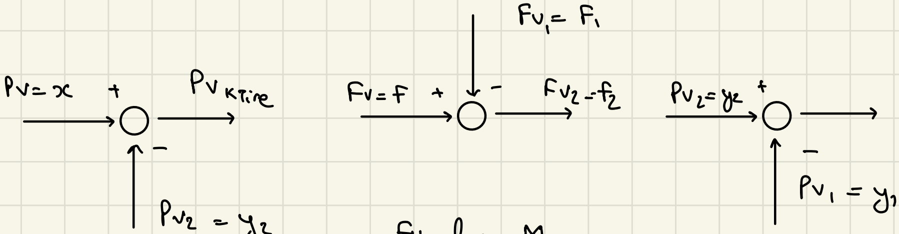
Step 2 :- Identify Pv & Fv Nodes

Fv node at y_2 : $Fv - Fv_1 - Fv_2 = 0$

Pv node for Z_{KTire} : $Pv - Pv_2 = Pv_{KTire}$

Pv node for Z_{KB} : $Pv_2 - Pv_1 = Pv_{KB}$

Step 3 :- Represent select nodes as a summing junction such that either gain or Causality results.



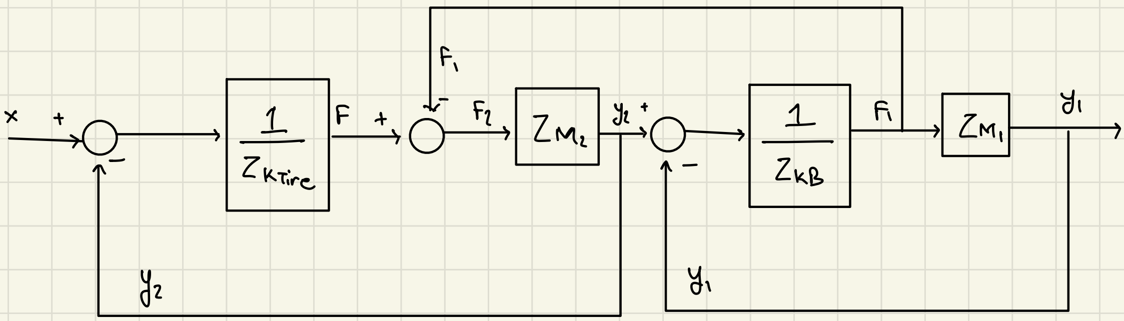
Fv for M_1

Pv for Tire spring

Pv for KB

Step 4 :- → Add the impedance blocks

→ Create all necessary intermediate & output signals to complete the block diagram



x
+
−
1
Z_KTire
F
+
F_1
−
F_2
Z_M2
y_2
+
−
1
Z_kB
F_1
Z_M1
y_1
y_2
y_1

UNIT - 3

Smart Sensors

CISS = Connected Industrial Solution Sensor

Primary Mechanical Sensors

converts mechanical / physical → electrical

Parts of Sensors :-

i) Sensing element
ii) Conditioning of signals & processing
iii) Sensor interface

Data Transimission

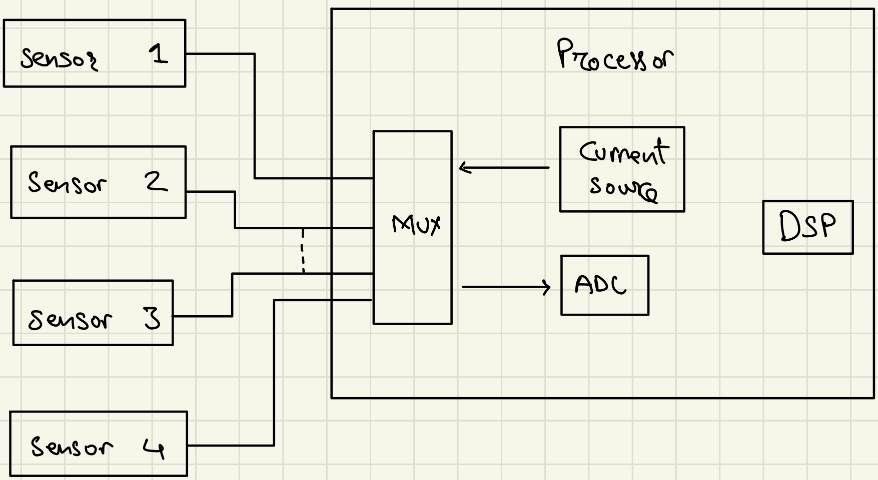
Do these for exam :-

ASI
CAN
Profibus
Foundation (H1)
Foundation (HSE)

Smart Sensors

Combine the 3 parts :-

i) Sensing
ii) Conditioning
iii) Interface



Smart Sensor Applications :-

i) Communications
ii) Computations
iii) Multi sensing
iv) Self calibration

Fuzzy Logic

Steps :-

i) fuzzification (analog → fuzzy variable)

ii) Logic inference (fuzzy logic is applied)

iii) Defuzzication (fuzzy → analog variable)

$$A \wedge B \wedge C = \min(A, B, C)$$
$$A \vee B \vee C = \max(A, B, C)$$
$$\bar{A} = 1 - A$$

Pattern Recognition System

Ex :- Binary Classification of Tumor

Mechanism :- ML Algo / Fuzzy Logic

Steps :-

i) Data Acquisition

↳ Training Data (70 - 80%)

ii) Pre processing

(Noise removal, segmentation, image enhancement, scaling)

iii) Feature extraction
(Change in colour / Texture,
Geometrical (shape, size),
other characteristics)

iv) Model learning

v) Testing

vi) Post - processing
(Image representation or enhancement)

vii) Decision

Algo	Actual				
Cancer	Cancer	⟵	TP	(True Positive)	Not dangerous
Cancer	Not Cancer	⟵	FP	(False Positive)	Not dangerous
Not Cancer	Not Cancer	⟵	TN	(True negative)	Not dangerous
Not cancer	Cancer	⟵	FN	(False negative)	Very dangerous

DESIGN CYCLE

Collect Data → Select Features → Select Model → Train classifier → Evaluate classifier

↓ (from Select Features)

Min 100 - 200

BIOMETRIC SENSORS

$\underbrace{\text{BIO}}_{\text{Life}}\underbrace{\text{METRIC}}_{\text{to measure}}$

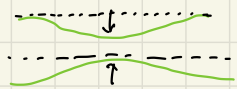
- → Authentication
- → Face recognition , Fingerprinting
- → Retina Scan

Capacitive Fingerprint Scanner

→ Difference in capacitance

ridge = (contact)

valley = (air)



↑ Accuracy = ↑ no. of cells

CD Johnson

UNIT - 5

CONTROL SYSTEMS

ON - OFF CONTROLLER

→ used in slow acting processes where lag is inavoidable

Implement ON-OFF with op-Amps where 100% ON or 100% OFF :- Linear switches

Implement ON-OFF with Dead band :- Schmidt trigger

% change in output ← $P = 0\%$ $\quad E_p < 0$ → % Error

$P = 100\%$ $\quad E_p > 0$

$$\text{Error} \to \begin{cases} \text{magnitude} \\ \text{direction} \end{cases}$$

Time proportional Control

→ Called as PWM (Pulse Width Modulation)

$$V_o = \underbrace{\frac{T_{on}}{T}}_{\text{Duty Cycle}} \cdot \underbrace{V_{in}}_{\text{Constant}}$$

$$V_o \propto T_{on}$$

$$N \propto V_o \propto T_{on}$$

↓

motor speed

Amplitude Proportional Control

% change in Output ← $P \propto E_p$ → Error %

$$P = \underbrace{K_p}_{\text{gain or controller gain}} E_p$$

$$\boxed{P = K_p E_p + \underbrace{P_0}_{\text{nominal output}}}$$

→ Control signal is proportional in amplitude to error signal

$$\text{proportional gain} = \frac{\text{output}}{\text{input}}$$

proportional band $\longleftarrow$ $P_B = \dfrac{100}{K_p}$ $\longrightarrow$ proportional gain

$\rightarrow$ Offset or SSE (Steady state Error)

M-2

Q. Sensors

A.
- → Element which produces signal relating to quantity being measured
- → Converts signals from one energy domain to electrical domain
- → 3 crucial parts
  - i) sensing element
  - ii) Conduction of signals and processing
  - iii) sensor interface

sensors ⟶ computer ⟶ output

Q. Classification of sensors

A. Based on physical properties :-
- → Active (Require external power)
- → passive (no external power to operate)
- → Analogue (continuous output signal)
- → Digital (discrete binary output signal)

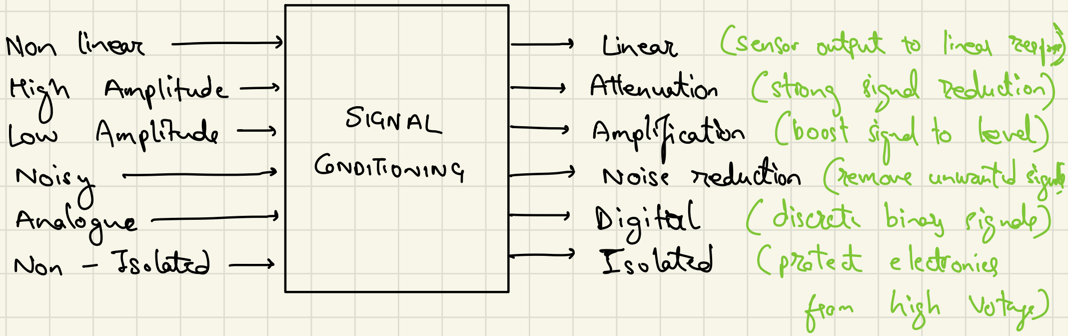
Classification
- → Primary Input quantity (Measurand)
- → Transduction principles (Physical & Chemical effects)
- → Material & Technology
- → Property
- → Application

Q. Selection of sensors

A.
- → Ranges available
- → Sensitivity
- → Squaring system
- → Max working temperature
- → Mounting details
- → Max depth
- → Natural frequency
- → Linearity & Hysteresis

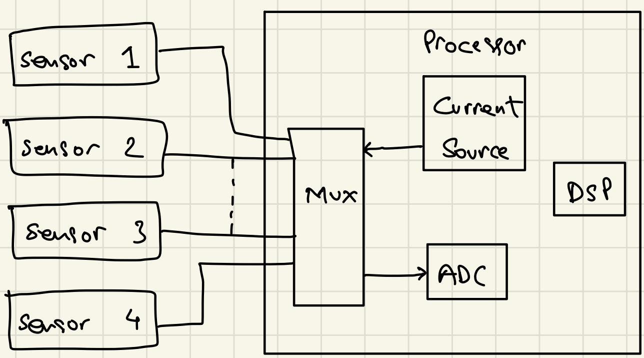
Q. Need of Signal Conditioning

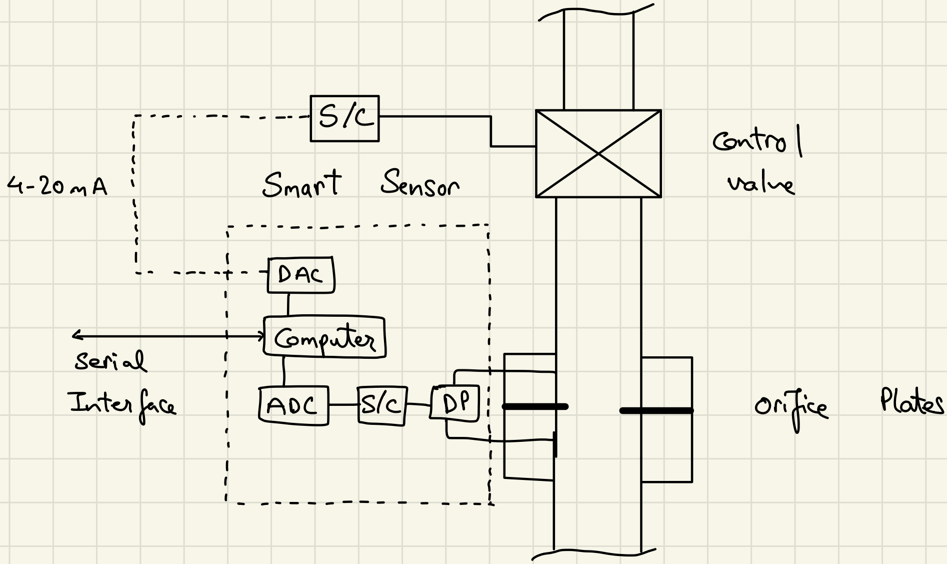
LAANDI



Q. Working of smart sensor with example.

A. Smart sensor → Combine signal conditioning & microprocessors





→ Sensor & computer housed at site of measurement

→ feedback signal delivered to valve via 4-20 mA current transmission

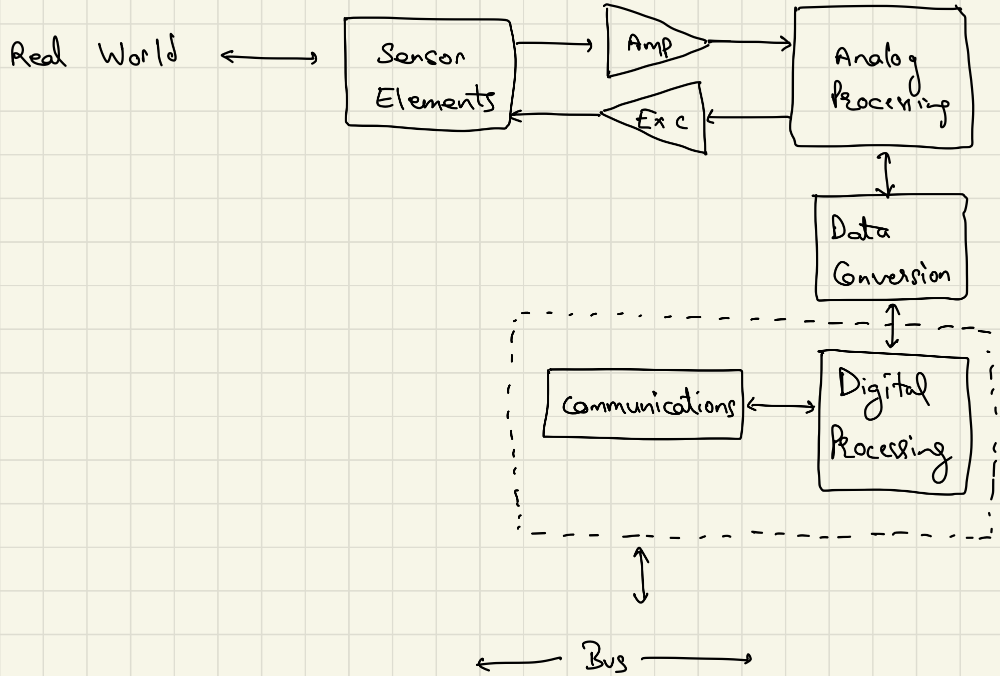
→ operation of flow control loop monitored via serial interface

9

Q. Architecture & capabilities of Intelligent Sensors

→ capable of modifying its internal behaviour to optimize collection of data from real world along with advanced learning capabilities.

→ device that combines sensing element & signal processor in single integrated circuit



→ Capabilities

i) Self calibration & diagnostic
modifying internal behaviour to optimize collection of data

ii) Compensation
Adjust gain by means of programmable gain amplifiers

iii) Computation
signal conditioning, signal conversion etc

iv) Integration
coupling of sensing & computation at chip level

Q. Fuzzy logic based system

A. → Computational approach that deals with uncertainty and imprecision by allowing for degrees of truth rather than strict binary true / false values

Example :- Fuzzy logic based Washing machine controller

→ Problem Statement

adjust wash cycle duration & water temp based on level of dirtiness

→ Fuzzfication

crisp input variable (dirt) → fuzzy sets

→ Degree of dirt

i) Low ii) Med iii) High

→ Rule - based Inference

If - then rules

→ If dirt low Then duration short & water temp cold

etc.

→ Defuzzification

fuzzy set → crisp output value

various methods like COG method

Q. Feed - forward neural networks

A. Structure

→ Input layer receives initial data or features
→ Hidden layers perform computations, not exposed
→ Output layers produce final result of computation

Characteristics

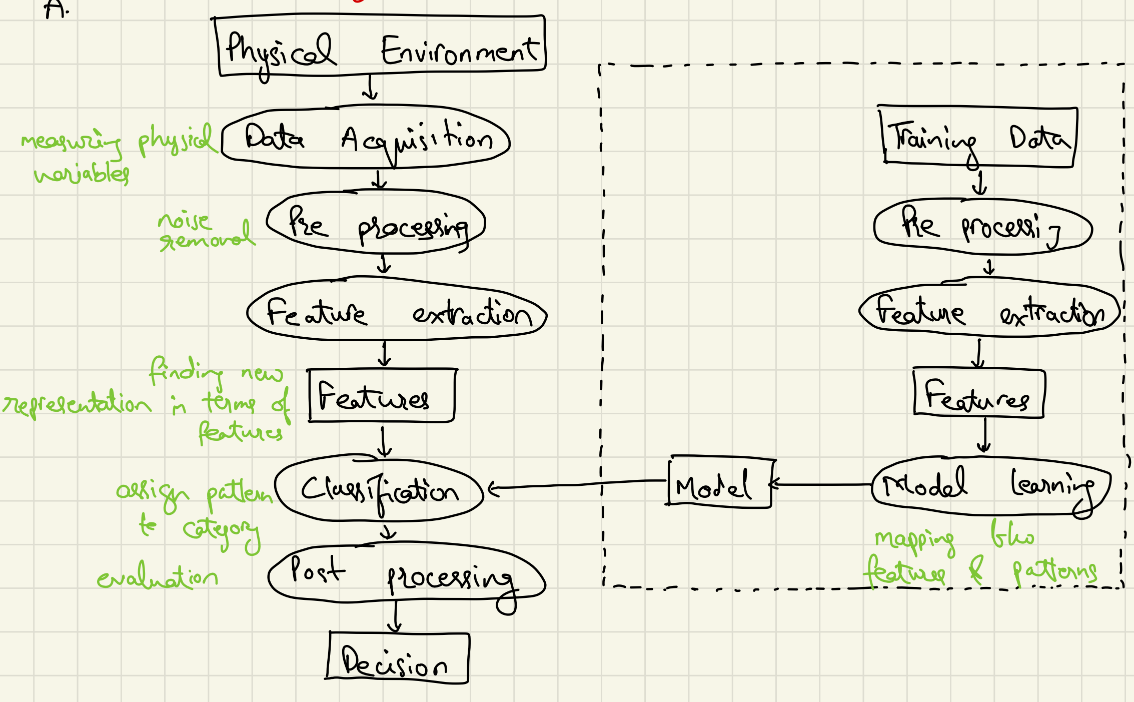
→ Feed forward propagation info flows from input → hidden → O
→ Neurons & activation func^n weighted sums to inputs
→ Weights & biases these determine strength of connection
→ Training & Back Propagation to adjust weights & biases to minimize error

Application

→ Classification image, text
→ Regression prediction of house prices, stock

Q. Pattern recognition system PDP FF CPD

A.



Q. Design cycle

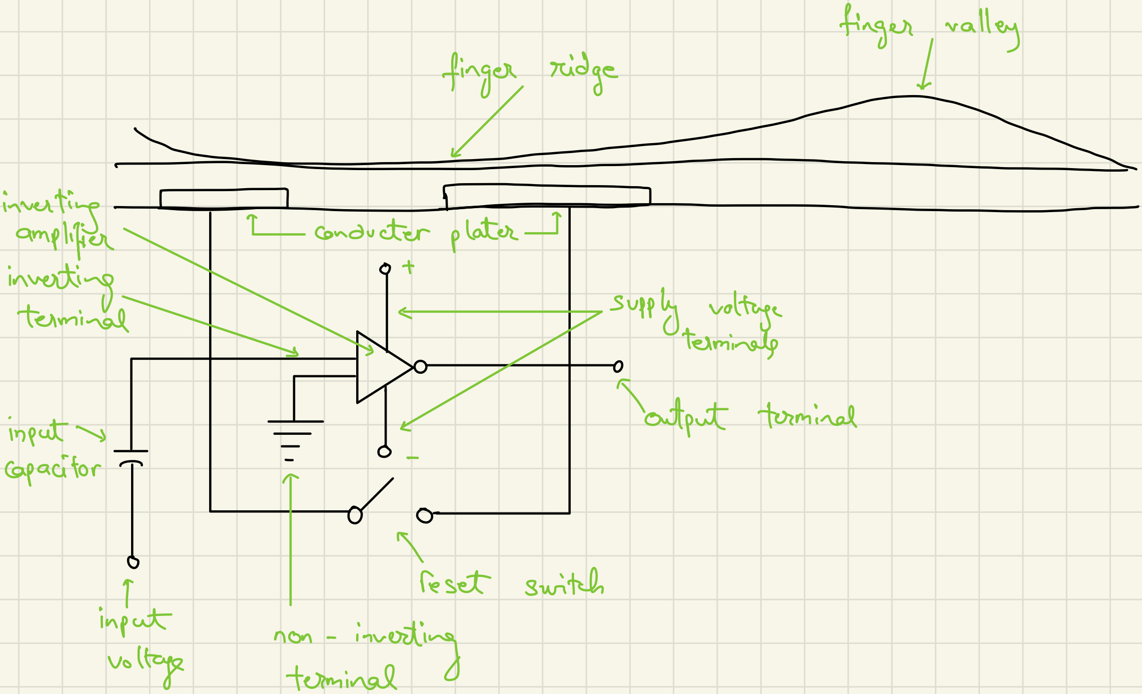
Collect Data → Select features → Select Model → Train classifier → Evaluate classifier

Collect Data: training & testing data 80 - 20

Train classifier: supervised, unsupervised, reinforcement

Evaluate classifier: estimate performance & error

Q. Fingerprint scanner



Q. Benefits of CISS Sensor

A. Connected Industrial Sensor Solution

→ Real-Time Monitoring real-time data temp, humid, pressure

→ Predictive Maintainance analyzing data, predic equipment failure

→ Remote monitoring accessed and monitored remotely

→ Improved efficiency optimize process, reduce waste

→ Reduced Downtime predictive maintainance reduce downtime

→ Environmental Benefits reduced energy consumptions

Q. Classification of control system

A. Objective

→ Regulator / Process Control

→ Servomechanism

Configuration

→ Open loop

→ Closed loop

Signal

→ Analog

→ Digital

PID Controller

Proportional :- One to one correspondence

Integral :- → Reduce the offset error
→ make system sluggish
→ $I = K_i \int_0^t e(t)\, dt$

→ only constant error not changing error

Derivative :- → works wrt rate of change of error but not in constant error
→ how fast to reach desired output

Inverse Derivative Controller :- → derivative :- output $\propto$ rate of change of error

inverse :- output $\propto \dfrac{1}{\text{rate of change of error}}$

Controller

Parallel
P + I + D

Ideal
(Non - interacting)
P(I + D)

PD Controller

- $p = K_p e_p + K_p K_D \frac{de_p}{dt} + p_0$
- handle fast load changes
- no removal of offset error

PID Controller

- all do not work simultaneously
- error changing – PD works
- error is constant → PI works
- $$p = K_p e_p + K_p K_I \int_0^t e_p dt + K_p K_D \frac{de_p}{dt} + p_I(0)$$
(ideal)

$$u = K_p e_p + K_I \int_0^t e_p dt + K_D \frac{de_p}{dt}$$
(parallel)

Implementation of Controllers :–

CD Johnson (UNIT 9 & 10)

Class Participation

Q. State the equation for digital PID controller. Compare the velocity form with position form implementation with PID.

TEE

Actuators → Handbook Unit 20

Unit 1
Unit 2 } Devdas shetty { Unit 1, Unit 2

Unit 3 PPT

Unit 4 → Handbook unit 20

Unit 5 → x 2 PPTs

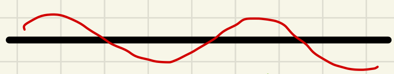
PID Tuning

Methods :-

- → Trial - and - Error Tuning
- → Ziegler – Nichols Tuning
  - ↳ Continuous cycling method
  - ↳ Process reaction curve method
    - ↓ self regulation
    - (tank level :- point where inlet & outlet would be same to regulate)

Continuous cycling method

→ tune it till you get sustained oscillations



(Constant frequency & amplitude)

→ Remember formula of tables

→ Three mode = PID

Ziegler - Nichols Reaction Curve

→ avoid cycling (valve can't be cycling (open or close))

Frequency Response Method

→ Bode Plot

UNIT - 5

ADVANCED CONTROL TECHNIQUES

Bela Liptak

Adaptive Control

→ tune itself according to change in error

Predictive Control

→ Like feed-forward

Model Predictive Control

→ meet control challenges of refineries
→ multivariable controller

Adaptive Control

→ self tuning

TEE

Block Diagram Modelling

Direct Method

Q. $T(s) = \dfrac{Y(s)}{R(s)} = \dfrac{s^2 - 3s + 4}{s^4 + 2s^3 - 5s^2 + 2s - 9}$

$$y(0) = 1 \qquad \ddot{y}(0) = 6$$
$$\dot{y}(0) = -2 \qquad \dddot{y}(0) = 3$$

A. i) State variable $x(t)$

$$r(t) \longrightarrow \boxed{\dfrac{1}{s^4 + 2s^3 - 5s^2 + 2s - 9}} \xrightarrow{x(t)} \boxed{s^2 - 3s + 4} \longrightarrow y(t)$$

order = 4

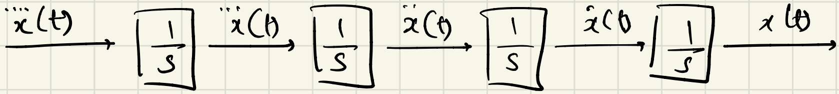
ii) State Equation :-

$$SE = \frac{x(t)}{r(t)} = \frac{1}{s^4 + 2s^3 - 5s^2 + 2s - 9}$$

$$r(t) = s^4 x(t) + 2s^3 x(t) - 5s^2 x(t) + 2s\, x(t) - 9x(t)$$

$$r(t) = \frac{d^4}{dt^4} x(t) + 2\frac{d^3}{dt^3} x(t) - 5\frac{d^2}{dt^2} x(t)$$
$$+ 2\frac{d}{dt} x(t) - 9\,x(t)$$

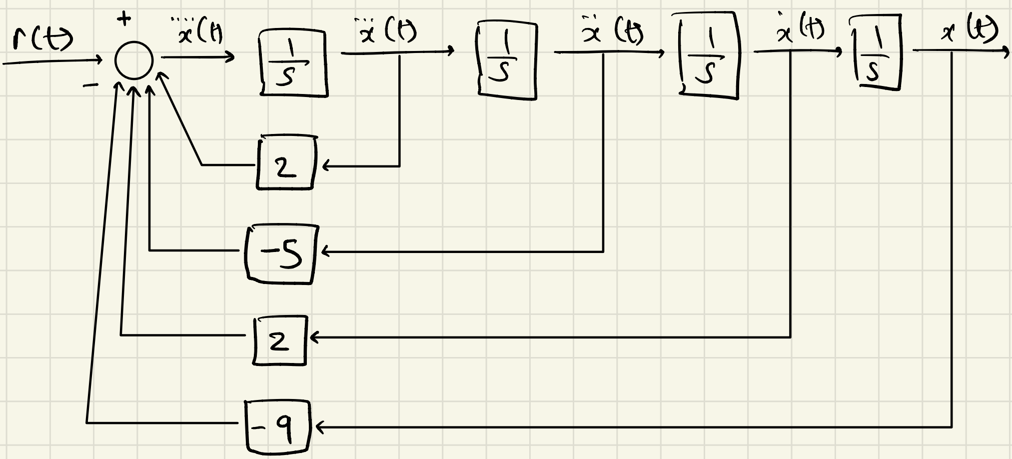
iii) Primary block diagram (ignore initial conditions)



iv) State Variable

$$\frac{d^4}{dt^4} x(t) = -2\frac{d^3}{dt^3} x(t) + 5\frac{d^2}{dt^2} x(t)$$
$$-2\frac{d}{dt} x(t) + 9x(t) + r(t)$$

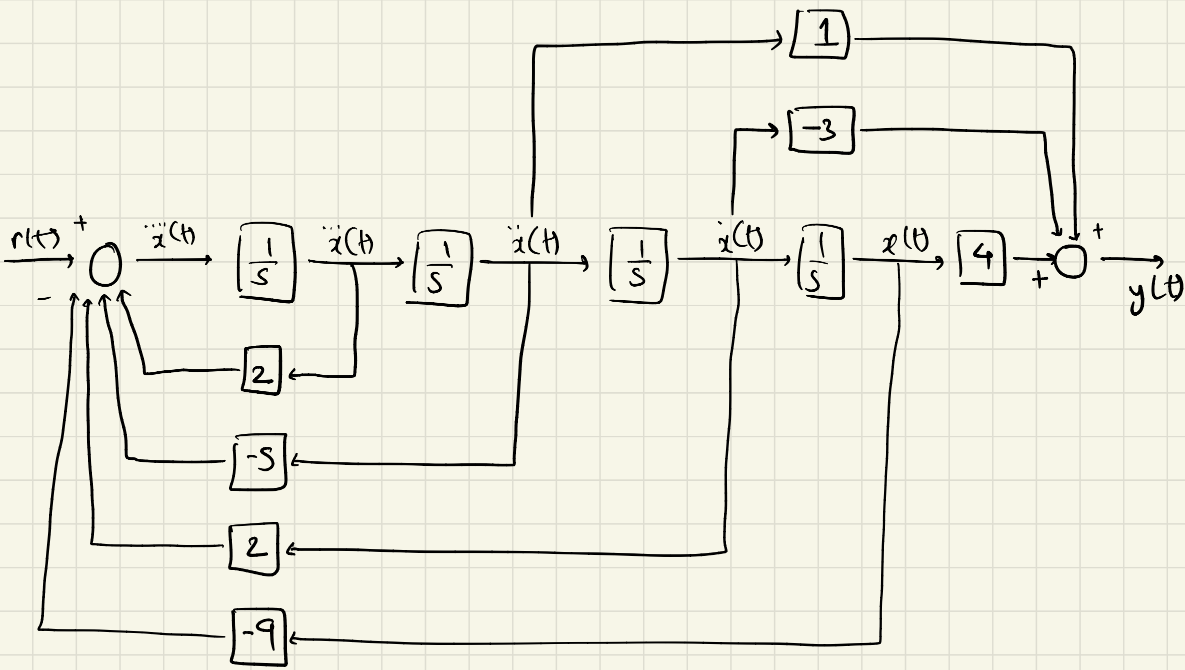
Add summing junction & gain blocks



v) OE → $\dfrac{y(t)}{x(t)} = s^2 - 3s + 4$

$$y(t) = \frac{d^2 x(t)}{dt^2} - 3\frac{d}{dt}x(t) + 4x(t)$$

$$y(t) = \ddot{x}(t) - 3\dot{x}(t) + 4x(t)$$



vi) Initial conditions

$$\ddot{x}(t) - 3\dot{x}(t) + 4x(t) = y(t)$$

From this,

$$\ddot{x}(0) - 3\dot{x}(0) + 4x(0) = y(0) = 1 \longrightarrow ①$$
$$\dddot{x}(0) - 3\ddot{x}(0) + 4\dot{x}(0) = \dot{y}(0) = -2 \longrightarrow ②$$
$$\ddddot{x}(0) - 3\dddot{x}(0) + 4\ddot{x}(0) = \ddot{y}(0) = 6 \longrightarrow ③$$

Substituting $\frac{d^4}{dt^4}x(t)$ in ③,

$$\left[-2\dddot{x}(0) + 5\ddot{x}(0) - 2\dot{x}(0) + 9x(0) + r(0)\right] - 3\dddot{x}(0) + 4\ddot{x}(0) = \ddot{y}(0) = 6$$

$$-5\dddot{x}(0) + 9\ddot{x}(0) - 2\dot{x}(0) + 9x(0) + r(0) = \ddot{y}(0) = 6 \longrightarrow ④$$

$$-5\ddddot{x}(0) + 9\dddot{x}(0) - 2\ddot{x}(0) + 9\dot{x}(0) + \dot{r}(0) = \dddot{y}(0) = 3 \longrightarrow ⑤$$

Again substitute $\frac{d^4}{dt^4}x(t)$ in ⑤,

$$-5\left[-2\dddot{x}(0) + 5\ddot{x}(0) - 2\dot{x}(0) + 9x(0) + r(0)\right] + 9\dddot{x}(0) - 2\ddot{x}(0) + 9\dot{x}(0) + \dot{r}(0) = \dddot{y}(0) = 3$$

$$19\dddot{x}(0) - 27\ddot{x}(0) + 19\dot{x}(0) + 45x(0) + \dot{r}(0) - 5r(0) = \dddot{y}(0) = 3$$

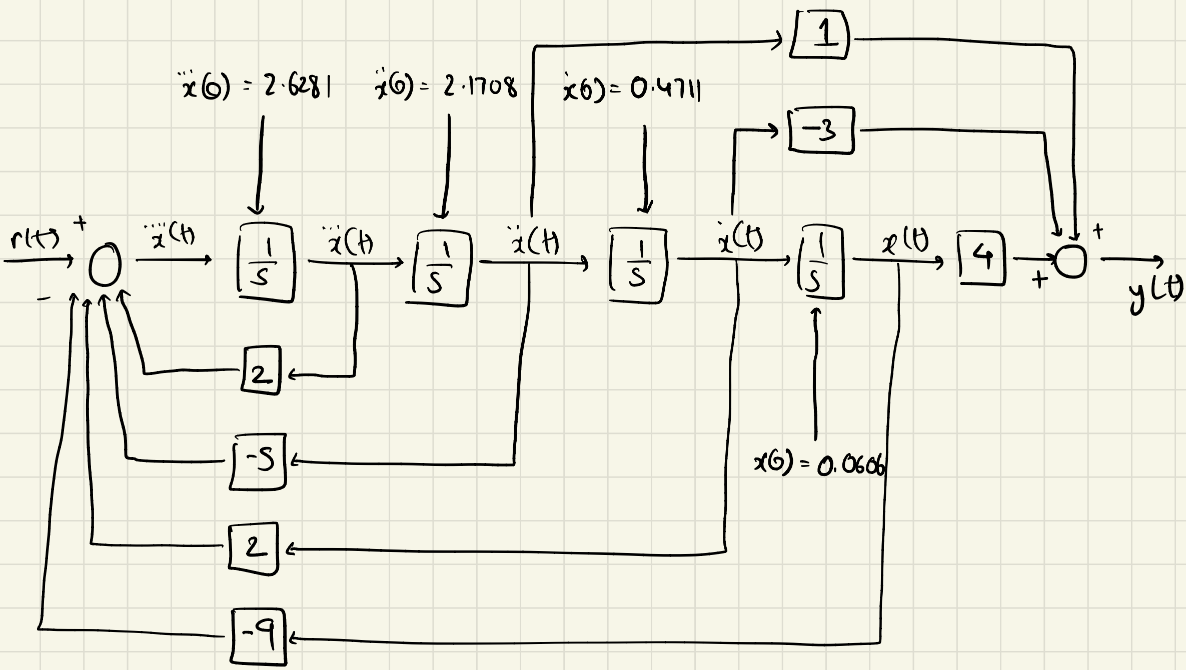
consider $r(0) = 0$

Then, $\dot{r}(0) = 0$

So,

$$\begin{bmatrix} 0 & 1 & -3 & 4 \\ 1 & -3 & 4 & 0 \\ -5 & 9 & -2 & 9 \\ 19 & -27 & 19 & 45 \end{bmatrix} \cdot \begin{bmatrix} \dddot{x}(0) \\ \ddot{x}(0) \\ \dot{x}(0) \\ x(0) \end{bmatrix} = \begin{bmatrix} y(0) = 1 \\ \dot{y}(0) = -2 \\ \ddot{y}(0) = 6 \\ \dddot{y}(0) = 3 \end{bmatrix}$$

$$\begin{bmatrix} \dddot{x}(0) \\ \ddot{x}(0) \\ \dot{x}(0) \\ x(0) \end{bmatrix} = \begin{bmatrix} 2.6281 \\ 2.1708 \\ 0.4711 \\ 0.0606 \end{bmatrix}$$



Q. $T(s) = \frac{Y(s)}{R(s)} = \frac{3}{5s^2 + 8s + 13}$

$y(0) = 2$

$\dot{y}(0) = -2$

A. i) $T(s) = \frac{Y(s)}{R(s)} = \frac{3}{5} \frac{1}{s^2 + \frac{8}{5}s + \frac{13}{5}}$

$= 0.6 \frac{1}{s^2 + 1.6s + 2.6}$

State Variable, $x(t)$

$$r(t) \longrightarrow \boxed{\frac{1}{s^2 + 1.6s + 2.6}} \xrightarrow{x(t)} \boxed{0.6} \xrightarrow{y(t)}$$

order $= 2$

ii) $\frac{x(t)}{r(t)} = \frac{1}{s^2 + 1.6s + 2.6}$

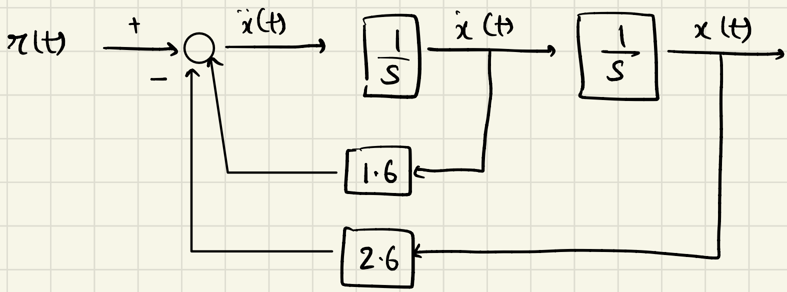
$r(t) = \ddot{x}(t) + 1.6\,\dot{x}(t) + 2.6\,x(t)$

iii)

$$\xrightarrow{\ddot{x}(t)} \boxed{\frac{1}{s}} \xrightarrow{\dot{x}(t)} \boxed{\frac{1}{s}} \xrightarrow{x(t)}$$

iv) $\ddot{x}(t) = -1.6\,\dot{x}(t) - 2.6\,x(t) + r(t)$

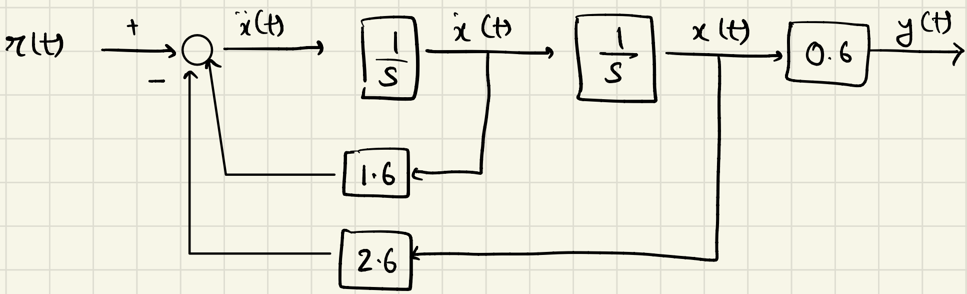
So,



v) OE :

$$\frac{y(t)}{x(t)} = 0.6$$

$$y(t) = 0.6\ x(t)$$



vi) $y(0) = 2$, $\dot{y}(0) = -2$

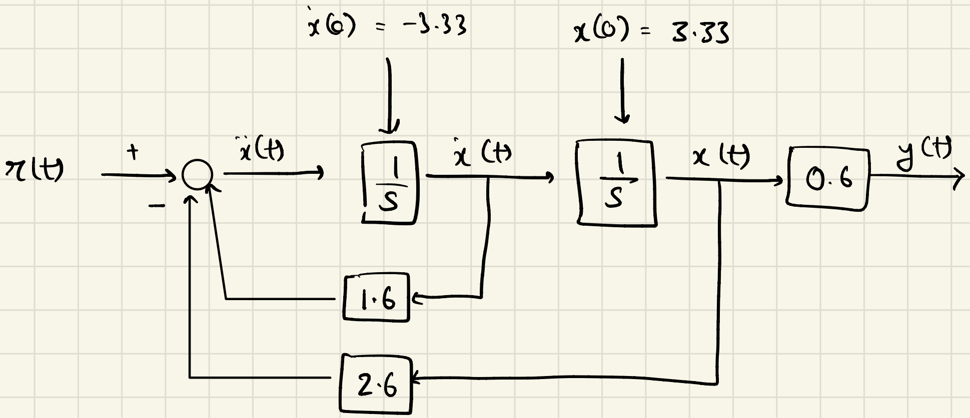
$$y(t) = 0.6\ x(t)$$

$$0.6\ x(0) = y(0) = 2$$

$$x(0) = 3.33 \longrightarrow ①$$

$$0.6\,\dot{x}(0) = \dot{y}(0) = -2$$

$$\dot{x}(0) = -3.33 \longrightarrow ②$$



UNIT 1

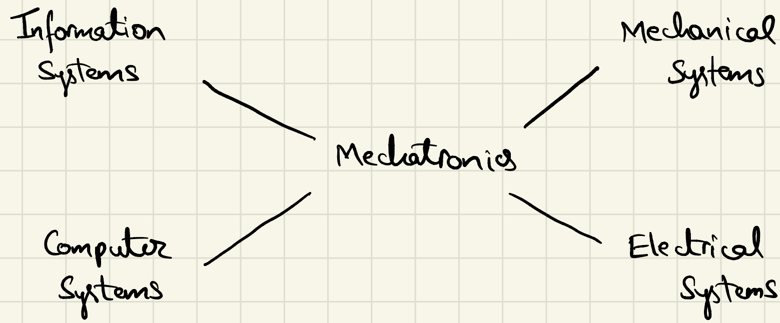
Q. Compare mechatronic system with electromechanical systems.

A.

Mechatronic Systems	Electromechanical Systems
→ Integration of mechanical, electrical, computing and control	→ Combination of mechanical & electrical components
→ Use of microcontrollers, software, and feedback systems	→ Moderate use of simple electronic control
→ Systems often have feedback and automated features.	→ Mostly manual or simple automated processes
→ System design for multifunctionality & adaptability	→ Design focused on specific mechanical - electrical interactions
→ More complex due to integration of various technologies	→ Simpler in comparision, focusing on fundamental interaction.
→ Application :- Robotics, automotive industry	→ Application :- Motors, generators, relays

Q. Discuss and explain with neat diagram the mechatronics constituents

A.



Information Systems :-
Includes all aspects of information transmission, from signal processing to control systems to analysis techniques

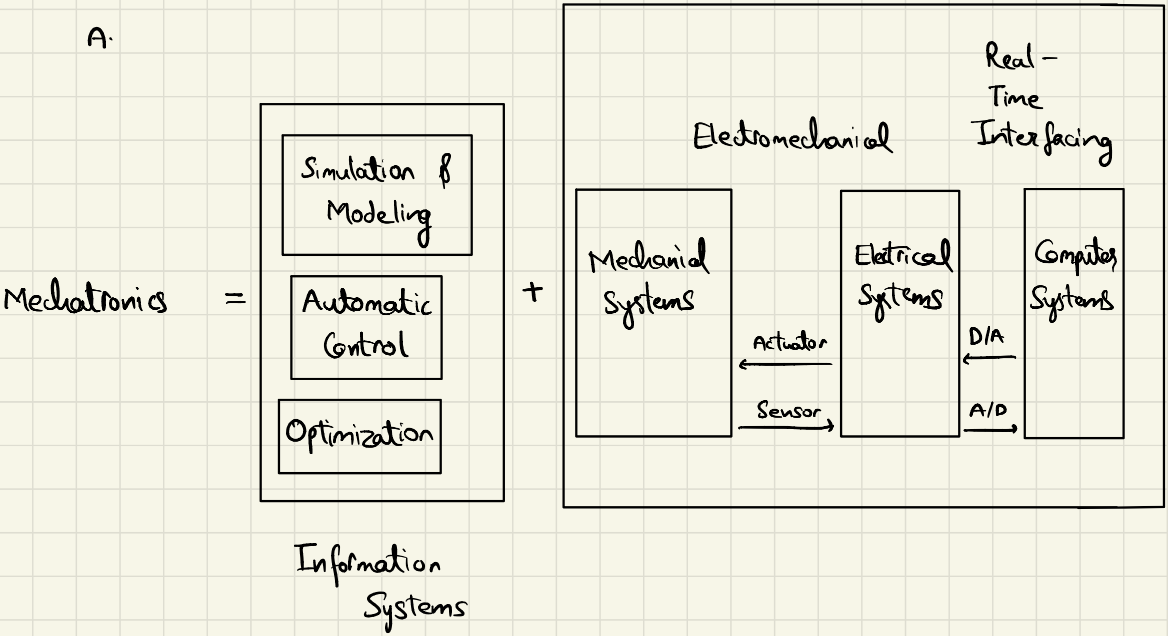
Mechanical Systems :-
Concerned with behaviour of matter under action of forces. Failure analysis and mechanics of materials are major fields based on deformable body systems.

Electrical Systems :-
Concerned with behaviour of 3 fundamental quantities : charge, current and voltage. Consist of two categories : power systems and communication systems.

Computer Systems :-
It processes input data from sensors, executes control algorithms, and manages the output to actuators. This allows the system to perform complex tasks, make decisions, and adapt to changing conditions.

Q. Mechatronic Key Elements

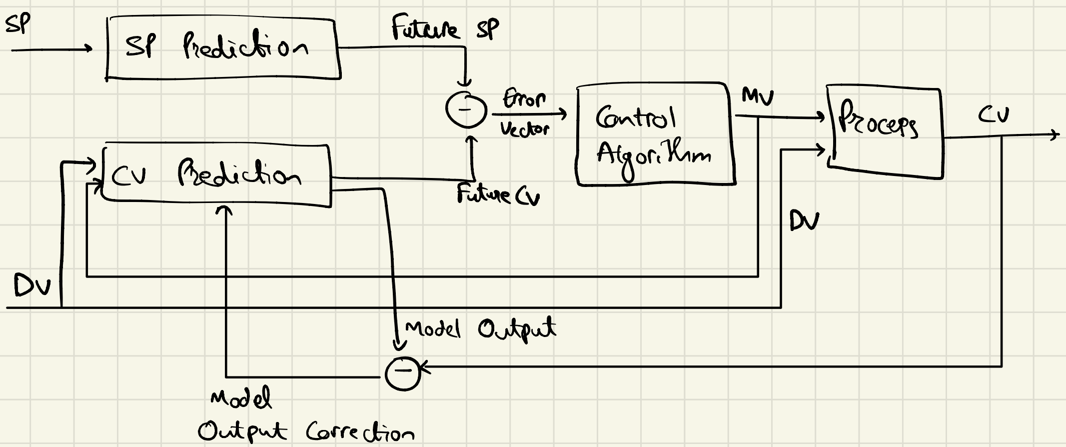
A.



i) Simulation & modeling

TEE : UNIT 5

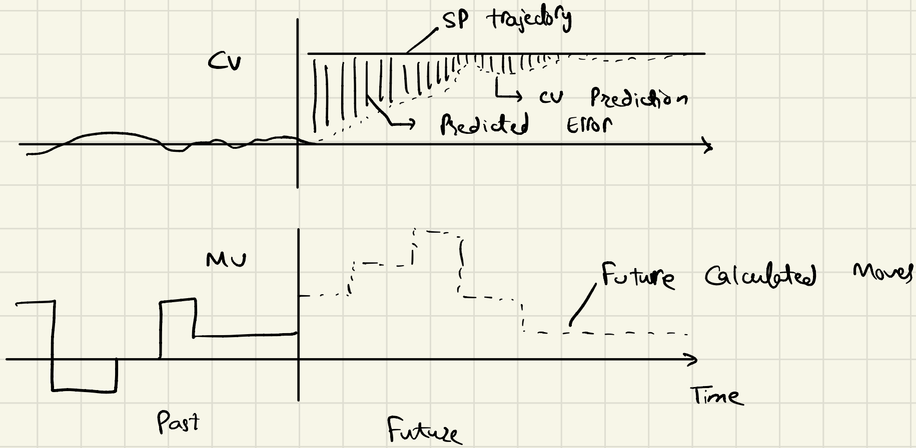
Model Predictive Control



→ Uses a model of the system to predict its future behaviour & make control decisions accordingly.

→ Makes predictions about what's going to happen in the near future then analyze diff actions it could take and predicts outcome of each action. Picks the best (efficient & safest) possibility to achieve its goal. Does it over & over to account for changes.

→ The Predictive Control Algo develops outputs to minimize sum of squared errors considering several future MV.



Adaptive Control

→ System that automatically designs a control system.

→ AC involves the automatic detection of changes that occur in the process parameters or in the SP & readjustment of the controller settings, thereby adapting the tuning of the loop to the changing conditions.

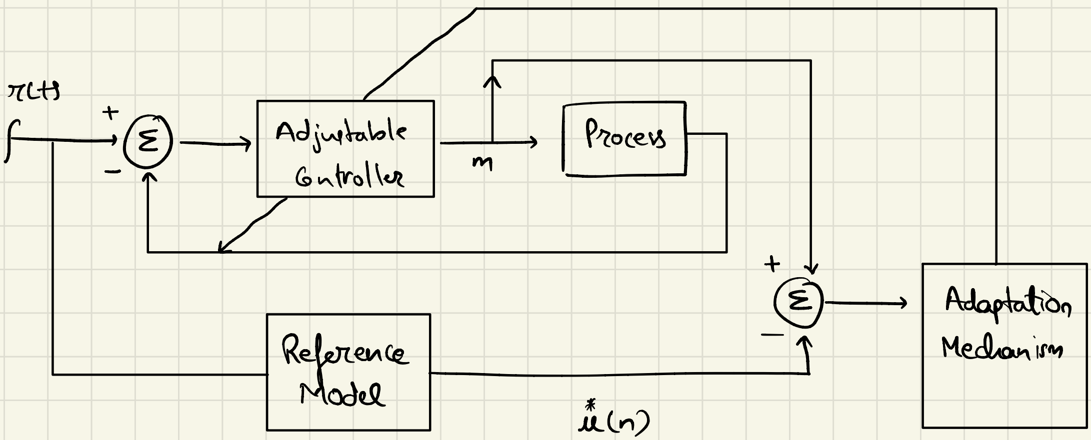
→ Adaptation can be based on :-

i) inputs entering the process, where the system is adjusted on basis of measurement of DV, called feed forward adaptation

ii) Closed loop Performance, where the system uses a measurement of its own performance, called feedback adaptation.

→ Approaches to AC
i) feed forward adaptation
ii) feedback adaptation
iii) MRAC
iv) Intelligent adaptive techniques

Model Reference Adaptive Controller



→ composed of reference model, which specifies desired performance, adjustable controller, whose performance should be as close to that of reference model; and an adaptation mechanism.

→ Adaptation mechanism processes error b/w reference model and real process in order to modify parameter of adjustable controller accordingly

Controller

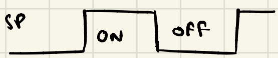
Controller

Discontinuous

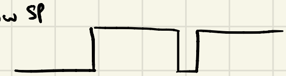
- ON/OFF (2 Pos)
  - → $P = 0\%$ $E_p < 0$
    $P = 100\%$ $E_p > 0$
  - → var b/w 2 limits
  - → switch output on/off based on MV below / above SP

Continuous

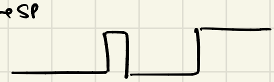
- → Time Proportional
  - → output cont. switched ON/OFF . PWM
  - → $\frac{T_{ON}}{T_{TOTAL}\ (T_{ON} + T_{OFF})}$ = Duty Cycle
  - → Speed Control of DCM
  - → AT SP



Below SP



Above SP

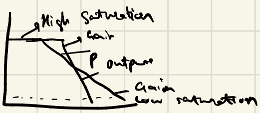


- → Amplitude Proportional

Proportional | Integral | Derivative | PI | PD | PID

Proportional

$P = K_P E_P + P_0$

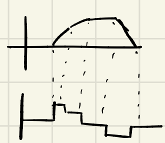


Integral

$I = K_I \int_0^t e_p\, dt + P_0$

Derivative

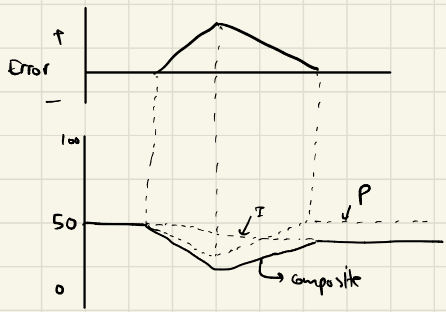
$p = K_D \dfrac{de_p}{dt}$



PI

- → Combine P & I
- → eleminate offset of P
- → action sluggish increase response time
- → Start-up, overshoot of error & output before settling

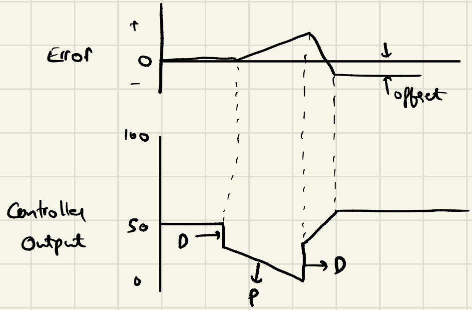
$$p = K_p e_p + K_p K_I \int_0^t e_p \, dt + P_0$$



PD

- → no elemination of offset by P
- → handle fast process load changes

$$p = K_p e_p + K_p K_D \frac{de_p}{dt} + P_0$$



PID

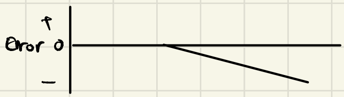
→ all not work continuously
→ error changing → PD works
→ error constant → PI works

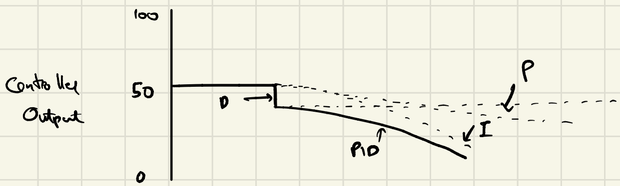
$$P = K_p e_p + K_p K_I \int_0^t e_p \, d\tau + K_p K_D \frac{de_p}{dt} + P_0$$

(ideal)

$$P = K_p e_p + K_I \int_0^t e_p \, d\tau + K_D \frac{de_p}{dt} + P_0$$

(parallel)





Fine Tuning

Adjust :-
i) Gain (P)
ii) Reset rate (I)
iii) Rate (D)

TEE : UNIT 4

Solenoid

→ Coil energized, magnetic field induced inside the coil

→ $$F \propto \frac{i^2}{\delta^2}$$

F ← magnetic force

i^2 ← applied current

δ^2 ← air gap

Motors

- MOTOR
  - DC
    - Permanent Magnet
    - Electromagnet
      - Shunt wound
      - Series wound
      - Compound wound
      - Separate wound
  - AC
    - 1P
      - Induction
      - Synchronous
    - Poly Phase
      - Induction
      - Synchronous
    - Universal
  - Stepper
    - Permanent
    - Variable Reluctance
    - Hybrid
  - Brushless DC
    - Poly Phase
      - Synchronous

Q. Integrated design issues of mechatronics

A. → Since Mechatronics involves concurrent approach to design discipline, it relies heavily on system modeling & simulation throughout design & prototyping stages.

→ Because the model would be altered by engineers from various disciplines, it is essential that the model is programmed in a visually intuitive environment.

→ Such environment include block diagrams and flowcharts.

→ Block diagram environment is extremely versatile, low cost and often includes a code generator option, which translates block diagram to a high level language like C.

→ Integration within a mechatronic system is performed through the combination of hardware & software