(3) $(-K_1)\theta_1 + (J_2 s^2 + D_3 s + k + M r^2 s^2 + \cancel{f_v r^2 s}$
$f_v r^2 s + K_2 r^2)\theta_2 - (D_3 s)\,\theta_3(s)$

$$\begin{bmatrix} J_1 s^2 + K_1 & -K_1 & 0 \\ -K_1 & \begin{matrix} M r^2 s^2 + f_v r^2 s + K_2 r^2 \\ + J_2 s^2 + D_3 s + K_1 \end{matrix} & -D_3 s \\ 0 & -D_3 s & J_3 s^2 + D_3 s \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix} = \begin{bmatrix} T(s) \\ 0 \\ 0 \end{bmatrix}$$

Relation is b/w θ_2 & $T(s)$

using crammer rule.

$$\frac{\begin{vmatrix} J_1 s^2 + K_1 & T(s) & 0 \\ -K_1 & 0 & -D_3 s \\ 0 & 0 & J_3 s^2 + D_3 s \end{vmatrix}}{\begin{vmatrix} J_1 s^2 + K_1 & -K_1 & 0 \\ -K_1 & \begin{matrix} M r^2 s^2 + f_v r^2 s + K_2 r^2 \\ + J_2 s^2 + D_3 s + K_1 \end{matrix} & -D_3 s \\ 0 & -D_3 s & J_3 s^2 + D_3 s \end{vmatrix}} = \frac{\theta_2(s)}{T(s)}$$

$$\begin{vmatrix} J_1 s^2 + K_1 & -K_1 & 0 \\ -K_1 & \begin{matrix} M r^2 s^2 + f_v r^2 s + K_2 r^2 \\ + J_2 s^2 + D_3 s + K_1 \end{matrix} & -D_3 s \\ 0 & -D_3 s & J_3 s^2 + D_3 s \end{vmatrix} = \Delta$$

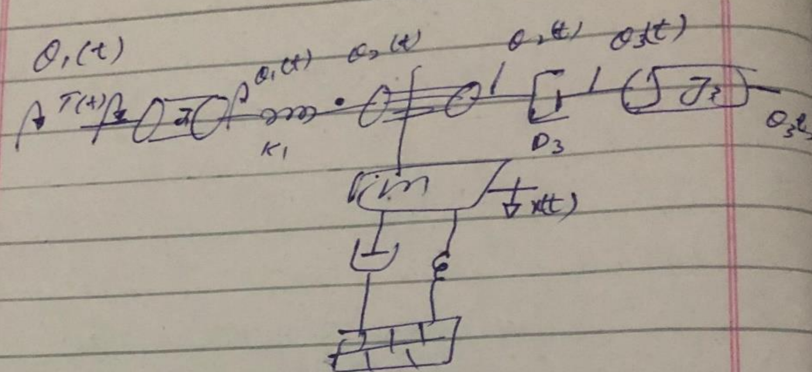
$$\frac{\theta_2(s)}{T(s)} = \frac{-(-K_1)(T_s)(D_3 s + J_3 s^2)}{\Delta}$$

$X(s) = r\,\theta_2(s)$

$$\boxed{\frac{X(s)}{T(s)} = \frac{K_1 (D_3 s + J_2 s^2)}{\Delta}}$$

step 1 : Linearly independent displacements

$\theta_1(t)$



$\frac{X}{T(s)} = ?$

$x(t) = r\theta_2(t)$

Eq!

eq 1

① $J_1 s^2 \theta_1(s) + K_1\theta_1(s) - k_1\theta_2(s) = T(s)$

$J_2 S^2 \theta_2(s) + K_1\theta_2 - k_1\theta_1 + D_3 s\theta_2$

$- D_3 s\theta_3 = r f(s)$

② $J_3 S^2 \theta_3(s) + D_3 s\theta_3(s) - D_3 S\theta_2(s) = 0$

$xt = r\theta_2(t)$

$Ms^2 X(s) + f_v s X(s) + K_2 X(s) = F(s)$

$J_2 S^2 \theta_2(s) + K_1\theta_2(s) - K_1\theta_1(s) + D_3 S\theta_2(s) - D_3 S\theta_3(s) - r(Ms^2 X(s)$

$+ f_v s X(s) + K_2 X(s))$

$(J_2 S^2 + D_3 S + K)\theta_2(s) - (K_1)\theta_1(s) -$

$r(Ms^2 + f_v s + K_2) r\theta_2 - (D_3 S)\theta_3(s)$

16-october-24

diff → TF → (ap → statespace.

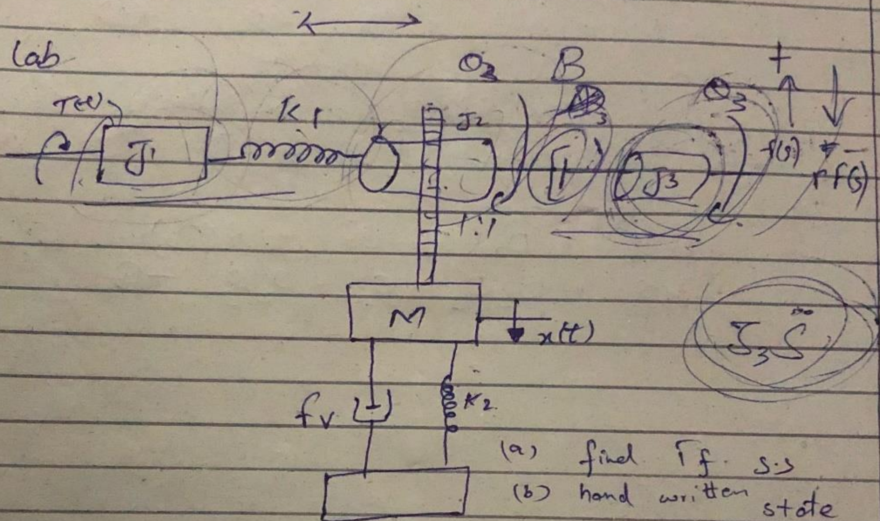
CEP (Example of multibody Parametric model)

Pedal, Potentiometer, SS, Buck → V_B, motor

$$\frac{X(s)}{SI(s)} \times \frac{I(s)}{X(s)} \times \frac{D}{V_p(s)} \times \frac{V}{D} \times \frac{\omega}{V}$$

$$\frac{\omega}{E(s)}$$

lab



(a) find Tf. s.s
(b) hand written state equation
(c)
(d)
(e)

$(J_1 s^2 + K) - K = T$

① $(J_1 s^2 + K_1)\theta_1 - (K)\theta_2 = T(s)$

② $(J_3 S^2 + Bs)\theta_3 - B\theta_2 = 0$

③ $\left(J_2\ddot{\theta}_2 + K_1\theta_2 + D_3\theta_2\right) - K_1\theta_1 - D_3\dot{\theta}_3 = -rf(s)$

$\because x = r\theta_2$

$M\ddot{x} + f_v\dot{x}_2 + K_2 x = f(s)$

$Mr\ddot{\theta}_2 + f_v r\dot{\theta}_2 + K_2 r\theta_2 = f(s)$ lines

```
clc ;

% Transfer function (Theta_gear(s) / T(s))
num = [1];          % Numerator
den = [J1 0 k1];    % Denominator

% Create transfer function
sys_tf = tf(num, den)

% State-space matrices
A = [0 1 0 0 0 0;
   -k1/J1 0 k1/J1 0 0 0;
   0 0 0 1 0 0;
   k1/(J2+m*r^2) 0 -(k1+k2*r^2)/(J2+m*r^2) -(fv*r^2+d3)/(J2+m*r^2) 0 d3/(J2+m*r^2);
   0 0 0 0 0 1;
   0 0 0 d3/J3 0 -d3/J3];

B = [0; 1/J1; 0; 0; 0; 0];
C = [1 0 0 0 0 0];
D = 0;

% Create the state-space system
sys_ss = ss(A, B, C, D);

%% Part A Variant Torque

clc;clear;
```

```
TR = [0 50];
X0 = [0;0;0;0;0;0];

k1=50;k2=50;fv=50;d3=30.5;T=40;m=15;J1=20;J2=10;J3=16;r=7.5;

for T=10:5:30

    [t,y]= ode45(@(t,y)randFun2(t,y,T,J1,J2,J3,m,r,fv,k1,k2,d3),TR,X0);

    thGear=y(:,3);
    omGear=y(:,4);

    x=r*thGear;
    v=r*omGear;

    % Compute acceleration
    a1 = gradient(v, t);
    a2 = gradient(omGear, t);

    subplot(2,3,4)
    plot(t,thGear)
    hold on
    xlabel('time')
    ylabel('theta-Gear')

    subplot(2,3,5)
    plot(t,omGear)
    hold on
    xlabel('time')
```

```
    ylabel('Angular velocity-Gear')

    subplot(2,3,1)
    plot(t,x)
    hold on
    xlabel('time')
    ylabel('displacement')

    subplot(2,3,2)
    plot(t,v)
    hold on
    xlabel('time')
    ylabel('velocity')

    subplot(2,3,3)
    plot(t, a1)
    hold on
    xlabel('time')
    ylabel('Acceleration-1')

    subplot(2,3,6)
    plot(t, a2)
    hold on
    xlabel('time')
    ylabel('Angular acceleration-Gear')

end

for i=1:6
```

```
subplot(2,3,i);legend('10N Torque', '15N Torque', '20N Torque','25N Torque', '30N Torque')
end


%%  Part B Variant Radius


clc;
clear;
TR = [0 50];
X0 = [0;0;0;0;0;0];
k1=50;k2=50;fv=50;d3=30.5;T=40;m=15;J1=20;J2=10;J3=16;r=7.5;
for r=1:1:8
    [t,y]=ode45(@(t,y)randFun2(t,y,T,J1,J2,J3,m,r,fv,k1,k2,d3),TR,X0);

    thGear=y(:,3);
    omGear=y(:,4);
    x=r*thGear;
    v=r*omGear;

    % Compute acceleration
    a1 = gradient(v, t);
    a2 = gradient(omGear, t);

    subplot(2,3,4)
    plot(t,thGear)
    hold on
    xlabel('time')
    ylabel('theta-Gear')
```

```
subplot(2,3,5)
plot(t,omGear)
hold on
xlabel('time')
ylabel('Angular velocity-Gear')

subplot(2,3,1)
plot(t,x)
hold on
xlabel('time')
ylabel('displacement')

subplot(2,3,2)
plot(t,v)
hold on
xlabel('time')
ylabel('velocity')

subplot(2,3,3)
plot(t, a1)
hold on
xlabel('time')
ylabel('Acceleration-1')

subplot(2,3,6)
plot(t, a2)
hold on
xlabel('time')
ylabel('Angular acceleration-Gear')
```

```
end

for i=1:6

subplot(2,3,i);legend('1m radius', '2m radius', '3m radius','4m radius', '5m radius', '6m radius', '7m
radius', '8mradius')

end



function dy= randFun2(t,y,T,J1,J2,J3,m,r,fv,k1,k2,d3)

dy(1)=y(2);

dy(3)=y(4);

dy(5)=y(6);

dy(2)=1/J1*(T - k1*y(1) + k1*y(3));

dy(4)=1/(J2+m*r*r)*(k1*y(1) - (d3+fv*r^2)*y(4) -(k1+k2*r^2)*y(3) + d3*y(6));

dy(6)=1/J3*(d3*(y(4)-y(6)));

dy=dy';

end
```