EXAM

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Problem 9:

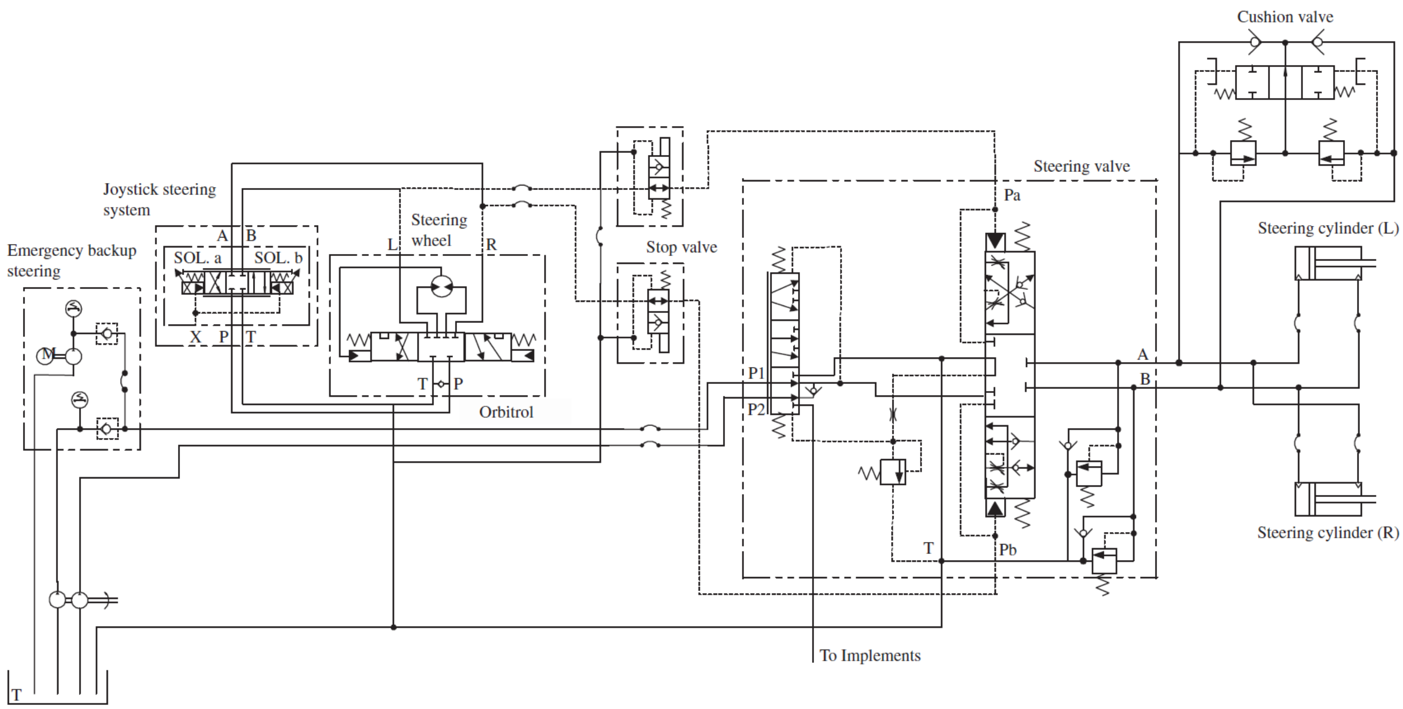


FIGURE 7.120: Hydraulic schematics for hand metering unit (HMU) steering system of wheel loader model WA450-5L by Komatsu.

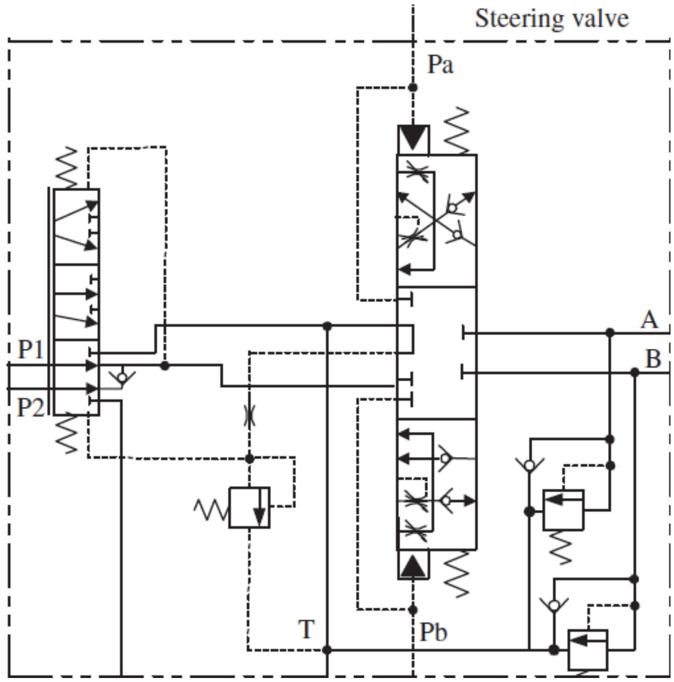
A) Circuit Workings:

Pumps:

i. The circuit has two unidirectional hydraulic pumps. They are fixed displacement pumps.
ii. A rotating shaft operates the pump. The function of Pump P1 is steering and function of Pump P2 is Compensator pump for steering and other implementations.
iii. These pumps utilize the hydraulic fluid from the Tank. This pressurized fluid is sent first to the valve which has the proportional function and further it is then sent to the valve which has the steering function.

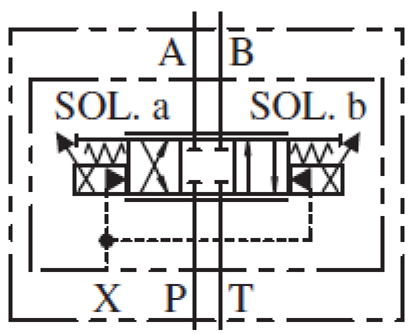
Different cases in Proportional Valve:

i. Very large P1 value:
When P1 is very and the valve moves completely down. In this condition the high-pressure liquid is sent to the tank directly without damaging the cylinder with high pressure fluids.
ii. Higher steering demand condition (P2>P1):
For the P2>P1 case the function of steering is handled by a combination of the 2 pumps by opening a check valve , the check valve will open, and flow from both the pumps will be added to serve the steering function. This happens when P1<P2, so the pressure is compensated by the pump P2.
iii. Optimum P1 conditions:
When P1 is optimum, the proportional valve is shifted to the middle condition and the pump P1 is connected to the steering valve. The pump P2 will serve the implementation function.



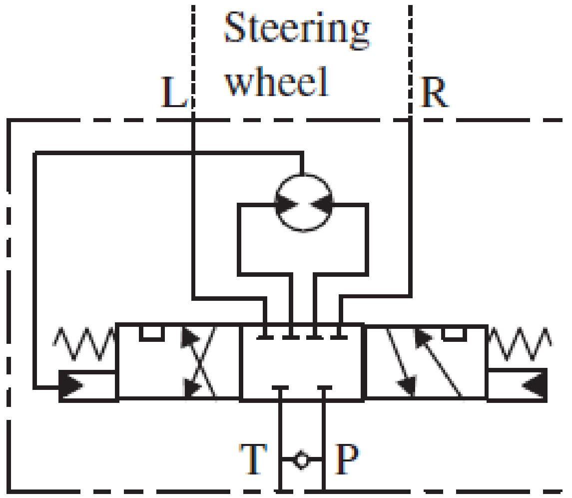
Joy-stick steering System:

This system has a proportional valve. During operation Solenoids A and B modulate pressurized flow of liquid by changing the steering valve positions. Safety valves open during cases of excess pressure.

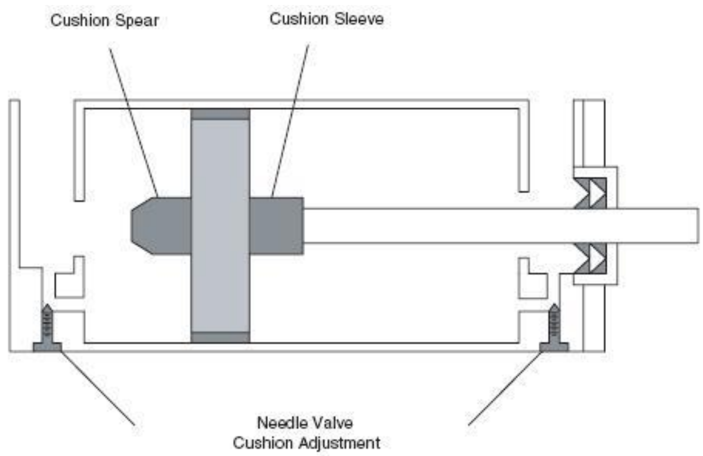


Steering wheel:
a) When the steering wheel turns right:
On right turn of steering, Steering valve is pushed down by flow of Fluid from P -> motor -> stop valve -> L . This is the top condition of steering. Line A is connected by P1 and P2. Position of Left cylinder and right cylinder are right and left respectively. The axle is turned to the right by these operations and thus vehicle turns right. Fluid of line B goes to the Tank.

b) When Steering wheel turns left:
On left turn of steering, Steering valve is pushed up by flow of Fluid from P -> motor -> stop valve -> R . This is the Bottom condition of steering. Line B is connected by P1 and P2. Position of Left cylinder and right cylinder are left and right respectively. The axle is turned to the left by these operations and thus vehicle turns left. Fluid of line A goes to the Tank.



CUSHION Valve:

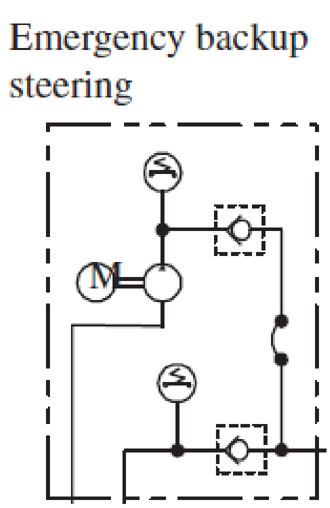


Cushioning of some sort normally is required to decelerate a cylinder's piston before it strikes the end cap. The stresses on the components reduces when velocity of piston is lowered on end cap approach thus reducing the vibration transmitted to the machine structure.

B)

Emergency BACKUP Steering:

When pressure P1 < Pmin condition or in P1 failure condition the emergency backup is activated for use . The function of backup is to provide steering control in failure condition by supplying fluid in pressurized conditions.

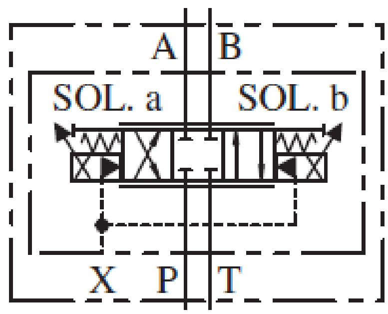


Operation of Emergency Backup steering:

i. The emergency backup steering block consists
   a. electric motor
   b. a pump
   c. 2 check valves
   d. Two valves which sense pressure.
ii. In $P1 < P_{min}$ condition steering failure is possible.
iii. To avoid this pump and electric motor supplies the pressurized fluid required through P1.
iv. After P_{pump} reaches specified safe value upper check valve is activated by opening it to continue the fluid flow through P1.
v. The pressure sensing valve settings and the check valve settings are adjusted for emergency situation operation of pump and motor.

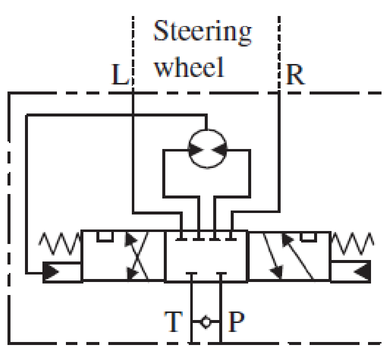
C)

a) JOYSTICK Steering System:



i. In this system the solenoids operate the PDC valves (Proportional Directional control).
ii. Joystick movement to right:
   a. Connection of P line to B line.
   b. Direction of flow of fluid B -> stop valve -> Pa. Upper case is used.
   c. P1 is connected to A moving axle and thus vehicle to right.
iii. Joystick movement to left:
   a. Connection of P line to A line.
   b. Direction of flow of fluid A -> stop valve -> Pb. Down case is used.
   c. P1 is connected to B moving axle and thus vehicle to Left.

b) Steering Wheel Orbitrol based System:



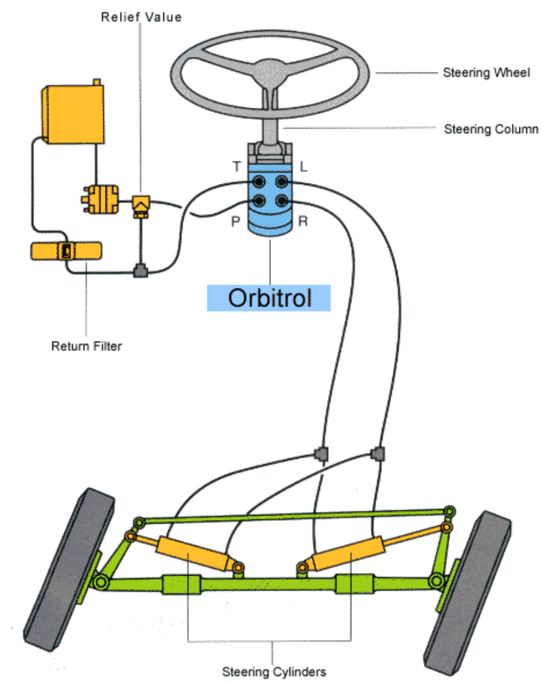
i. Steering wheel rotation α Flow of oil to L port and R port.
ii. No movement of steering L and R cylinders:
   a. Proportional valve in the bottom condition.
   b. Steering wheel in straight orientation.
   c. This results in equal lines A and B pressure.

iii. Right turn of steering:

When the steering wheel turns right: On right turn of steering, Steering valve is pushed down by flow of Fluid from P -> motor -> stop valve -> L . This is the top condition of steering. Line A is connected by P1 and P2. Position of Left cylinder and right cylinder are right and left respectively. The axle is turned to the right by these operations and thus vehicle turns right. Fluid of line B goes to the Tank.

iv. Left turn of steering:

On left turn of steering, Steering valve is pushed up by flow of Fluid from P -> motor -> stop valve -> R . This is the Bottom condition of steering. Line B is connected by P1 and P2. Position of Left cylinder and right cylinder are left and right respectively. The axle is turned to the left by these operations and thus vehicle turns left. Fluid of line A goes to the Tank.



Problem 10:

i) $\frac{d}{dt}(p_A(t)) = \frac{\beta}{V_{hose,VA} + y \cdot A_A}(Q_{PA}(t) - \dot{y}(t) A_A) = 0$

$\Rightarrow \quad Q_{PA}(t) - \dot{y}(t) A_A = 0$

$\dot{y}(t) = \frac{Q_{PA}(t)}{A_A} \quad -(1)$

$\frac{d}{dt}(p_B(t)) = \frac{\beta}{V_{hose,VB} + (l_{cyl} - y) \cdot A_B}(-Q_{BT}(t) + \dot{y}(t) \cdot A_B) = 0$

$\Rightarrow \quad \dot{y}(t) = \frac{Q_{BT}(t)}{A_B} \quad -(2)$

$\frac{d}{dt}(p_P(t)) = \frac{\beta}{V_{hose,PU} + V_{acc}}[Q_P(t) - Q_{PA}(t) + Q_r(t) + Q_{acc}(t) + Q_{PT}(t)] = 0$

$Q_{PT}(t) = 0 \quad , Q_{acc}(t) = 0$

$\Rightarrow \quad Q_P(t) = Q_r(t) + Q_{PA}(t) \quad -(3)$

$Q_P(t) = D_P \cdot \omega_{pump}(t) \quad -(4)$

$Q_{PT}(t) = \sqrt{p_P(t) - p_T(t) / \Delta P_r} = 0$

$p_P(t) = p_T(t) \quad -(5)$

$Q_{PA}(t) = Q_r \cdot \frac{x_s(t)}{x_{s.max}} \sqrt{\frac{p_P(t) - p_A(t)}{\Delta P_r}} \quad -(6)$

$Q_{BT}(t) = Q_r \cdot \frac{x_s(t)}{x_{s\,max}} \sqrt{\frac{P_B(t) - P_T(t)}{\Delta P_r}} \quad -(7)$

Case I

~~Accum~~ Simplified Model.

$$A_{PA}(x_s) = \frac{20 \times 10^{-6}}{100 - x_{db}} (|x_s| - x_{ab}) \quad - (8)$$

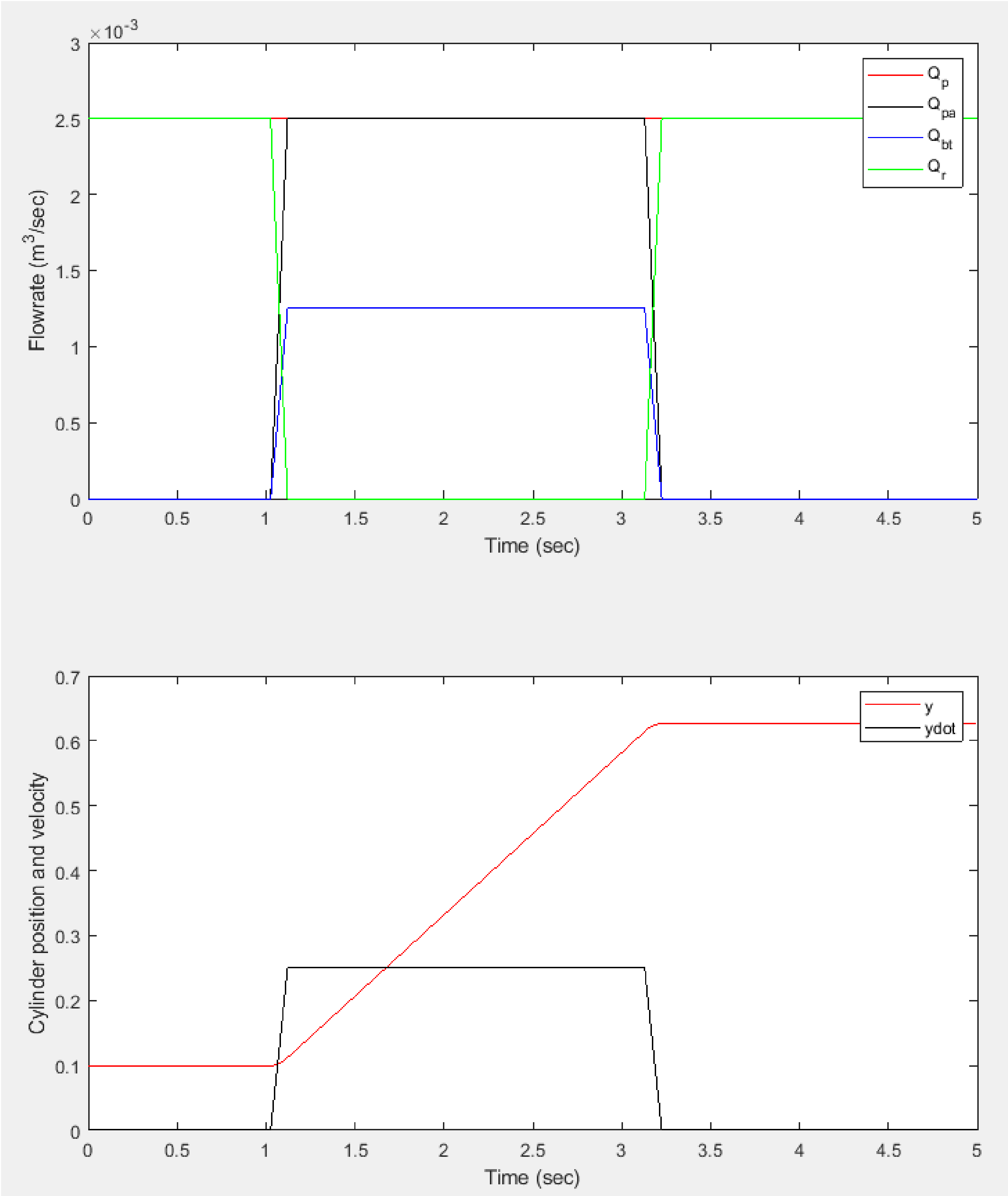
$$A_{BT}(x_s) = \frac{10 \times 10^{-6}}{100 \times x_{ab}} (|x_s| - x_{db}) \quad - (9)$$

$$m\dot{y}(t) = -c\dot{y}(t) + p_A(t) \cdot A_A - p_B(t) \cdot A_B$$
$$- F_{load}(t).$$

```
% CASE1:Simplified Model

global Disp_pump Const_d x_deadband pres_rel K_relief_const ;
global Cyl_Aa Cyl_Ab Cyl_length Cyl_mass c ;
global Q_p Q_pa Q_pb Q_at Q_bt Q_pt Q_r ;
global p_p p_a p_b p_t ;
global y y_diff_dot ;
global Pump_shaft_w ;
global x_shaft Force_load ;

Disp_pump = 0.0001 ;
Const_d= 0.065 ;
x_deadband = 10 ;
warning('off')
pres_rel = 20 * 10^6 ; % Pa
K_relief_const = 0.01 * 10^-6 ;

Cyl_Aa = 0.01 ;

Cyl_Ab = 0.005 ;
Cyl_length=1.0 ;% m
Cyl_mass = 10000 ; % kg
c = 0.0 ; % Pa

% Input Parameters

Pump_shaft_w = 25 ; % input
Force_load= Cyl_mass*9.81; % N

% Cylinder_initial_conditions

y = 0.1 ;
y_diff_dot = 0.0 ;
p_p = pres_rel ; %Pump
p_a = Force_load/Cyl_Aa ;%Tank
p_b = 0.0;
Q_r = Disp_pump * Pump_shaft_w;
```

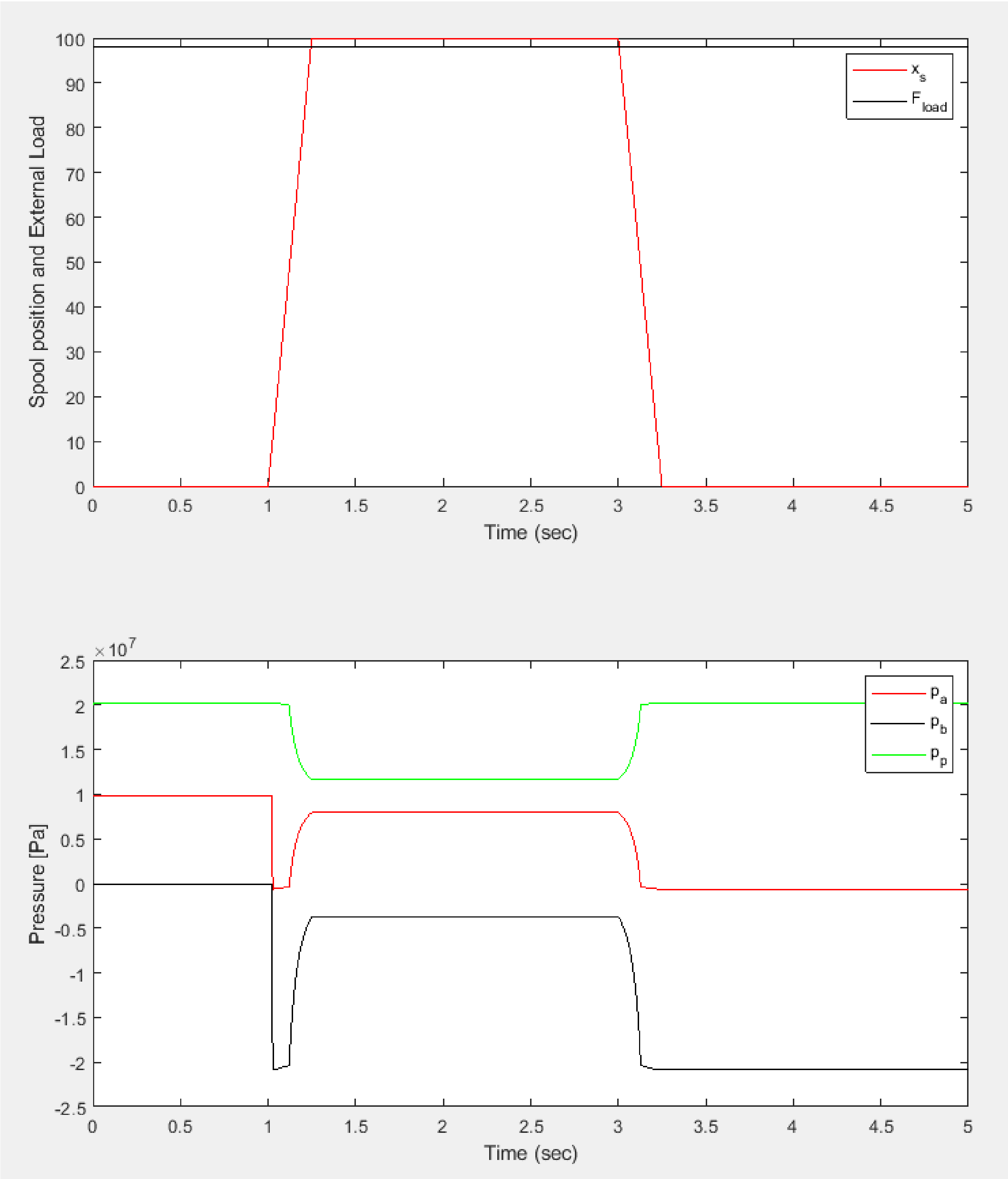
```
p_t = 0.0 ;

t_0 =0.0;
t_f =5.0 ;
t_sample = 0.001;

z=zeros(1);
x =zeros(4) ;

z(1) = y ;
x(1) = y_diff_dot ;
x(2) = p_a ;
x(3) = p_b ;
x(4) = p_p;
z_out=[Q_p Q_pa Q_pb Q_at Q_bt Q_r x_shaft Force_load/1000 y y_diff_dot p_a p_b p_p] ;
for t=t_0: t_sample:t_f
if t<1.0
x_shaft = 0.0 ;
elseif (t>= 1.0 && t<=1.25)
    x_shaft = (100/0.25) *(t-1.0) ;
elseif (t> 1.10 && t<=3.0)
    x_shaft=100 ;
elseif (t> 3.0 && t<=3.25)
x_shaft = 100 - (100/0.25) * (t - 3.0) ;
else
x_shaft = 0.0 ;
end

% Algebraic Equations....
options = optimset('Display','off','TolFun',1e-11,'TolX',1e-10);
x = fsolve(AE_cylinder_case',x,options) ;
y_diff_dot =x(1);
p_a =x(2);
p_b =x(3);
p_p =x(4);

% Solve ODEs...

t_span=[t,t+t_sample] ;
[T,z1] = ode45('cyl_dyn1',t_span, z);
[m,n]=size(z1);
z(:)=z1(m,:) ;
y = z(1);
z_out=[ z_out
    Q_p Q_pa Q_pb Q_at Q_bt Q_r x_shaft Force_load/1000 y y_diff_dot p_a p_b p_p ] ;
end

[m,n]=size(z_out);
t_inc = (t_f-t_0)/m ;
tout = t_0:t_inc:(t_f - t_inc);
tout = tout' ;
figure(1) ;
plot1 ;
```

Result



a) Flow rate vs Time Cylinder

b) Position and velocity vs time



c) Spool position and External Load vs Time
d) Pressure vs Time

Functions used:

```
% cylinder dynamics case1
function z_diff_dot=cyl_dyn1(t,z)
global y y_diff_dot ;
z_diff_dot(1) = y_diff_dot ;
return;
% cylinder AE solver
function F=AE_cylinder_case(x)
global Disp_pump Const_dx_deadband pres_rel K_relief_const ;
global Cyl_Aa Cyl_Ab Cyl_length Cyl_mass c ;
global Q_p Q_pa Q_pb Q_at Q_bt Q_pt Q_r ;
global p_p p_a p_b p_t ;
global y y_diff_dot ;
global Pump_shaft_w ;
global x_shaft Force_load ;

y_diff_dot = x(1);
p_a = x(2);
p_b = x(3);
p_p = x(4);

if abs(x_shaft) >= x_deadband

Cyl_Apa = ((20*10^-6)/(100-x_deadband))* (abs(x_shaft) - x_deadband) ;
Cyl_Apb = (( 10*10^-6)/(100-x_deadband))* (abs(x_shaft) - x_deadband) ;
Cyl_Aat = ((40*10^-6)/(100-x_deadband))* (abs(x_shaft) - x_deadband) ;
Cyl_Abt = ((10*10^-6)/(100-x_deadband))* (abs(x_shaft) - x_deadband) ;
else

Cyl_Apa = 0.0 ;
Cyl_Apb = 0.0 ;
Cyl_Aat = 0.0 ;
Cyl_Abt = 0.0 ;
end

Q_p = Disp_pump * Pump_shaft_w ;
Q_pt = 0.0 ; % closed center valve.
if(x_shaft >= 0.0 )
  Q_pa = Const_d* Cyl_Apa * (abs(p_p - p_a))^0.5 ;
  Q_bt = Const_d*  Cyl_Abt * (abs(p_b - p_t))^0.5 ;
  Q_pb = 0.0 ;
  Q_at = 0.0 ;
else
Q_pb = Const_d* Cyl_Apb * (abs(p_p - p_b))^0.5 ;
Q_at = Const_d*  Cyl_Aat * (abs(p_b - p_t))^0.5 ;
Q_pa = 0.0 ;
Q_bt = 0.0 ;
end

Q_acc = 0.0 ;

% Ideal relief valve, without transient dynamics
% Notice the * 10^6 multiplier to scale the equations to force a
% numerically more accurate solution.
if (p_p < pres_rel)
    Q_r = 0.0 ;
if x_shaft >= 0.0
    F=[ (-c*y_diff_dot+p_a*Cyl_Aa-p_b*Cyl_Ab-Force_load);
         (Q_pa - y_diff_dot * Cyl_Aa) *10^6 ;
         (-Q_bt + y_diff_dot * Cyl_Ab)*10^6;
         (Q_p-(Q_pa + Q_pt + Q_r + Q_acc))* 10^6] ;
```

```
else
    F=[ (-c*y_diff_dot+p_a*Cyl_Aa-p_b*Cyl_Ab-Force_load);
        (-Q_at - y_diff_dot * Cyl_Aa)* 10^6 ;
        (Q_pb + y_diff_dot * Cyl_Ab)* 10^6 ;
        (Q_p-(Q_pb + Q_pt + Q_r + Q_acc))* 10^6 ] ;
end
else
Q_r = K_relief_const * (p_p - pres_rel) ;
if x_shaft >= 0.0
    F = [(-y_diff_dot*c - p_b *Cyl_Ab+ p_a * Cyl_Aa - Force_load);
        (Q_pa - y_diff_dot * Cyl_Aa)* 10^6 ;
        (-Q_bt + y_diff_dot * Cyl_Ab)* 10^6 ;
        (Q_p-( Q_pt + Q_r +Q_pa+ Q_acc))* 10^6 ] ;
else
    F=[ (-c*y_diff_dot+p_a*Cyl_Aa-p_b*Cyl_Ab-Force_load);
        (-Q_at - y_diff_dot * Cyl_Aa)* 10^6 ;
        (Q_pb + y_diff_dot * Cyl_Ab)* 10^6 ;
        (Q_p-(Q_pb + Q_r + Q_pt + Q_acc))* 10^6 ] ;
end
end
return
```

Plot Function

```
plot(1) ;
plot(tout, z_out(:,1), 'k',tout, z_out(:,2), 'b',tout, z_out(:,5), 'm',tout, z_out(:,6),
'c');
xlabel('Time (sec)') ;
ylabel('Flowrate (m^3/sec)') ;
legend('Q_p','Q_{pa}','Q_{bt}','Q_r');

plot(2) ;
plot(tout, z_out(:,7), 'k',tout, z_out(:,8), 'b');
xlabel('Time (sec)') ;
ylabel('Spool position and External Load') ;
legend('x_shaft','F_{load}');

plot(3) ;
plot(tout, z_out(:,9) , 'k',tout, z_out(:,10), 'b');
xlabel('Time (sec)') ;
ylabel('Cylinder position and velocity') ;
legend('y','y_diff_dot');

plot(4) ;
plot(tout, z_out(:,11), 'k',tout, z_out(:,12), 'b',tout, z_out(:,13), 'g');
xlabel('Time (sec)') ;
ylabel('Pressure [Pa]') ;
legend('p_a','p_b','p_p');
```

Case II : Consider cylinder and load inertial dynamics, and fluid compressibility on both pump and load side of the line:

$$A_{PA} = \frac{20\times10^{-6}}{100-x_{db}}\left(|x_s|-x_{db}\right) \quad \text{if } x_s \geq x_{db}$$

$$A_{Pb} = \frac{10\times10^{-6}}{100-x_{db}}\left(|x_s|-x_{db}\right) \; ; \quad \text{if } x_s \leq -x_{db}$$

Discharge :

$$Q_{PB} = \left(Q_r \times \frac{x_s(t)}{x_{s,max}}\right) \times \left(\frac{P_P-P_A}{\Delta P_r}\right)^{1/2}$$

$$Q_{AT} = \left(Q_r \times \frac{x_s(t)}{x_{s,max}}\right) \times \left(\frac{P_b-P_T}{\Delta P_r}\right)^{1/2}$$

System Pressure:

	$x_s \geq 0$	$x_s < 0$
$\frac{d}{dt}(P_a)$	$= \frac{Q_{PA}\beta - \dot{y} A_A \beta}{V_{hose,VA} + y A_A}$	$= \frac{-\beta Q_{AT} - \dot{y}(t) A_A \beta}{V_{hose,VA} + y \cdot A_A}$
$\frac{d}{dt}(P_b)$	$= \frac{-Q_{bt}\beta + \dot{y} A_B \times \beta}{V_{hose,VB} + (l_{cyl}-y) A_B}$	$= \frac{Q_{PB}(t)\beta + \dot{y}(t) A_B \beta}{V_{hose,VB} + (l_{cyl}-y)\cdot A_B}$
$\frac{d}{dt}(P_p)$	$= \frac{Q_P\beta - (Q_{PA}+Q_r)\beta}{V_{hose,PV} + V_{acc}}$	$= \frac{\beta Q_P(t) - \beta(Q_{PB}(t) + Q_r(t))}{V_{hose,PV} + V_{acc}}$

Integrating $\ddot{y}$ to obtain pressure values.

$$m\ddot{y}(t) = -c\dot{y}(t) + P_A(t)\cdot A_A - P_B(t)\cdot A_B - F_{load}(t)$$

$c = 0$

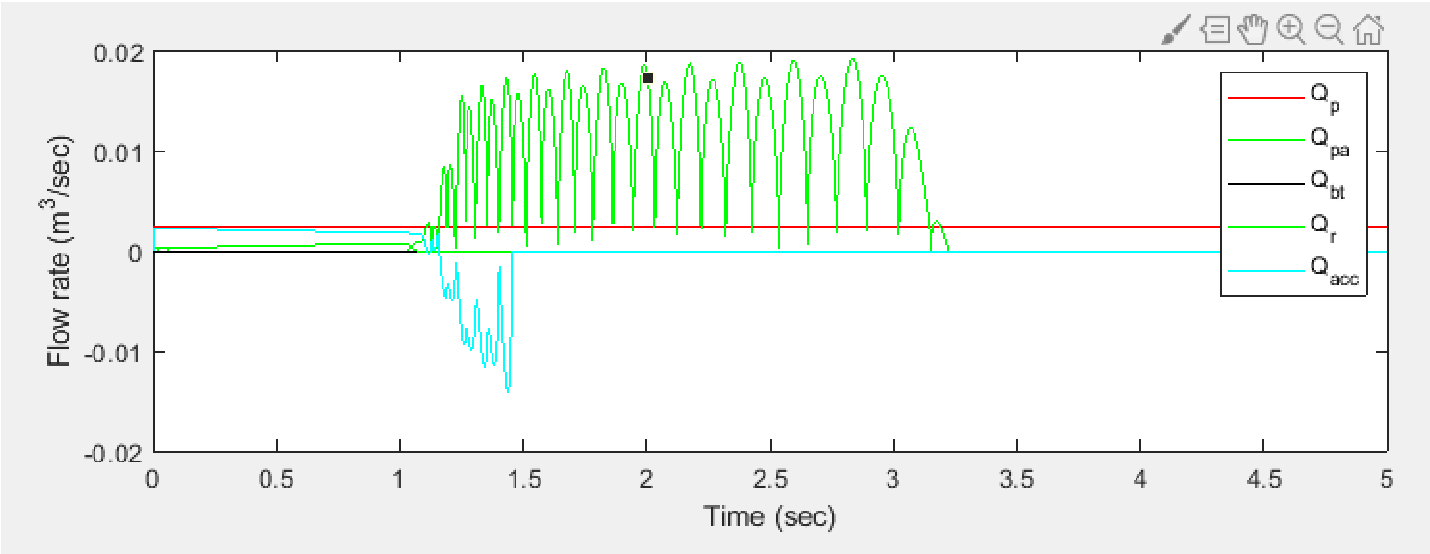
$$\ddot{y}(t) = \frac{p_A(t)\,A_A - p_B(t)\,A_B - f_{load}(t)}{m}$$

$\dot{y}(t)$ & $y(t)$ obtained after integration.

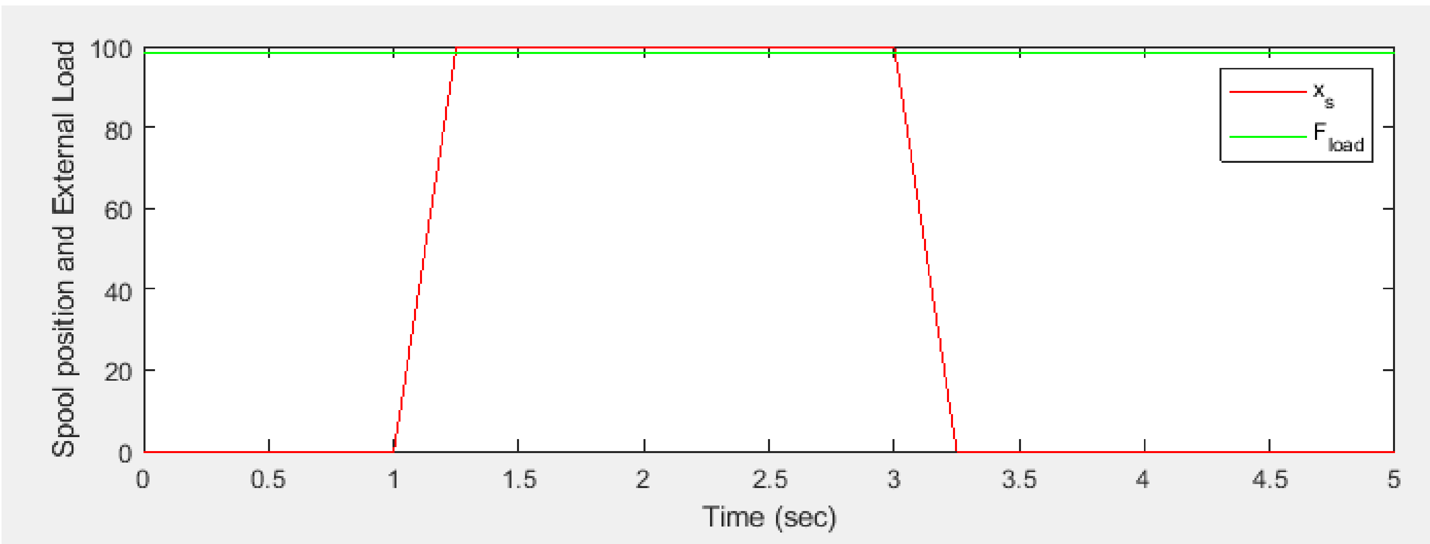
```
% Case2
global Disp_pump Const_dx_deadband pres_rel T_r_p K_relief_const ;
global maxp minp prep Disharge_V Accum_K C_acc;
global Cyl_Aa Cyl_Ab Cyl_length Cyl_mass c ;
global Bulk_modulus Pv_hosevolume Va_hosevolume vb_hosevolume;
global Q_p Q_pa Q_pb Q_at Q_bt Q_pt Q_r Q_acc ;
global p_p p_a p_b p_t accum_p Accum_V ;
global y y_diff_dot ;
global Pump_shaft_w ;
global x_shaft Force_load


% Parameters

Disp_pump = 0.0001 ;
Const_d= 0.065 ;
x_deadband = 10 ;
pres_rel = 20 * 10^6 ; Pa
T_r_p = 0.025 ;
K_relief_const = 0.01*10^-6 ;

maxp = 20*10^6 ;
minp= 15*10^6 ;
prep = 15*10^6 ;
Disharge_V = 0.005 ;
Accum_V = 0.0 ;
Accum_K = 1.0*10^-6 ;
C_acc = Disharge_V/(maxp - p_min) ;

Cyl_Aa = 0.01 ;
Cyl_Ab = 0.005 ;
Cyl_length=1.0 ;% m
Cyl_mass = 10000 ; % kg
c = 10.0 ;

Bulk_modulus = 15.0*(10^8) ;
Pv_hosevolume= 0.0001 ; % m^3
Va_hosevolume= 0.0001 ; % m^3
Vb_hosevolume= 0.0001 ; % m^3

Pump_shaft_w = 25 ; rev/sec
Force_load= Cyl_mass*9.81; % N

y = 0.1 ;
y_diff_dot = 0.0 ;
p_p = 0.0 ;
p_a = Force_load/Cyl_Aa ; % Pa
```

```
p_b = 0.0 ; % Pa
accum_p = minp; %initial fluid volume in the accumulator (Pa)
Accum_V = 0.0 ; % [m^3]
Q_r = 0.0 ;
p_t = 0.0 ; % Tank pressure

t_0 =0.0;
t_f =5.0 ;
t_sample = 0.001;
z=zeros(7,1);
z(1) = y ;
z(2) = y_diff_dot ;
z(3) = p_a ;
z(4) = p_b ;
z(5) = p_p;
z(6) = accum_p ;
z(7) = Accum_V ;
z_out=[Q_p Q_pa Q_pb Q_at Q_bt Q_r Q_acc x_shaft Force_load/1000 z(1) z(2) z(3) z(4) z(5)
z(6)/10^7 z(7)*1000 ] ;
for t=t_0: t_sample:t_f
%Valve spool position
if t<1.0
x_shaft = 0.0 ;
elseif (t>= 1.0 && t<=1.25)
    x_shaft = (100/0.25) *(t-1.0) ;
elseif (t> 1.10 && t<=3.0)
    x_shaft=100 ;
elseif (t> 3.0 && t<=3.25)
x_shaft = 100 - (100/0.25) * (t - 3.0) ;
else
x_shaft = 0.0 ;
end
% ODEs
t_span=[t,t+t_sample] ;
[T,z1] = ode45('cyl_dyn2',t_span, z);
[m,n]=size(z1);
z(:)=[z1(m,:)] ;
0.001 ;
y= z(1);
y_diff_dot =z(2);
p_a =z(3);
p_b =z(4);
p_p =z(5);
accum_p = z(6);
Accum_V = z(7);
z_out=[z_out ;
    Q_p Q_pa Q_pb Q_at Q_bt Q_r Q_acc x_shaft Force_load/1000 z(1) z(2) z(3) z(4) z(5)
z(6)/10^7 z(7)*1000 ] ;
end
[m,n]=size(z_out);
t_inc = (t_f-t_0)/m ;
tout=t_0:t_inc:t_f-t_inc;
tout = tout' ;
figure(2) ;
plot2 ;
```

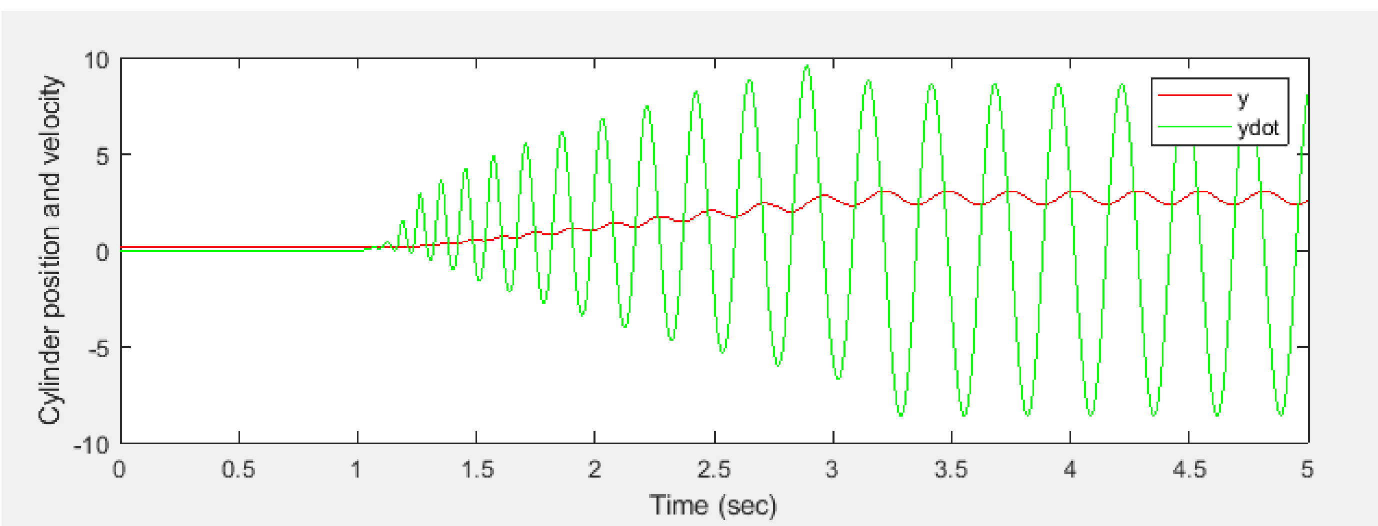
Results



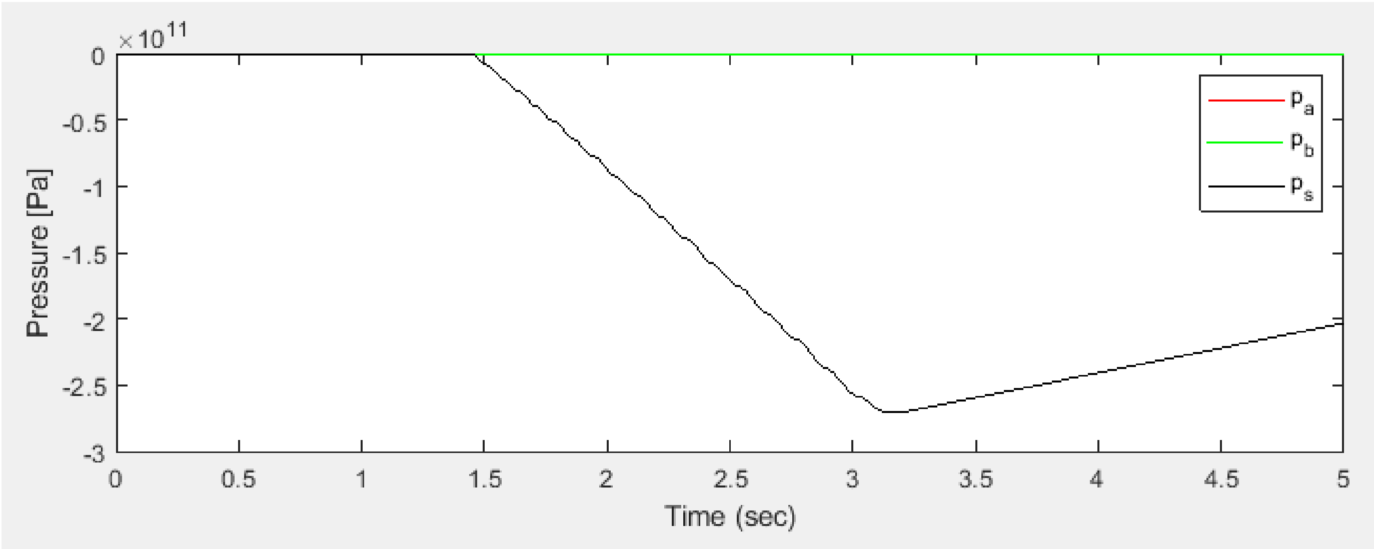
Flow rate vs Time



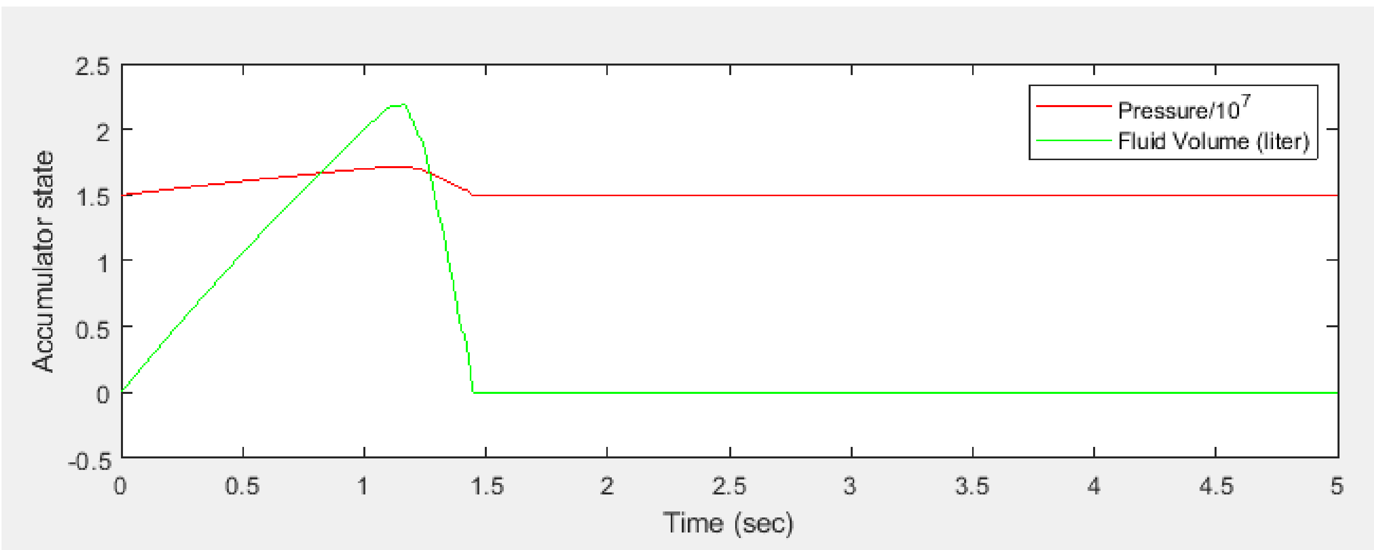
Spool position and External Load vs Time



Cylinder position and velocity vs Time



Pressure vs Time



Accumulator state vs Time

Functions Used:

```
function z_diff_dot=cyl_dyn2(t,z)
global Disp_pump Const_dx_deadband pres_rel T_r_p K_relief_const ;
global maxp minpprep Disharge_V Accum_K C_acc;
global Cyl_Aa Cyl_Ab Cyl_length Cyl_mass c ;
global Bulk_modulus Pv_hosevolumeVa_hosevolumeVb_hosevolume;
global Q_p Q_pa Q_pb Q_at Q_bt Q_pt Q_r Q_acc ;
global p_p p_a p_b p_t accum_p Accum_V ;
global y y_diff_dot ;
global Pump_shaft_w ;
global x_shaft Force_load ;
    y=z(1);
    y_diff_dot =z(2);
    p_a =z(3);
    p_b =z(4);
    p_p =z(5);
    accum_p= z(6) ;
    Accum_V = z(7) ;
```

```
if abs(x_shaft) >= x_deadband
Cyl_Apa = ((20*10^-6)/(100-x_deadband))* (abs(x_shaft) - x_deadband) ;
Cyl_Apb = (( 10*10^-6)/(100-x_deadband))* (abs(x_shaft) - x_deadband) ;
Cyl_Aat = ((40*10^-6)/(100-x_deadband))* (abs(x_shaft) - x_deadband) ;
Cyl_Abt = ((10*10^-6)/(100-x_deadband))* (abs(x_shaft) - x_deadband) ;
else
Cyl_Apa = 0.0 ; Cyl_Apb = 0.0 ; Cyl_Aat = 0.0 ; Cyl_Abt = 0.0 ;
end

% Flow rates
Q_p = Disp_pump * Pump_shaft_w ;
Q_pt = 0.0 ;
if(x_shaft >= 0.0 )
    Q_pa = Const_d* Cyl_Apa * (abs(p_b - p_a))^0.5 ;

    Q_bt = Const_d* Cyl_Abt * (abs(p_b- p_t))^0.5 ;

    Q_pb = 0.0 ;
    Q_at = 0.0 ;
else
     Q_pb = Const_d* Cyl_Apb * (abs(p_p - p_b))^0.5 ;

    Q_at = Const_d* Cyl_Abt * (abs(p_b- p_t))^0.5 ;

    Q_pa = 0.0 ;
    Q_bt = 0.0 ;
end



% with Accumulator
if Accum_V <= 0.0 && p_p < accum_p
    Q_acc = 0.0;
else
    Q_acc= sign(p_p-accum_p)*Accum_K*(abs(p_p-accum_p))^0.5;
end

% Non-Ideal relief valve
if p_p < pres_rel
    Q_r = 0.0 ;
else
Q_r = K_relief_const * (p_p - pres_rel) ;
end

z_diff_dot=zeros(7,1) ;
% ODE
z_diff_dot(1) = y_diff_dot ;
z_diff_dot(2) = (1/Cyl_mass)*(-c * y_diff_dot + p_a * Cyl_Aa - p_b * Cyl_Ab - Force_load)
;
if x_shaft >= 0.0
z_diff_dot(3) = (Bulk_modulus/(Va_hosevolume+ y * Cyl_Aa))*(Q_pa - y_diff_dot * Cyl_Aa) ;
z_diff_dot4=(Bulk_modulus/(Vb_hosevolume+ (Cyl_length - y) * Cyl_Ab))*(-Q_bt + y_diff_dot
* Cyl_Ab);
z_diff_dot(5) = (Bulk_modulus/(Pv_hosevolume+  Accum_V))*(Q_p-(Q_pa + Q_pt + Q_r +
Q_acc));
else
z_diff_dot(3) = (Bulk_modulus/(Va_hosevolume+y * Cyl_Aa))*(-Q_at - y_diff_dot * Cyl_Aa) ;
z_diff_dot(4) = (Bulk_modulus/(Vb_hosevolume+(Cyl_length - y) * Cyl_Ab))*(Q_pb +
y_diff_dot * Cyl_Ab);
z_diff_dot(5) = (Bulk_modulus/(Pv_hosevolume+Accum_V))*(Q_p-(Q_pb + Q_pt + Q_r + Q_acc));
end
z_diff_dot(6) = (1/C_acc)* Q_acc ;
```

```
z_diff_dot(7) = Q_acc;
return;
```

Plot Function

```
plot(1) ;
plot(tout, z_out(:,1), 'k',tout, z_out(:,2), 'b',tout, z_out(:,5), 'm',tout, z_out(:,6),
'c',tout, z_out(:,7), 'g');
xlabel('Time (sec)') ;
ylabel('Flow rate (m^3/sec)') ;
legend('Q_p','Q_{pa}','Q_{bt}','Q_r', 'Q_{acc}');
plot(2) ;
plot(tout, z_out(:,8), 'k',tout, z_out(:,9), 'b');
xlabel('Time (sec)') ; ylabel('Spool position and External Load') ;
legend('x_shaft','F_{load}');
plot(3) ;
plot(tout, z_out(:,10) , 'k',tout, z_out(:,11), 'b'); xlabel('Time (sec)') ;
ylabel('Cylinder position and velocity') ; legend('y','y_diff_dot');
plot(4) ;
plot(tout, z_out(:,12), 'k',tout, z_out(:,13), 'b',tout, z_out(:,14), 'g'); xlabel('Time
(sec)') ; ylabel('Pressure [Pa]') ;
legend('p_a','p_b','p_s');
plot(5) ;
plot(tout, z_out(:,15), 'k',tout, z_out(:,16), 'b'); xlabel('Time (sec)') ;
ylabel('Accumulator state') ; legend('Pressure/10^7','Fluid Volume (liter)');
```