Magnetic ball suspension system

SEMESTER PROJECT REPORT

GROUP 11

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Content

Objective

The linearized state equation of the ball-suspension control system described below $\Delta\dot{x}(t) = A * \Delta x(t) + B * \Delta i(t)$

Where

$$A^* = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 115.2 & -0.05 & -18.6 & 0 \\ 0 & 0 & 0 & 1 \\ -37.2 & 0 & 37.2 & -0.1 \end{bmatrix} \qquad B^* = \begin{bmatrix} 0 \\ -6.55 \\ 0 \\ -6.55 \end{bmatrix}$$

Let the control current $\Delta i(t)$ be derived from the state feedback

$\Delta i(t) = -K\Delta x(t)$ where $K = [\ k_1\ k_2\ k_3\ k_4\ ]$

a) Find the element of K so that the eigen values of $A^* - B^*K$ are at $-2 + j2$, $-2 - j2$, -20, -20
b) Check controllability and observability in MATLAB
c) Plot the response of $\Delta x_1(t) = \Delta y_1(t)$ (magnet displacement) and $\Delta x_3(t) = \Delta y_2(t)$ (ball displacement) with the initial condition $\Delta x(0) = \begin{bmatrix} 0.1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$
d) Repeat part above with the initial condition $\Delta x(0) = \begin{bmatrix} 0 \\ 0 \\ 0.1 \\ 0 \end{bmatrix}$

   Comment on the response of the close-loop system with the two sets of initial conditions.
a) Use MATLAB to plot the step response of the system.

Theory

A ball suspension control system is a system that uses magnetic fields to suspend a ball or a sphere in mid-air and control its position by adjusting the strength and direction of the magnetic field. By adjusting the strength of the magnetic field and the distance between the ball and the base, the position of the ball can be controlled and it can be made to move or hover in different directions.

The control system typically consists of a set of sensors, a controller and a set of electromagnets that generate the magnetic field. The sensors are used to measure the position and velocity of the ball and the controller uses this information to generate a control signal that adjusts the magnetic field to keep the ball in a desired position.

The linearised state equation of a ball suspension control system describes the dynamics of the system in terms of a set of state variables, which can be used to design a control system that stabilizes the ball in a desired position. The state equation can be derived by linearising the nonlinear equation of the motion of the system around an operating point. In general, the state equation would be a set of linear differential equations that describe how the state variables change over time in response to the control inputs and the system's internal dynamics.

MATLAB code and results

a) Finding K matrix

```
j=sqrt(-1);
% Define the system matrices
A = [0 1 0 0;115.2 -0.05 -18.6 0;0 0 0 1;-37.2 0 37.2 -0.1];
B = [0;-6.55;0;-6.55];
C = [1 0 0 0];
%D=[0;0;0;0]
D=[0];
sys=ss(A,B,C,D);

% Define the desired eigenvalues
poles = [-2+2j -2-2j -20 -20];

% Compute the state feedback gain matrix
K = acker(A, B, poles)
```

RESULT

```
K =

  -171.3023  -13.4723   62.3267    6.7776
```

b) Check for controllability and observability

```
% Define the system matrices
A = [0 1 0 0;115.2 -0.05 -18.6 0;0 0 0 1;-37.2 0 37.2 -0.1];
B = [0;-6.55;0;-6.55];
C = [1 0 0 0];
%D=[0;0;0;0]
D=[0];
sys=ss(A,B,C,D);
% Determine the controllability and observability of the system
Co = ctrb(A, B);
Ob = obsv(A, C);
% Check if the system is controllable and observable
if rank(Co) == size(A,1)
   disp('System is controllable')
else
   disp('System is not controllable')
end
if rank(Ob) == size(A,1)
   disp('System is observable')
else
   disp('System is not observable')
end
 [num,den]=ss2tf(A,B,C,D)
 g=tf(num,den)
 step(sys)
 hold on
```

RESULT

```
System is controllable
System is observable
```

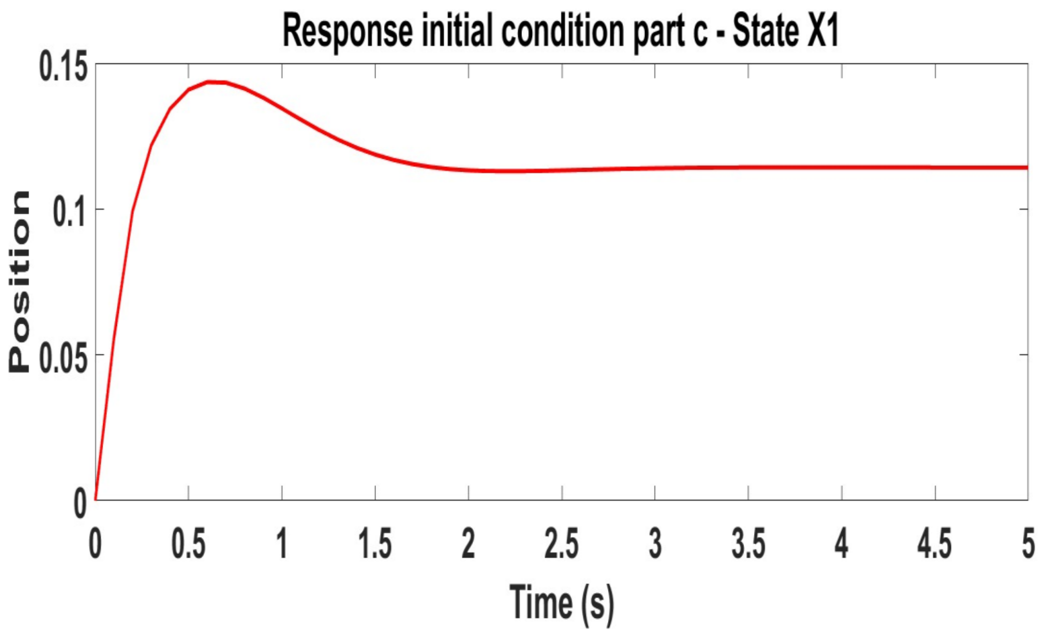
c) Plot responses of magnet displacement and ball displacement with initial condition $\Delta x(0) = \begin{bmatrix} 0.1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$

CODE:

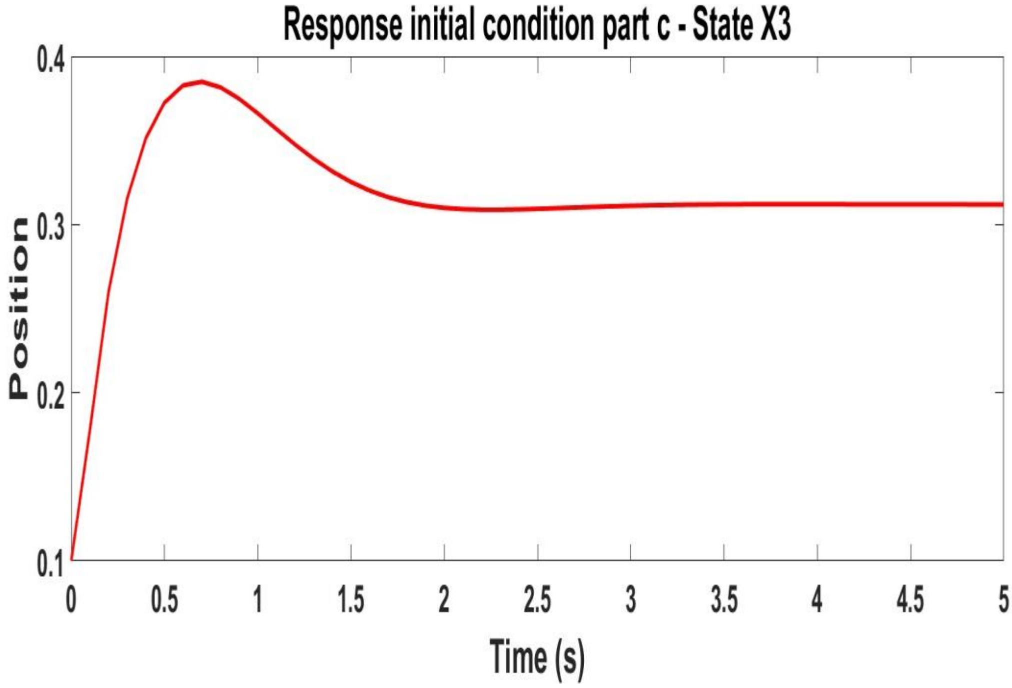
```
A=[0      1       0       0;
   115.2  -.05   -18.6      0;
   0       0       0       1;
   -37.2     0     37.2      -0.1];

B=[0;   -6.55;   0;   -6.55];
D=0;

t = 0:0.1:5;
timeStep=size(t,2);
for j=1:1:timeStep
        u(j)=1;
end

%Part c
x_c=[0;0;0.1;0]; % Initial state part c
% Code for State X1
C=[1 0 0 0];% C matrix for state X1
bal_sys_ol=ss(A,B,C,D);
p=[-20 -20 -2+2i -2-2i];
K = acker(A,B,p);
Acl = A-B*K;
bal_sys_cl = ss(Acl,B,C,D);
Pcl = pole(bal_sys_cl);
sys = ss(Acl, B, C, D);

[y, t, z]=lsim(sys, u, t, x_c);
figure (1)
plot(t, z(:,1),'r', 'LineWidth', 2);
```

```
xlabel('Time (s)');
ylabel('Position');
title('Response initial condition part c - State X1');

%Code for State X3
C=[0 0 1 0];% C matrix for state X3
bal_sys_ol=ss(A,B,C,D);
p=[-20 -20 -2+2i -2-2i];
K = acker(A,B,p);
Acl = A-B*K;
bal_sys_cl = ss(Acl,B,C,D);
Pcl = pole(bal_sys_cl);
sys = ss(Acl, B, C, D);

[y, t, z]=lsim(sys, u, t, x_c);
figure (2)
plot(t, z(:,3),'r', 'LineWidth', 2);
% plot(t_c,x1);
xlabel('Time (s)');
ylabel('Position');
title('Response initial condition part c - State X3');
```

RESULT for state X1



RESULT for state X3



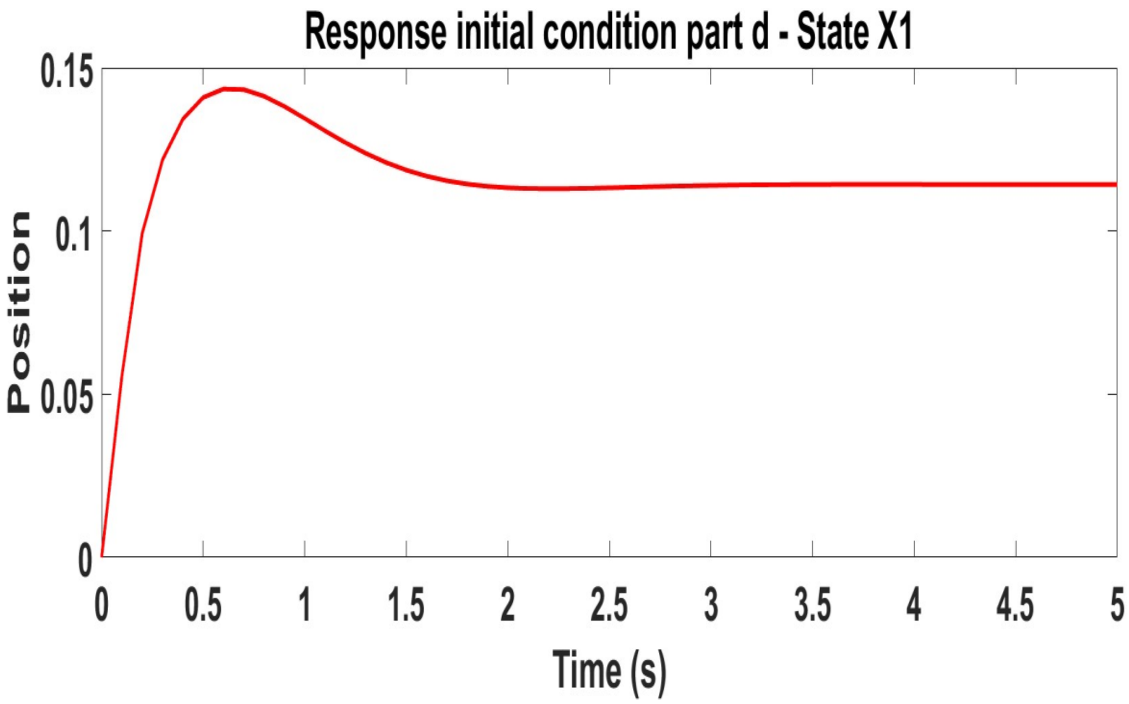
d) Plot responses of magnet displacement and ball displacement with initial condition $\Delta x(0) = \begin{bmatrix} 0 \\ 0 \\ 0.1 \\ 0 \end{bmatrix}$

CODE:

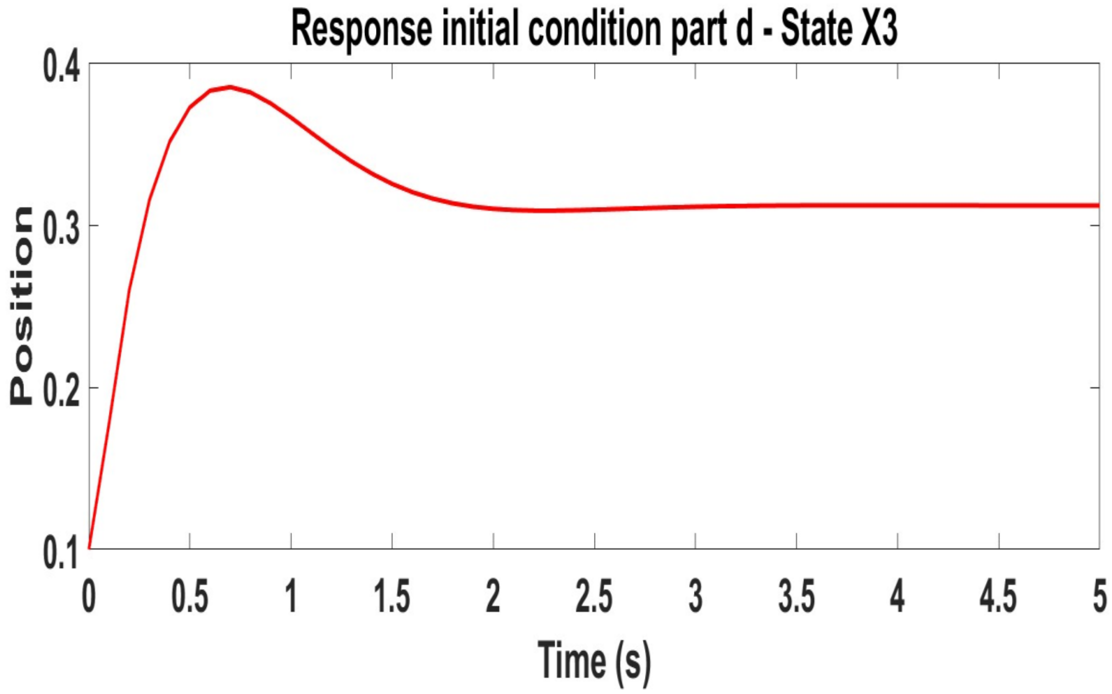
```
A=[0      1      0      0;
   115.2  -.05   -18.6     0;
   0       0      0       1;
   -37.2    0     37.2      -0.1];

B=[0;   -6.55;   0;   -6.55];
D=0;

t = 0:0.1:5;
timeStep=size(t,2);
for j=1:1:timeStep
        u(j)=1;
end

x_d=[0;0;0.1;0]; % Initial state part d
%Code for State X1
C=[1 0 0 0];% C matrix for state X1
bal_sys_ol=ss(A,B,C,D);
p=[-20 -20 -2+2i -2-2i];
K = acker(A,B,p);
Acl = A-B*K;
bal_sys_cl = ss(Acl,B,C,D);
Pcl = pole(bal_sys_cl);
sys = ss(Acl, B, C, D);
[y, t, z]=lsim(sys, u, t, x_d);
figure (3)
plot(t, z(:,1),'r', 'LineWidth', 2);

xlabel('Time (s)');
ylabel('Position');
title('Response initial condition part d - State X1');
```

```
%Code for State X3
C=[0 0 1 0];% C matrix for state X3
bal_sys_ol=ss(A,B,C,D);
p=[-20 -20 -2+2i -2-2i];
K = acker(A,B,p);
Acl = A-B*K;
bal_sys_cl = ss(Acl,B,C,D);
Pcl = pole(bal_sys_cl);
sys = ss(Acl, B, C, D);
[y, t, z]=lsim(sys, u, t, x_d);
figure (4)
plot(t, z(:,3),'r', 'LineWidth', 2);
xlabel('Time (s)');
ylabel('Position');
title('Response initial condition part d - State X3');
```

RESULT for state X1



RESULT for state X3



e) Plot for step response

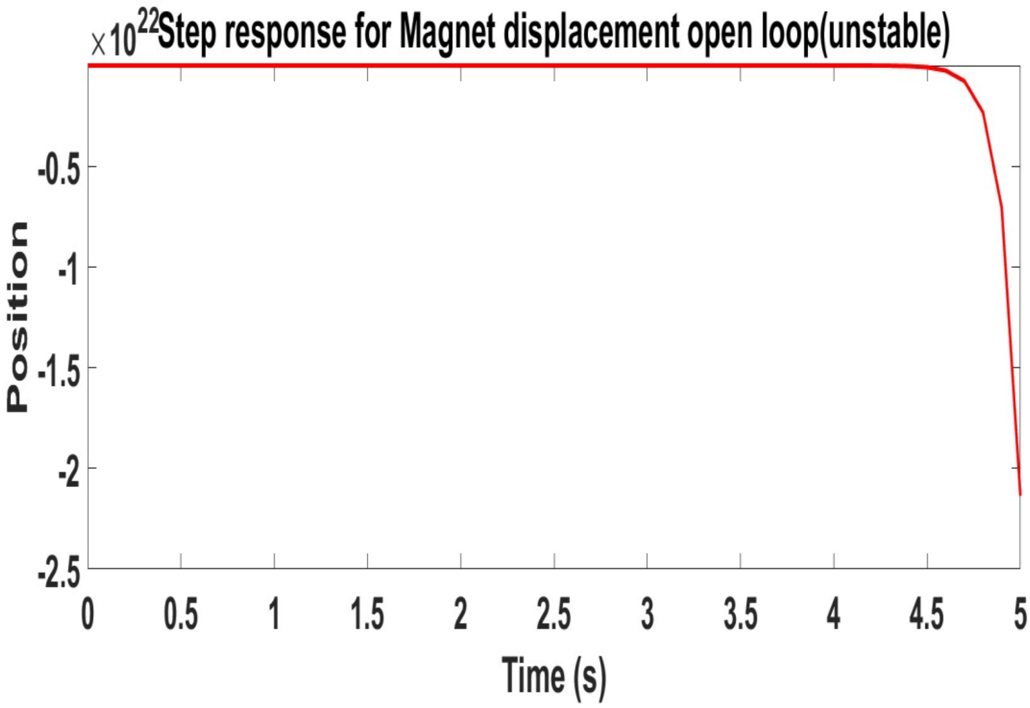
CODE:

```
clc; clear;
t = 0:0.1:5;
timeStep=size(t,2);
for j=1:1:timeStep
        u(j)=1;
end
A=[0       1       0       0;
   115.2  -.05   -18.6      0;
   0        0       0        1;
   -37.2     0     37.2      -0.1];

B=[0;   -6.55;   0;   -6.55];
D=0;
% Code for State X1
C=[1 0 0 0];% C matrix for state X1

[b,a]=ss2tf(A, B, C, D);
sys=tf(b,a);
```

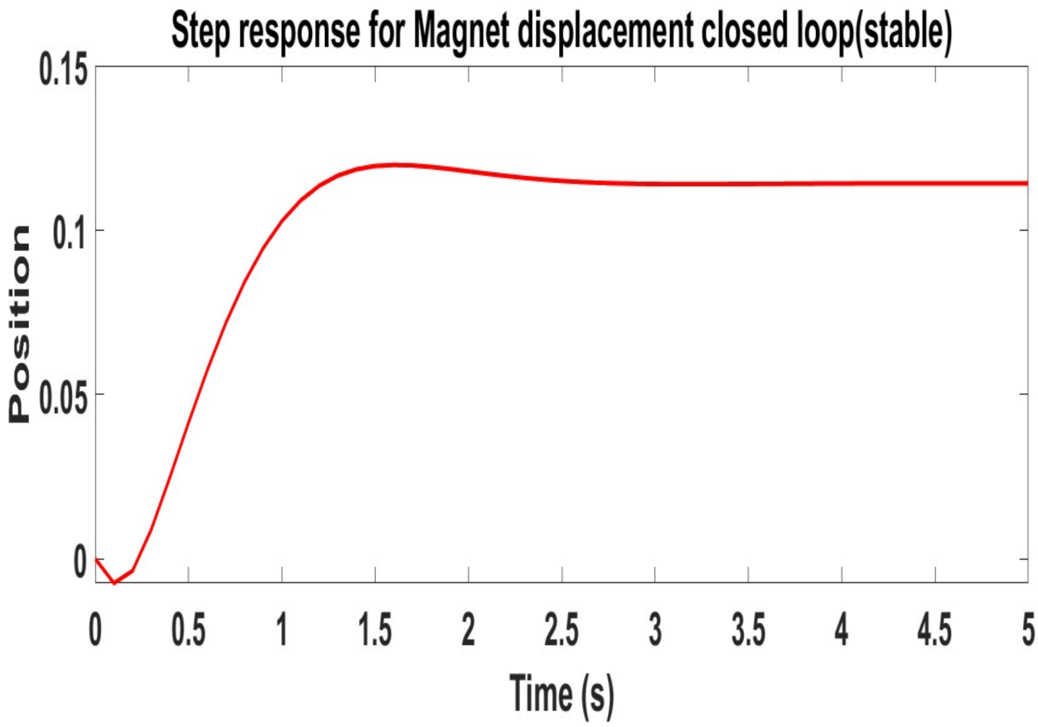
```
[y, t, z]=lsim(sys, u, t );
figure(1);
plot(t, y(:,1),'r', 'LineWidth', 2);
xlabel('Time (s)');
ylabel('Position');
title('Step response for Magnet displacement open loop(unstable)');

p=[-20 -20 -2+2i -2-2i];
K = acker(A,B,p);
Acl = A-B*K;
bal_sys_cl = ss(Acl,B,C,D);
Pcl = pole(bal_sys_cl);
[b,a ] = ss2tf(Acl, B, C, D);
sys=tf(b,a);
[y, t, z]=lsim(sys, u, t );
figure(2);
plot(t, y(:,1),'r', 'LineWidth', 2);
xlabel('Time (s)');
ylabel('Position');
title('Step response for Magnet displacement closed loop(stable)');

% Code for State X1
C=[0 0 1 0];% C matrix for state X1

[b,a]=ss2tf(A, B, C, D);
sys=tf(b,a);
[y, t, z]=lsim(sys, u, t );
figure(3);
plot(t, y(:,1),'r', 'LineWidth', 2);
xlabel('Time (s)');
ylabel('Position');
title('Step response for Ball displacement open loop(unstable)');

p=[-20 -20 -2+2i -2-2i];
K = acker(A,B,p);
Acl = A-B*K;
bal_sys_cl = ss(Acl,B,C,D);
```

```
Pcl = pole(bal_sys_cl);
[b,a ] = ss2tf(Acl, B, C, D);
sys=tf(b,a);
[y, t, z]=lsim(sys, u, t );
figure(4);
plot(t, y(:,1),'r', 'LineWidth', 2);
xlabel('Time (s)');
ylabel('Position');
title('Step response for ball displacement close loop(stable)’);
```

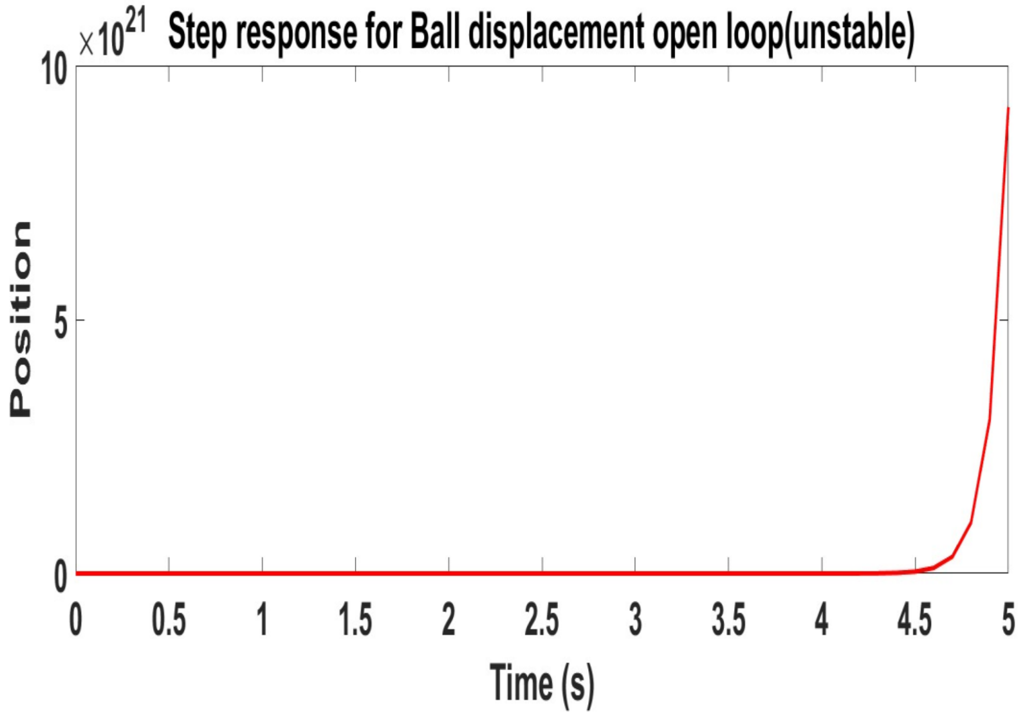
RESULT for magnetic displacement open loop (unstable)



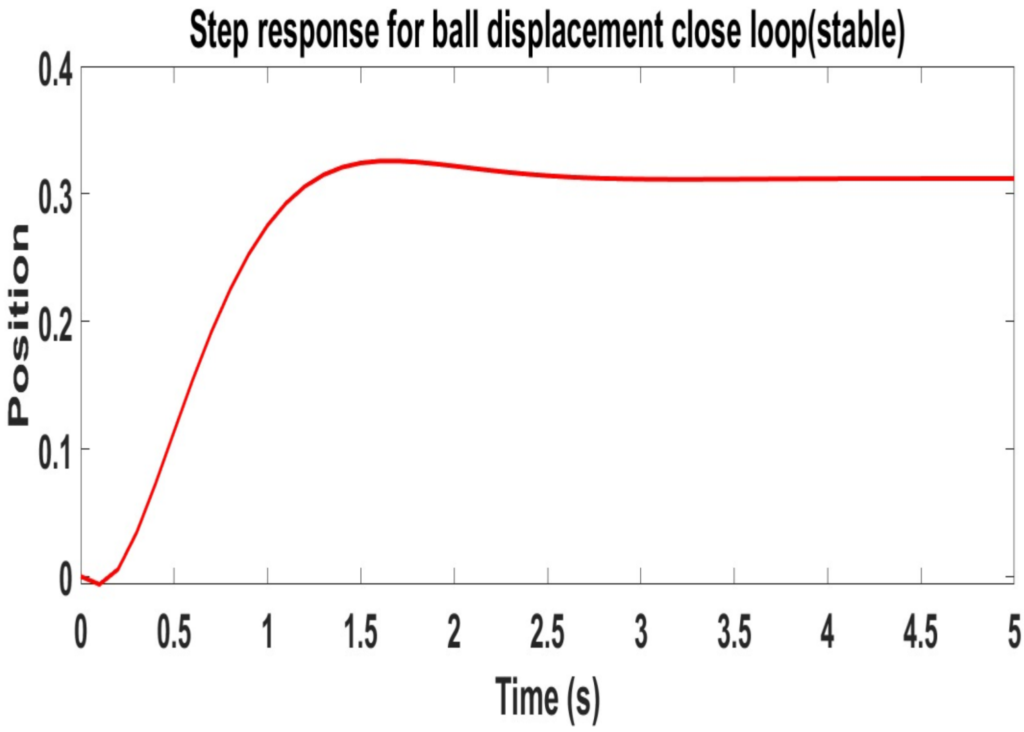
RESULT for magnetic displacement close loop (stable)



RESULT for ball displacement open loop (unstable)



RESULT for ball displacement close loop (stable)



Conclusion

Designing an effective ball suspension control system requires a good understanding of dynamics of the system and control algorithms that are best suited for the specified application.

The state feedback gain matrix has been found using the state space equation of the system.

Controllability and observability are two important concepts in control theory because they are closely related to the design of controllers and observers for dynamic systems and using the state space equation, we are able to determine whether the system is controllable and observable.

The step responses of magnetic displacement and ball displacement for both open loop and close loop are found for the given objective.