香港中文大學
The Chinese University of Hong Kong

The Chinese University of Hong Kong

Department of Mechanical & Automation Engineering

MAEG5080 Smart Materials & Structures

Assignment #3

by

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Problem 1

Under sinusoidal input with amplitude $0.03\ \mathrm{m}$, $90°$ phase angle and frequency $2.5\ \mathrm{Hz}$, plot the following figures (SIMULINK is highly recommended) and hand in the results with your own program codes:

(i) Damping force $F_d\ (t)$ versus displacement $x\ (t)$ (for v = 0 V, 1 V, 2 V cases).

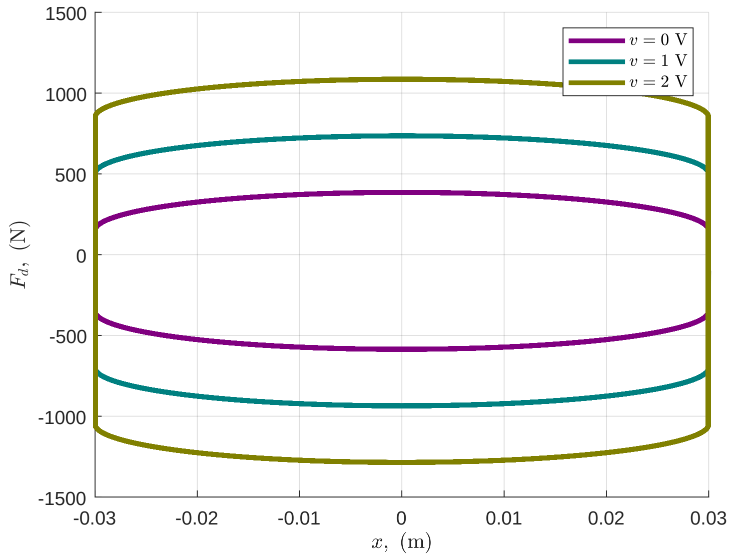

Figure 1: Damping force $F_d\ (t)$ versus displacement $x\ (t)$ (for v = 0 V, 1 V, 2 V cases).

(ii) Damping force $F_d\ (t)$ versus velocity $\dot{x}\ (t)$ (for v = 0 V, 1 V, 2 V cases).

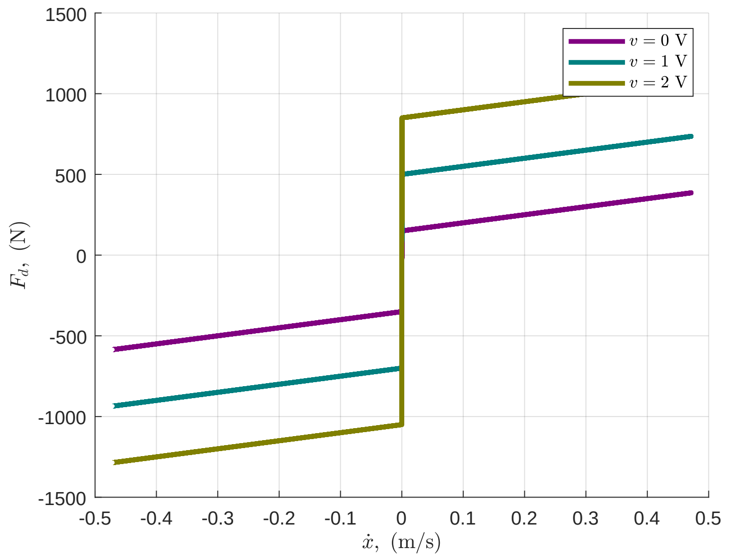

Figure 2: Damping force $F_d\ (t)$ versus velocity $\dot{x}\ (t)$ (for v = 0 V, 1 V, 2 V cases).

Problem 2

(a) The equation of motion is shown as follows:

$$\begin{cases} m_1\ddot{x}_1 + k_1 x_1 - k_1 x_2 + F_d = 0 \\ m_2\ddot{x}_2 + c_2\dot{x} + (k_1 + k_2)\, x_2 - c_2\dot{x}_b - k_2 x_b - k_1 x_1 - F_d = 0 \end{cases} \tag{1}$$

(b) The state space representation of the car suspension system with the outputs $x_1, \dot{x}_1, \dot{x}_2$ is

$$\begin{aligned} \dot{X} = \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \ddot{x}_1 \\ \ddot{x}_2 \end{bmatrix} &= \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -\frac{k_1}{m_1} & \frac{k_1}{m_1} & 0 & 0 \\ \frac{k_1}{m_2} & -\frac{k_1+k_2}{m_2} & 0 & -\frac{c_2}{m_2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ -\frac{1}{m_1} & 0 & 0 \\ \frac{1}{m_2} & \frac{k_2}{m_2} & -\frac{c_2}{m_2} \end{bmatrix} \begin{bmatrix} F_d \\ x_b \\ \dot{x}_b \end{bmatrix} \\ &\triangleq AX + Bu \end{aligned} \tag{2}$$

$$\begin{aligned} Y = \begin{bmatrix} \dot{x}_1 \\ \ddot{x}_1 \\ \ddot{x}_2 \end{bmatrix} &= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} \\ &\triangleq CX + Du \end{aligned} \tag{3}$$

Problem 3

The on-off controller is set up as follows:

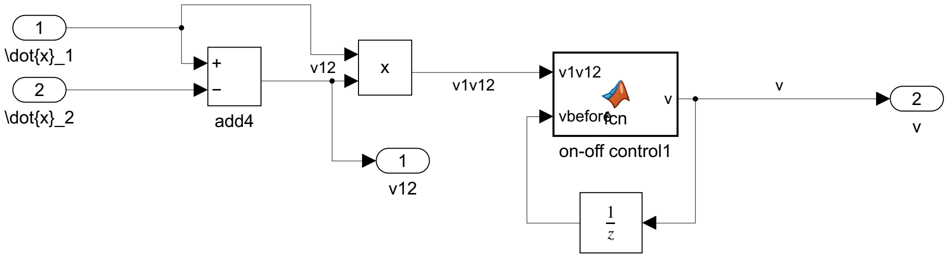

Figure 3: On-off controller.

Problem 4

The response for the system is list below:

(a) Bump excitation: displacement versus time for $t = 0 : 0.001 : 8$.

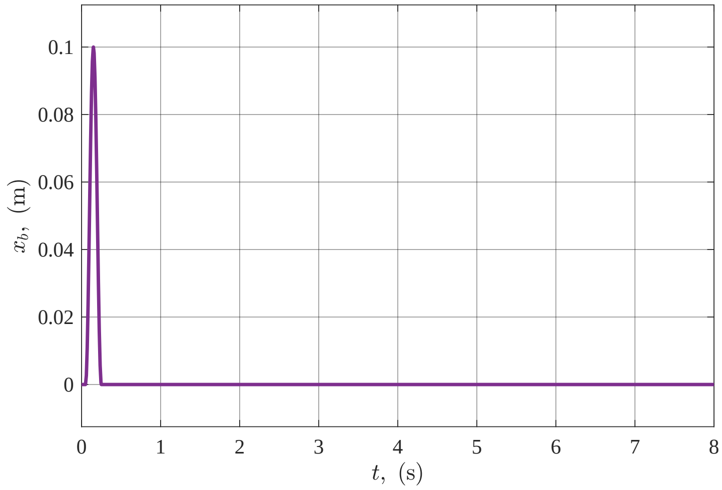

Figure 4: Bump excitation: displacement versus time for $t = 0 : 0.001 : 8$.

(b) $x_1(t)$ versus t for $t = 0 : 0.001 : 8$ (for $v = 0$ V, 2 V and controlled cases).

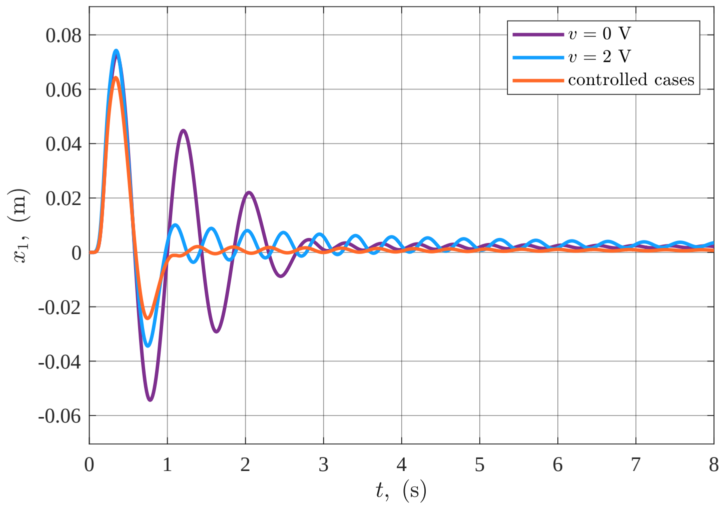

Figure 5: $x_1(t)$ versus t for $t = 0 : 0.001 : 8$ (for $v = 0$ V, 2 V and controlled cases).

(c) $\ddot{x}_1(t)$ versus t for $t = 0 : 0.001 : 8$ (for $v = 0$ V, 2 V and controlled cases).

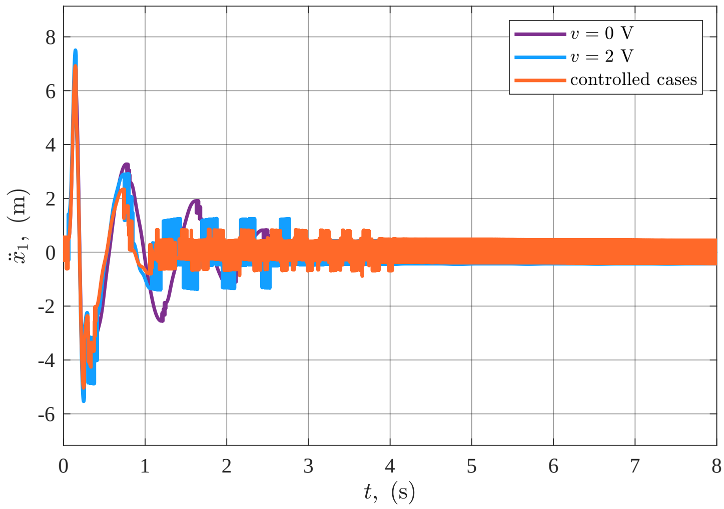

Figure 6: $\ddot{x}_1(t)$ versus t for $t = 0 : 0.001 : 8$ (for $v = 0$ V, 2 V and controlled cases).

(d) Voltage $v(t)$ versus t for $t = 0 : 0.001 : 8$ (only for the controlled case).

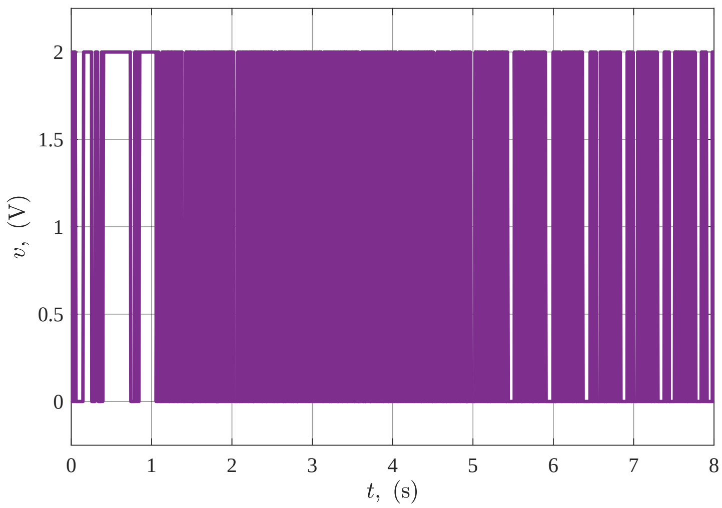

Figure 7: Voltage $v(t)$ versus t for $t = 0 : 0.001 : 8$ (only for the controlled case).

Discussion: From Figure 5, we can know that the controlled case converges to stability more quickly than the other two cases and has a lower overshoot and oscillation. The amplitude of oscillation for the acceleration when the system is controlled by on-off controller is also lower than that of other cases. Therefore, we can conclude that the MR damper has the better performance and can make the system stable to equilibrium point.

Appendix

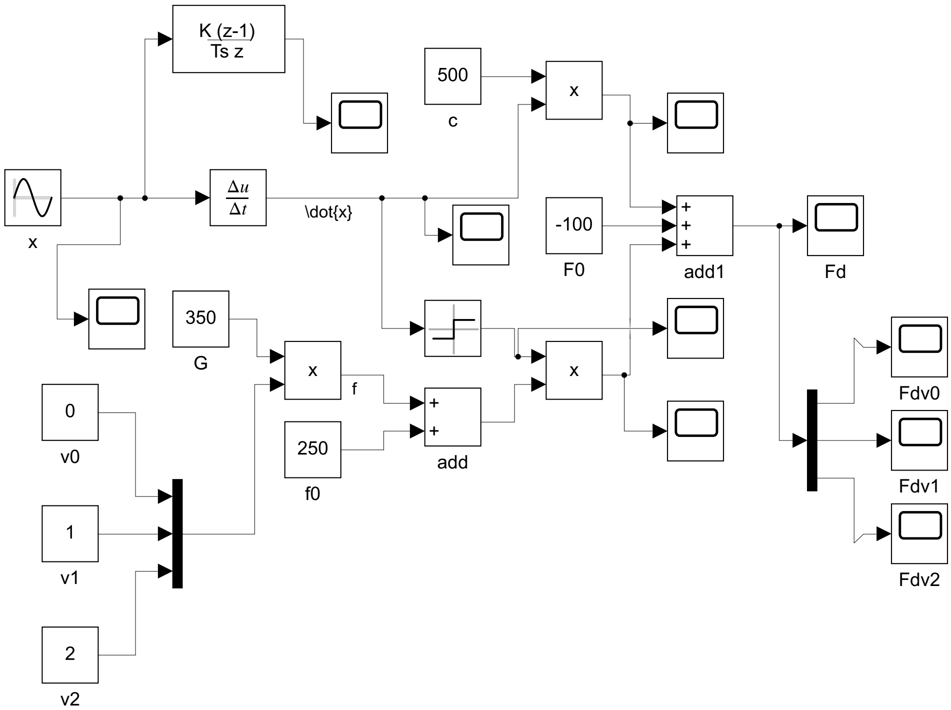

Figure 8: Block diagram for MR damper.

Input Matlab source for plot MR damper response diagram:

```
clf;
x = out.xin.signals.values;
dx = out.dxin.signals.values;
Fdv0 = out.Fdv0.signals.values;
Fdv1 = out.Fdv1.signals.values;
Fdv2 = out.Fdv2.signals.values;

figure(1);
hold on;
plot(x,Fdv0,"Color",[128, 0, 128]/256,'LineWidth',2.5);
plot(x,Fdv1,"Color",[0, 128, 128]/256,'LineWidth',2.5);
plot(x,Fdv2,"Color",[128, 128, 0]/256,'LineWidth',2.5);
hold off;
grid on;
xlabel('$x, \mathrm{\ \left(m\right)}$','interpreter','latex');
ylabel('$F_d, \mathrm{\ \left(N\right)}$', 'interpreter','latex');
legend('$v=0 \mathrm{\ V}$','$v=1 \mathrm{\ V}$','$v=2 \mathrm{\ V}$',...
    'interpreter','latex');
% a = get(gca,'XTickLabel');
% set(gca,'XTickLabel',a,'FontName','Times','fontsize',12);
set(gcf,'renderer','painters');
filename = "Q3-1-Fd-x"+".pdf";
```

```
saveas(gcf,filename);
figure(2);
hold on;
plot(dx,Fdv0,"Color",[128, 0, 128]/256,'LineWidth',2.5);
plot(dx,Fdv1,"Color",[0, 128, 128]/256,'LineWidth',2.5);
plot(dx,Fdv2,"Color",[128, 128, 0]/256,'LineWidth',2.5);
hold off;
grid on;
xlabel('$\dot{x}, \mathrm{\ \left(m/s\right)}$','interpreter','latex');
ylabel('$F_d, \mathrm{\ \left(N\right)}$', 'interpreter','latex');
legend('$v=0 \mathrm{\ V}$','$v=1 \mathrm{\ V}$','$v=2 \mathrm{\ V}$',...
    'interpreter','latex');
% a = get(gca,'XTickLabel');
% set(gca,'XTickLabel',a,'FontName','Times','fontsize',12);
set(gcf,'renderer','painters');
filename = "Q3-1-Fd-dx"+".pdf";
saveas(gcf,filename);
```

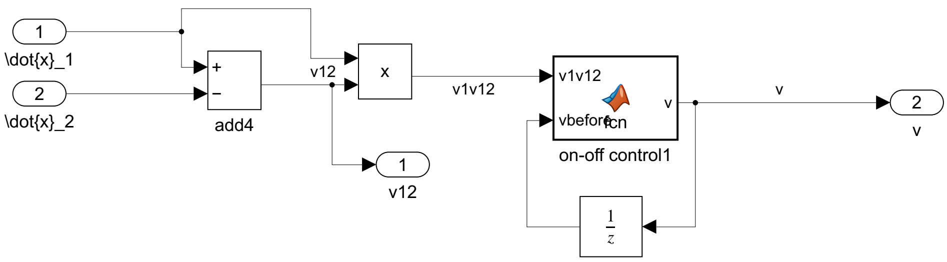

Figure 9: Block diagram for on-off controller.

Input Matlab source for on-off controller:

```
function v = fcn(v1v12,vbefore)

if v1v12 > 0
    v = 2;
elseif v1v12 < 0
    v = 0;
else
    v = vbefore;
end
```

Input Matlab source for plotting x_b, v, x_1, and $\ddot{x}_1$:

```
clear all; clc;
figg1 = openfig('v.fig','reuse');
grid on;
xlabel('$t, \mathrm{\ \left(s\right)}$','interpreter','latex');
ylabel('$v, \mathrm{\ \left(V\right)}$', 'interpreter','latex');
% legend('$v=0 \mathrm{\ V}$','$v=1 \mathrm{\ V}$','$v=2 \mathrm{\ V}$',...
```

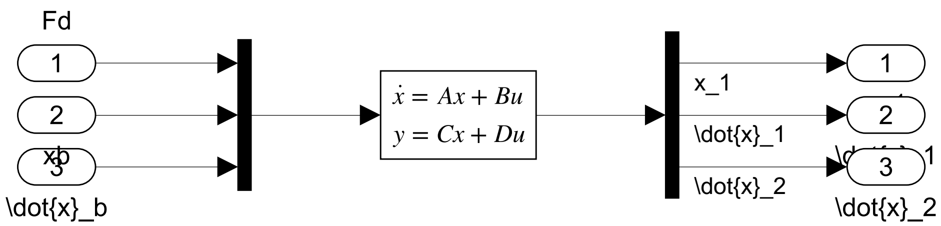

Figure 10: Block diagram for state space function.

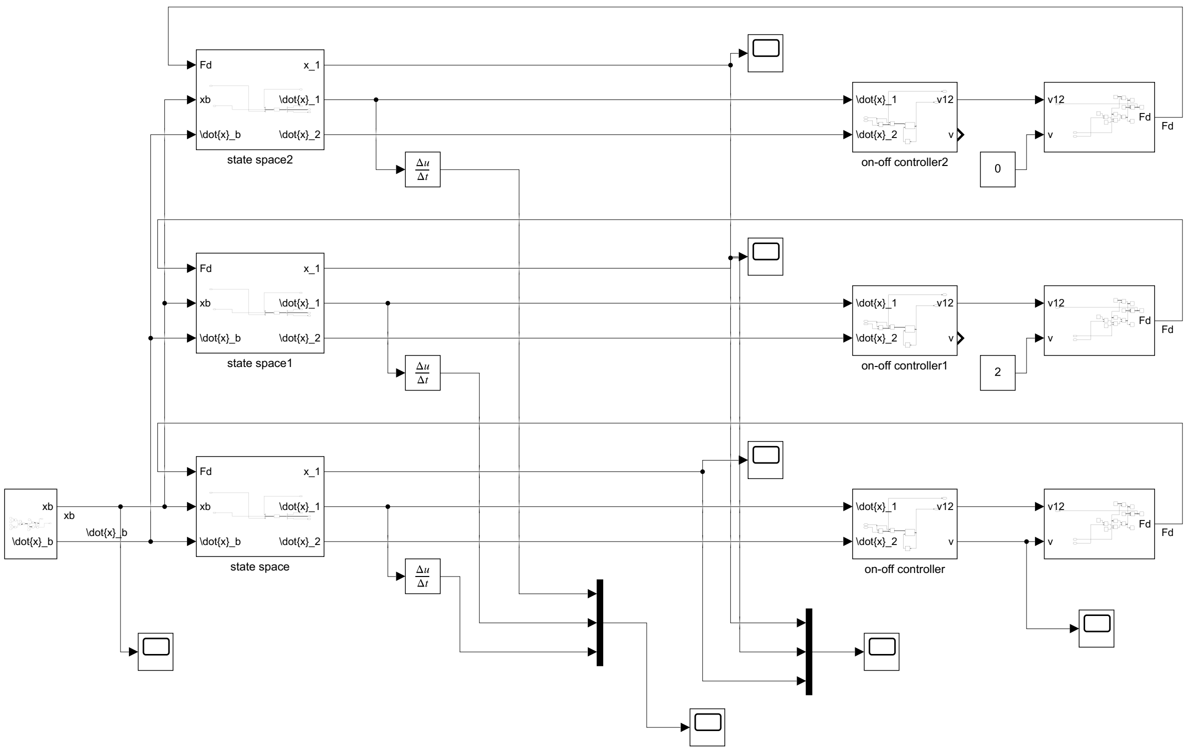

Figure 11: Block diagram for the whole system.

```
%      'interpreter','latex');
a = get(gca,'XTickLabel');
set(gca,'XTickLabel',a,'FontName','Times','fontsize',12);
set(gcf,'renderer','painters');
filename = "v"+".pdf";
saveas(gcf,filename);
close(figg1);
figg2 = openfig('xb.fig','reuse');
grid on;
xlabel('$t, \mathrm{\ \left(s\right)}$','interpreter','latex');
ylabel('$x_b, \mathrm{\ \left(m\right)}$', 'interpreter','latex');
title('');
% legend('$v=0 \mathrm{\ V}$','$v=2 \mathrm{\ V}$','$\text{controlled cases}$',...
%      'interpreter','latex');
a = get(gca,'XTickLabel');
set(gca,'XTickLabel',a,'FontName','Times','fontsize',12);
```

```
set(gcf,'renderer','painters');
filename = "xb"+".pdf";
saveas(gcf,filename);
close(figg2);
figg3 = openfig('x.fig','reuse');
grid on;
xlabel('$t, \mathrm{\ \left(s\right)}$','interpreter','latex');
ylabel('$x_1, \mathrm{\ \left(m\right)}$', 'interpreter','latex');
title('');
legend('$v=0 \mathrm{\ V}$','$v=2 \mathrm{\ V}$','controlled cases',...
    'interpreter','latex');
a = get(gca,'XTickLabel');
set(gca,'XTickLabel',a,'FontName','Times','fontsize',12);
set(gcf,'renderer','painters');
filename = "x"+".pdf";
saveas(gcf,filename);
close(figg3);
figg4 = openfig('ddotx.fig','reuse');
grid on;
xlabel('$t, \mathrm{\ \left(s\right)}$','interpreter','latex');
ylabel('$\ddot{x}_1, \mathrm{\ \left(m\right)}$', 'interpreter','latex');
title('');
legend('$v=0 \mathrm{\ V}$','$v=2 \mathrm{\ V}$','controlled cases',...
    'interpreter','latex');
a = get(gca,'XTickLabel');
set(gca,'XTickLabel',a,'FontName','Times','fontsize',12);
set(gcf,'renderer','painters');
filename = "ddotx"+".pdf";
saveas(gcf,filename);
close(figg4);
```