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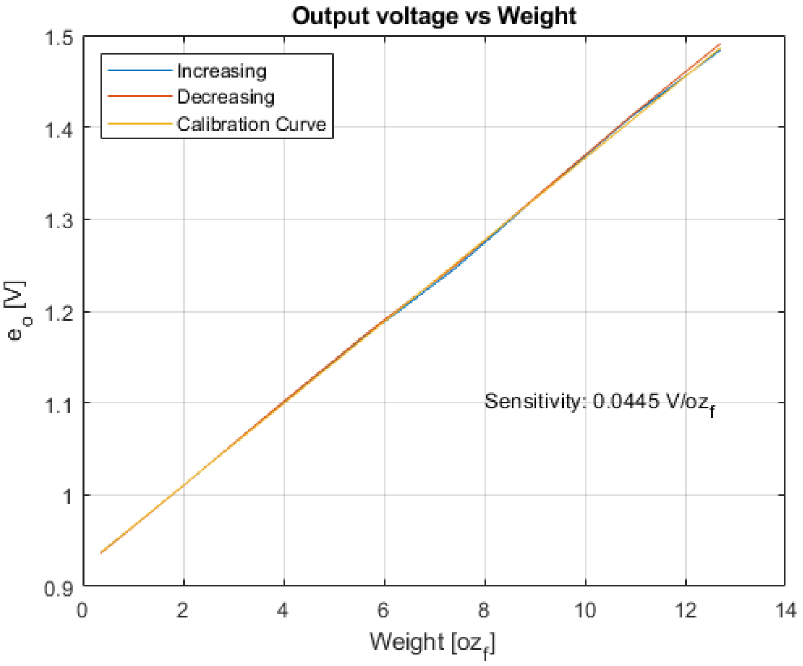
Section 3B

Senior Lab – Mechanical Engineering – ME 747

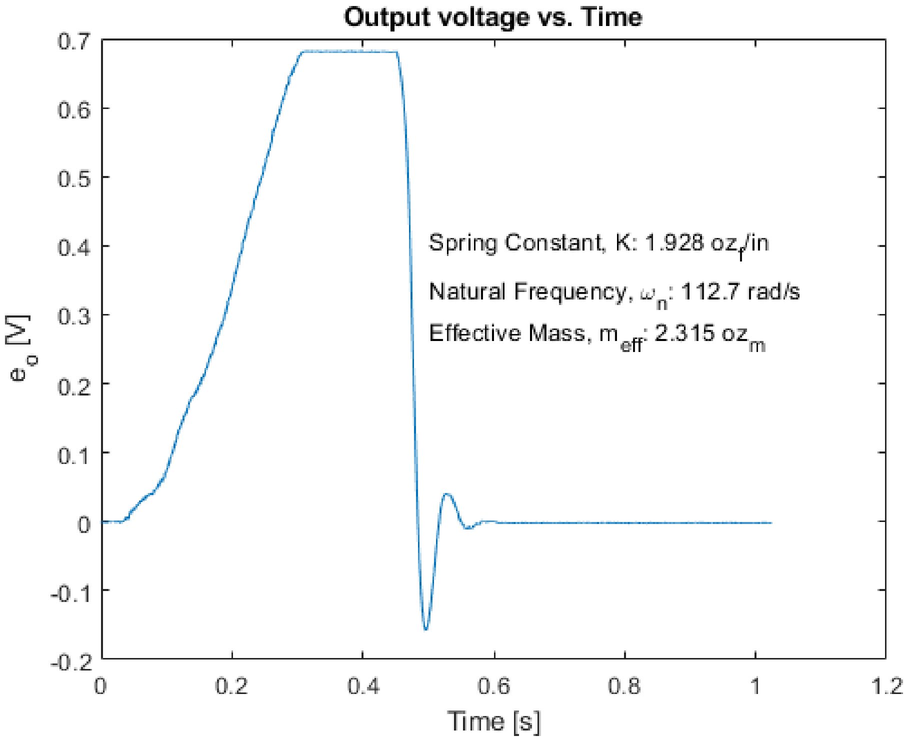
Lab 4: Accelerometers and Force Sensors, Modeling and Calibration, Measuring Vibration

1 Potentiometer Accelerometer

a) **Plot eo vs. weight and find the sensitivity in volts/ozf.**



b) **Plot eo(t) vs. time for the initial displacement and, along with the plot from a), determine the following parameters for the accelerometer (use % overshoot plot given in Canvas to get ζ): spring constant K (ozf/in), natural frequency ωn (rad/sec), effective mass M (ozm), damping ratio ζ.**

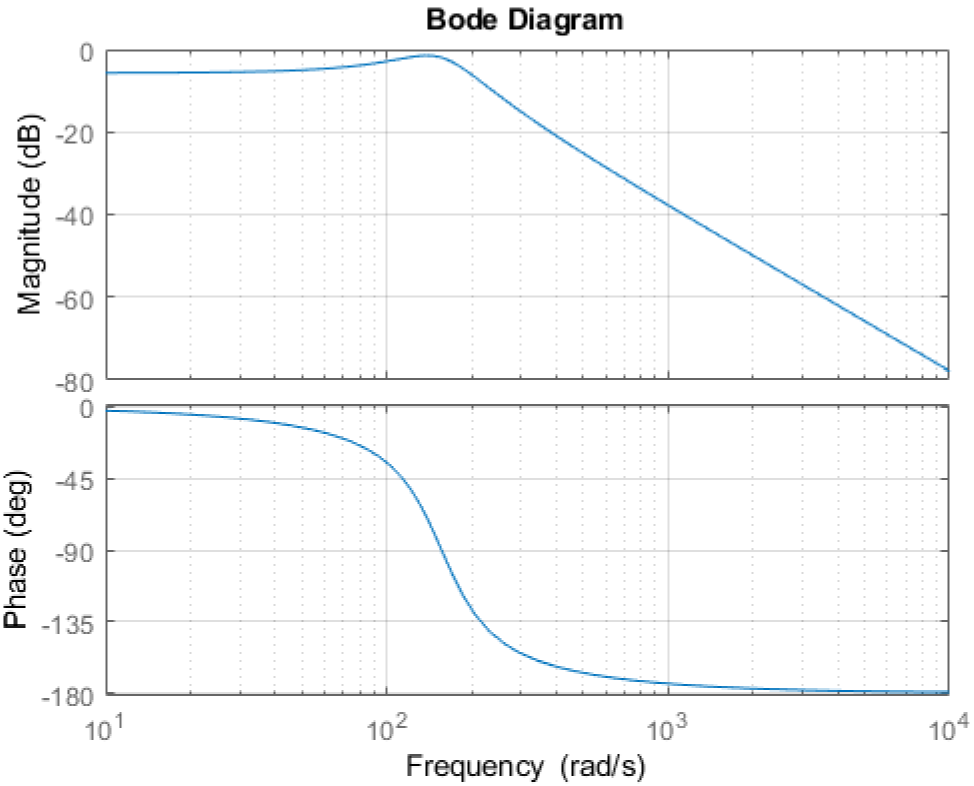


c) **What is the sensitivity of the accelerometer in volts/(in/sec2)?**

$.000266\ \frac{V}{in/_{s^2}}$ which means for every .000266 volts the sensor outputs, it equals 1 in/sec2 of acceleration.

d) **What is the maximum acceleration that can be measured with this instrument?**
5600 $^{in}/_{s^2}$ which was found by finding max acceleration the sensor recorded and dividing it by the sensors sensitivity to convert it to physical units, not electrical.

e) **Use Matlab to make a Bode plot of the transfer function E□ሺsሻ/Xሷ □ሺsሻ and comment on the accuracy of the accelerometer for measuring sinusoidal accelerations.**

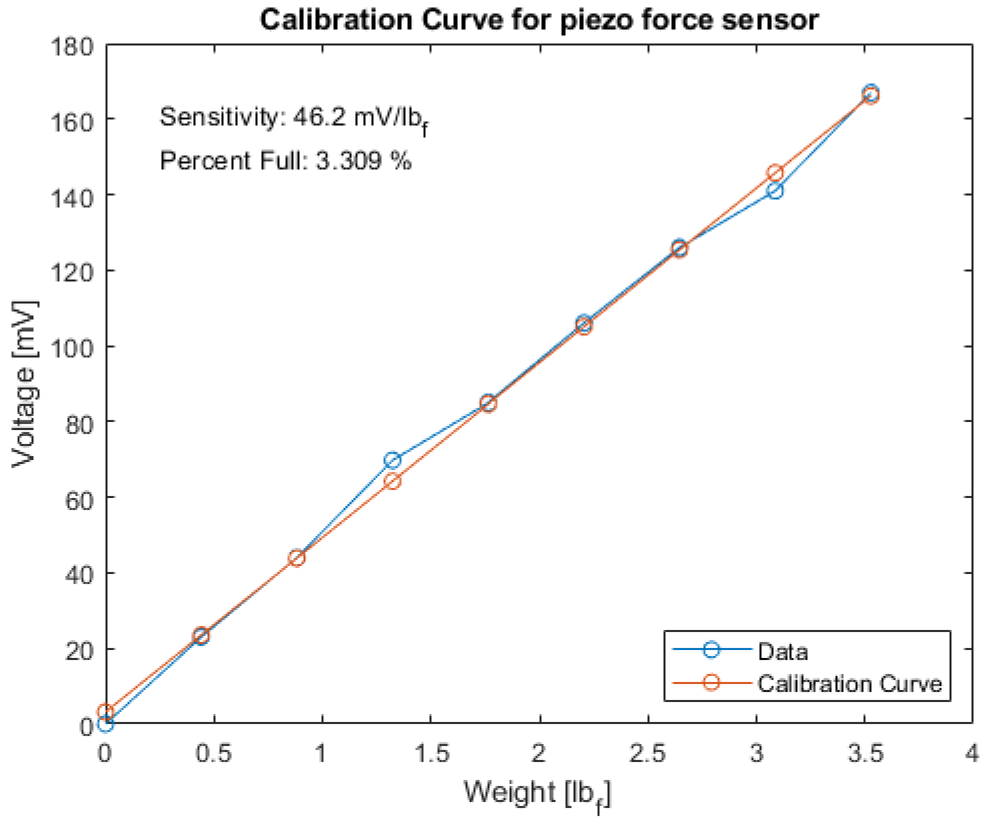


This accelerometer is meant to measure from low frequencies as that is the region that is flat up until its break frequency of around 150 rad/s. If the signal is in that region, the system will have time to react, but if its not, it wont have time causing the acceleration data to attenuate and become less pronounced.

2 Piezoelectric Force Sensor

2.1 PCB Characteristics

a) Plot the calibration curve and give the sensitivity (mV/lbf) and error in % full scale (FS).



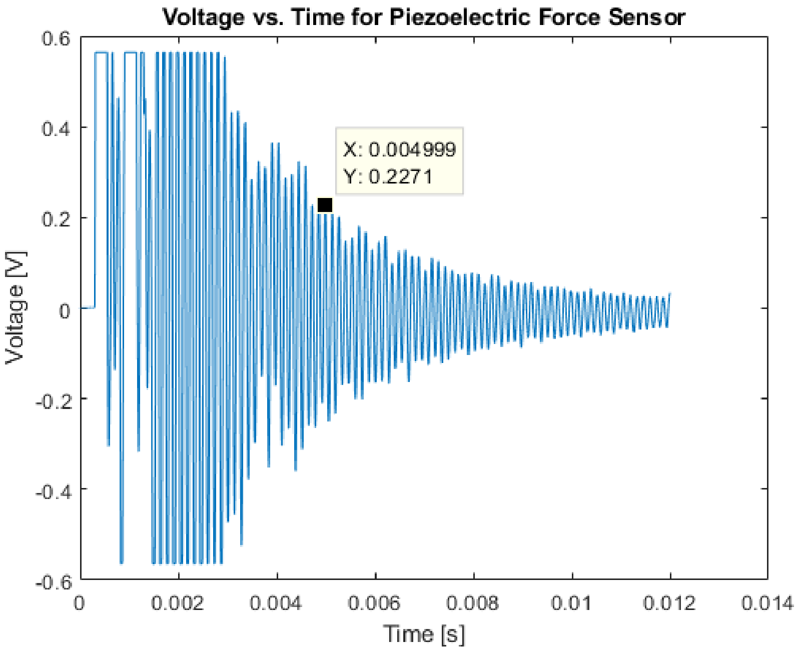
This was fitted with a 1st order poly fit.

b) Give the decay time constant of the PCB and comment on the sensor's ability to measure steady state forces.

The time constant was calculated to be 13.4 seconds. Being a piezoelectric, it can not measure steady state forces and the signal attenuates very quickly.

c) Find the natural frequency of the PCB/structure, and discuss what this means in terms of dynamic performance.

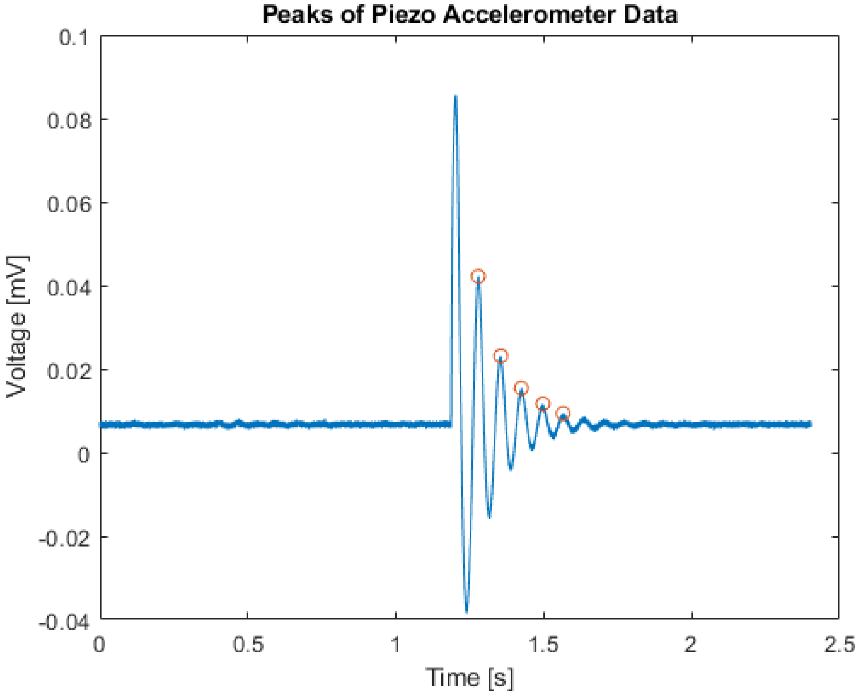
$9.3084 * 10^4 \frac{rad}{s}$ was found to be the natural frequency. For dynamic performance, this means that it can measure and record high dynamic forces before attenuating that signal after its break frequencies.



2.2 Impulse Loading and Vibration

a) For the foam-mass system, find the damping ratio ζ, natural frequency ωn , and spring constant k (lbf/in).

Damping Ratio ( )	**.028**
Natural Frequency (rad/s)	**83.1**
Spring Constant (lbf/in)	**0.91**

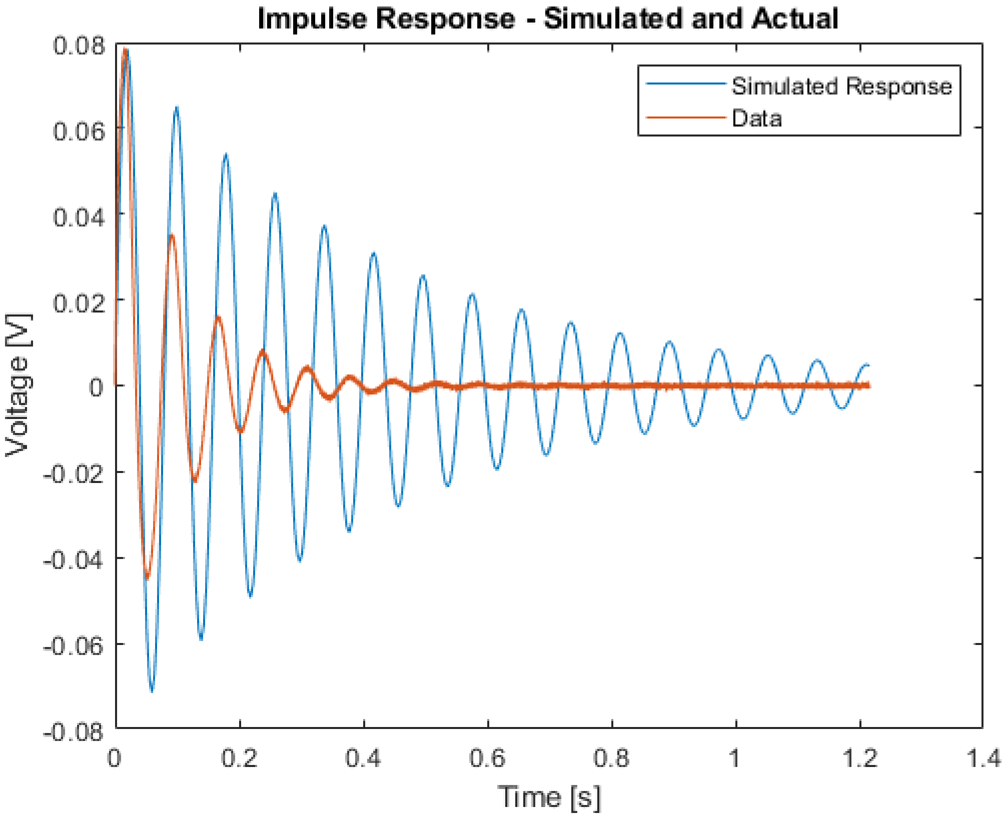


b) **Find the damping coefficient B, lbf/(in/sec), of the foam-mass system.**

The damping coefficient is related to the damping ratio and natural frequency with the equation $B = \frac{2\zeta}{w_n}$ so it came out to be $0.000674\ \frac{lbf}{in/_s}$

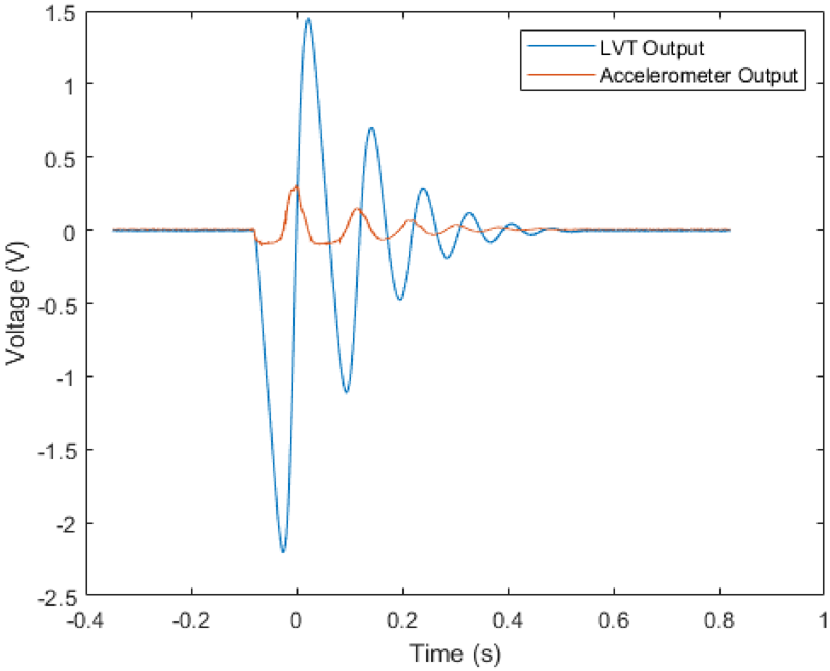
c) **Write the "governing" differential equation of the system and simulate the response of the system to the "impulse" force (use MATLAB and/or Simulink). You will have to approximate the "impulse" loading from the tapping. Plot the simulated and experimental data on the same plot and compare them.**

$M\ddot{x} = M\ddot{y} + B\dot{y} + Ky$ where $y = x - x_m$ is the governing equation for the system which contains a mass, spring, and damper. X is the location of the frame, xm is the position of the mass. The data of these values were recorded and graphed below.



3 Vibration Analysis

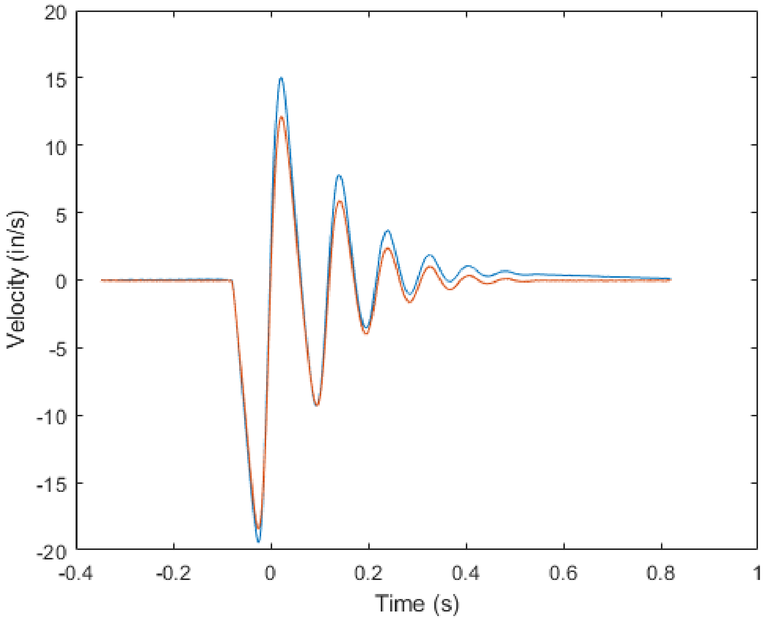
a) **Plot the LVT and accelerometer output vs. time. Find the sensitivity of the accelerometer in volts/(in/sec2) and the LVT in volts/(in/sec).**



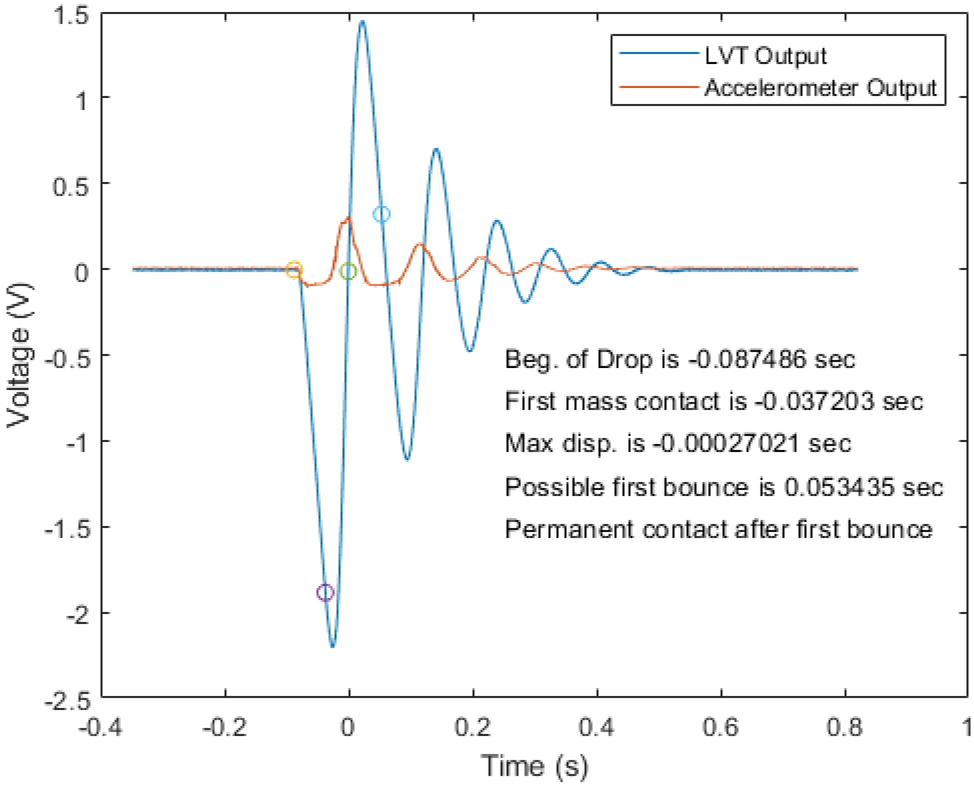
LVT Sensitivity: $0.118 \frac{V}{in/_{s}}$

Accelerometer Sensitivity: $0.000238 \frac{V}{in/_{s}}$

b) **Integrate the accelerometer signal using Matlab (cumtrapz) and plot that signal (units of in/sec) and the LVT signal (units of in/sec) vs. time. Compare them.**



c) **Indicate on the plot from a) the time that the following occur: i) beginning of the drop, ii) first contact between the core shaft and foam, iii) the maximum displacement of the core shaft, iv) the separation between the core and foam (bounce), v) permanent contact between the core and foam.**

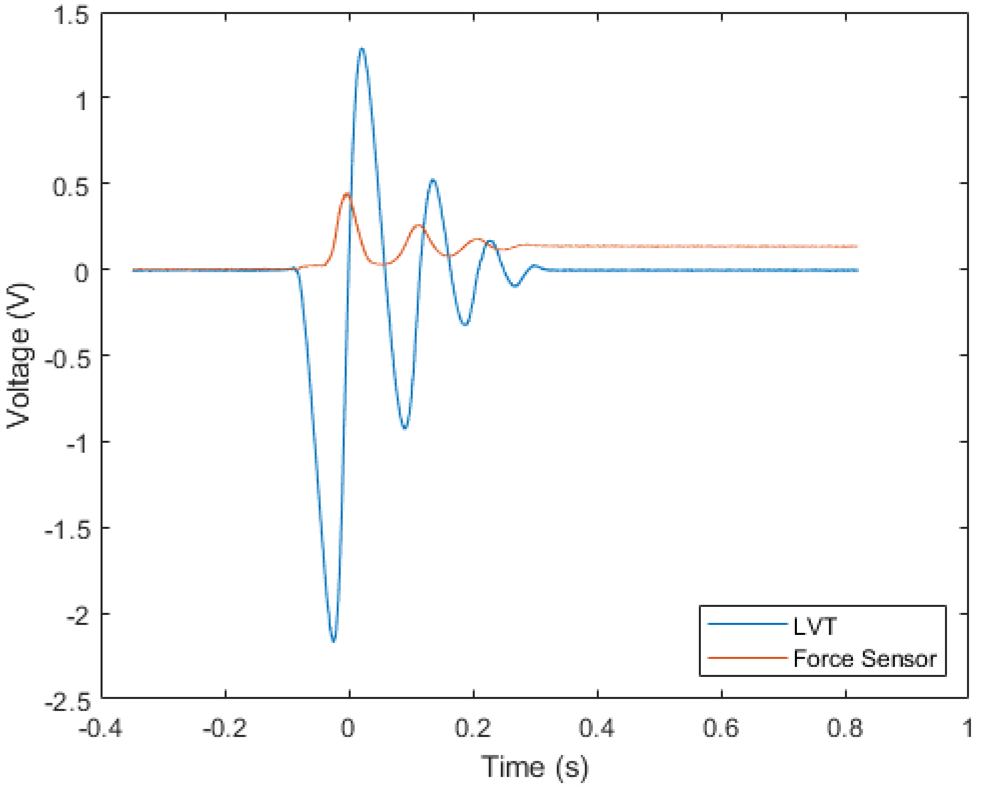


d) **Calculate the maximum velocity of the core.**

A speed of 18.46 in/s was observed from the core and occurred during the first contact of the foam when the force of gravity was overcome by the spring and damping force of the foam onto the core.

e) **Plot the LVT and force sensor output vs. time. Using the sensitivity of the force sensor, 0.491 volts/lbf, find the force on the foam at maximum velocity of the core, and the steady-state force between the foam and the core. Finally, calculate the total mass of the core with attached sensors.**

Force at Vmax (lbf)	**.22**
Force at Steady State (lbf)	**.27**
Total Mass of Core (lbm)	**.0085**


1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
Voltage (V)
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Time (s)
LVT
Force Sensor

Code

```
%Charlie Nitschelm, 11/13/19
clear all
close all

addpath('C:\Users\User\Desktop\Charlie\Classes\Senior Year\S-Lab\Lab4\1');
addpath('C:\Users\User\Desktop\Charlie\Classes\Senior Year\S-Lab\Lab4\2.1.3');
addpath('C:\Users\User\Desktop\Charlie\Classes\Senior Year\S-Lab\Lab4\2.1.4');
addpath('C:\Users\User\Desktop\Charlie\Classes\Senior Year\S-Lab\Lab4\2.2.1');
addpath('C:\Users\User\Desktop\Charlie\Classes\Senior Year\S-Lab\Lab4\3.1');
addpath('C:\Users\User\Desktop\Charlie\Classes\Senior Year\S-Lab\Lab4\3.2');
```

Part 1

```
% a.)
Weight     = [10.1 60.1 110.1 160.1 210.1 260.1 310.1 360.1]./28.35;
Increasing = [937 1015 1095 1173 1246 1330 1412 1484]./1000;
Decreasing = [936 1015 1096 1175 1249 1331 1413 1491]./1000;

% reading in data from accelerometer
Acc_Volt   = xlsread('Instrument_2 Capture 2019-10-31 15-14-13 Oscilloscope - Waveform Data.csv', 'A7:A100006');
t          = 0:1.024e-5:(1.024e-5) * 1e5;
t          = t(1:end-1);
dV         = 103/1000;


a          = polyfit(Weight, Increasing, 1);
Sensitivity       = a(1);
Cal_curve  = a(1)*Weight + a(2);

figure(1)
plot(Weight, Increasing, Weight, Decreasing, Weight, Cal_curve);
xlabel('Weight [oz_{f}]');
ylabel('e_{o} [V]')
title('Output voltage vs Weight')
legend('Increasing', 'Decreasing', 'Calibration Curve','Location', 'northwest')
text(8, 1.1, strcat({'Sensitivity: '}, num2str(Sensitivity,4), ' V/oz_{f}'))
grid on




% b.)

smooth               = 4;
[Acc_Volt, smooth]   = wsmooth(Acc_Volt, t, smooth);
Acc_Volt             = Acc_Volt - Acc_Volt(1);
```

```
min = -.1;
for j = 1:length(Acc_Volt)
    if Acc_Volt(j) <= min
        min = Acc_Volt(j);
    else
    end
end

zeta_overshoot    = 0.45;
p_overshoot = 0.1524/0.6819;
meff              = (dV/a(1));
Acc_Volt          = Acc_Volt.*-1;

%find peaks now
th = 0.01;
[peakLoc, peakMag] = peakfinder(Acc_Volt, th);
peakLoc(1)         = [];
peakMag(1)         = [];
% finding damped natural frequency
Td                 = 1/(t(peakLoc(2)) - t(peakLoc(1)));
wd                 = Td*2*pi;                        % wd

figure(2)
plot(t, Acc_Volt, t(peakLoc), peakMag, 'd')
xlabel('Time (s)')
ylabel('Position ( )')


for j = 1:length(peakLoc)
    y(j)          = log(peakMag(1)/peakMag(j));
end

n = 0:length(y)-1;
dampr         = zeros(1, length(peakLoc));

for jj = 1:length(peakLoc)
    num            = ((1/length(n))*log(peakMag(1)/peakMag(jj)));
    dampr(jj) = num/(sqrt(4*pi^2 + num^2));
end
zeta               = mean(dampr);
wn                 = wd/(sqrt(1 - zeta_overshoot^2));    % wd = wn*sqrt(1-zeta^2)
[rad/s]
spring_Const       = (meff*(wn/(2*pi))^2)/(32.2 * 12);   % ozf/in


figure(4)
plot(t, -1*Acc_Volt);
title('Output voltage vs. Time')
xlabel('Time [s]');
ylabel('e_{o} [V]')
```

```
text(0.5, 0.4, strcat({'Spring Constant, K: '}, num2str(spring_Const,4), '
oz_{f}/in'));
text(0.5, 0.33, strcat({'Natural Frequency, \omega_{n}: '}, num2str(wn,4), ' rad/s'));
text(0.5, 0.27, strcat({'Effective Mass, m_{eff}: '}, num2str(meff,4), ' oz_{m}'));


% c.)
sens1              = (meff*Sensitivity)/386;                    % V/(in/s2)
% d.)
max_acc            = (Increasing(end))/sens1;
% e.)
num                = [1];
den                = [1/(wn^2) ((2*zeta_overshoot)/wn) spring_Const];
sys                = tf(num, den);


% bode plot of data motherfucker!
figure(3)
bode(sys)
grid on


% da plots
```

Part 2 Piezoelectric Force Sensor

Part 2.1

```
piezo_weight    = 0:200:1600;                         % grams
piezo_weight    = (piezo_weight./453.6);
voltage    = [0 23 44 69.8 85 106 126 141 167]; % mV

b          = polyfit(piezo_weight, voltage, 1);
sensitivity2      = b(1);
cal_curve2 = b(1)*piezo_weight + b(2);

for j = 1:length(voltage)

    residual(j) = abs(voltage(j) - cal_curve2(j));

end

max_error  = max(residual);
percent_FS = max_error/voltage(end);

% Plots
figure(5)
plot(piezo_weight, voltage, '-o', piezo_weight, cal_curve2, '-o')
text(0.25, 160, strcat({'Sensitivity: '}, num2str(sensitivity2,4), ' mV/lb_{f}'));
text(0.25, 150, strcat({'Percent Full: '}, num2str(percent_FS*100,4), ' %'));
title('Calibration Curve for piezo force sensor');
xlabel('Weight [lb_{f}]');
ylabel('Voltage [mV]');
legend('Data', 'Calibration Curve', 'Location', 'southeast');

num_peaks  = 2;
time_e     = .00460 - .00446;
nat_freq   = 2*pi*(num_peaks/time_e);

%reading in data of voltage
volt_data  = xlsread('Instrument Capture 2019-10-31 14-39-55 Oscilloscope - Waveform
Data.csv', 'A6:A12008'); % Volt
t          = 0:1e-6:(1e-6)*12002;
t          = t(1:end-1);



figure(6)
plot(t, volt_data);
xlabel('Time [s]');
ylabel('Voltage [V]');
title('Voltage vs. Time for Piezoelectric Force Sensor');

% Part 2.2
impulse_mass  = 2; %in lbf
impulse_volt  = xlsread('Impulse Loading.xlsx' ,'A7:A100007');
impulse_t  = t:2.4030e-5:(2.4030e-5)*100000;
impulse_t  = impulse_t(1:end-1);

%plot(impulse_time, impulse_volt)

th = 0.005;
[peakLoc, peakMag] = peakfinder(impulse_volt, th);
peakLoc(1)         = [];
peakMag(1)         = [];
% Damped Natural Frequency
n_peaks            = length(peakLoc);
Td                 = 1/(impulse_t(peakLoc(2)) - impulse_t(peakLoc(1)));
wd                 = Td*2*pi;                         % wd
%
figure(7)
plot(impulse_t, impulse_volt, impulse_t(peakLoc), peakMag, 'o')
xlabel('Time [s]')
ylabel('Voltage [mV]')
title('Peaks of Piezo Accelerometer Data')


for j = 1:length(peakLoc)
    y(j)          = log(peakMag(1)/peakMag(j));
end
```

```
n = 0:length(y)-1;
dampr         = zeros(1, length(peakLoc));

for jj = 1:length(peakLoc)
    num            = ((1/length(n))*log(peakMag(1)/peakMag(jj)));
    dampr(jj) = num/(sqrt(4*pi^2 + num^2));
end

impulse_zeta               = mean(dampr);
impulse_wn                 = wd/(sqrt(1 - impulse_zeta ^2));  % 6/(1.6396 - 1.2787)  %
this comes from counting

impulse_springConst        = (impulse_mass*(impulse_wn/(2*pi))^2)/(32.2*12);
impulse_dampCoeff          = ((2*impulse_zeta)/impulse_wn);

impulse_volt = impulse_volt(49393:end);
impulse_volt = impulse_volt - impulse_volt(1);
impulse_t = impulse_t(49393:end);
impulse_t = impulse_t - impulse_t(1);


impulse_num                = [1];
impulse_den                = [1/(impulse_wn^2) (2*impulse_zeta)/impulse_wn
impulse_springConst];
impulse_sys                = tf(impulse_num, impulse_den);
[force, x]                 = impulse(impulse_sys, impulse_t(end));

figure(8)
plot(x, 0.00094*force, impulse_t, impulse_volt)
xlabel('Time [s]'); ylabel('Voltage [V]');
title('Impulse Response - Simulated and Actual')
legend('Simulated Response', 'Data')
```

Part 3

```
LVT_Acc = xlsread('LVTandAccel.csv', 'A8:A100007');
Acc = xlsread('LVTandAccel.csv', 'B8:B100007');
Time = linspace(-.34745,-.34745+0.00001168*100000,100000)';

%part a
figure(9)
plot(Time,LVT_Acc)
hold on
plot(Time,Acc)
xlabel('Time (s)')
ylabel('Voltage (V)')
legend('LVT Output','Accelerometer Output')
```

```
Acc_Fall = -.09; %Volts for 1g
Sens_Acc = abs(Acc_Fall/(32.2*12)) %volts/in/sec2

% At t = -.06, object starts falling and is constant till t=-.04
for x = 1:100000
    if Time(x)>-.06
        t1_x = x;
        break
    end
end

for x = 1:100000
    if Time(x)>-.04
        t2_x = x;
        break
    end
end

Change_V = (32.2*12)*.02;
Delta_Voltage = abs(LVT_Acc(t2_x) - LVT_Acc(t1_x));
Sens_LVT_Acc = Delta_Voltage/Change_V %volt/in/sec
```

```
%b

Acc_In = Acc./Sens_Acc;
Acc_In = Acc_In - mean(Acc_In(1:1500));
LVT_Acc_In = LVT_Acc./Sens_LVT_Acc;


Int_Acc = cumtrapz(Time,Acc_In);
figure(10)
plot(Time,Int_Acc,Time,LVT_Acc_In)
xlabel('Time (s)')
ylabel('Velocity (in/s)')
```

C

```
LVT_Force = xlsread('LVTandForce.csv', 'A8:A100007');
Force = xlsread('LVTandForce.csv', 'B8:B100007');
Force = Force-mean(Force(1:100));
%beginning of the drop
for x = 1:100000
    if Acc_In(x)<-30
```

```
        x_drop = x;
        break
    end
end

%first contact of core and foam
for x = 1:100000
    if Force(x)> .03
        x_hit = x;
        break
    end
end

%max displacement --- max force!

Force_Max = max(Force);
for x = 1:100000
    if Force(x)== Force_Max
        x_maxdisp = x;
        break
    end
end

% finding first bounce
th = 0.03;
[peakLoc, peakMag] = peakfinder(Force, th,'minima',-1);
figure(11)
plot(Time,Force,Time(peakLoc),Force(peakLoc))

x_firstbounce = peakLoc(2); %possible, might not be a bounce, very close

%permanent contact
% once it hits foam, it doesnt seem to bounce at all


figure(12)
plot(Time,LVT_Acc)
hold on
plot(Time,Acc)
plot(Time(x_drop),LVT_Acc(x_drop),'o',Time(x_hit),LVT_Acc(x_hit),'o',Time(x_maxdisp),L
VT_Acc(x_maxdisp),'o',Time(x_firstbounce),LVT_Acc(x_firstbounce),'o')
text(.25,-.5,strcat('Beg. of Drop is ' ,{' '},num2str(Time(x_drop)),{' '}, 'sec'))
text(.25,-.75,strcat('First mass contact is' ,{' '},num2str(Time(x_hit)),{' '},
'sec'))
text(.25,-1,strcat('Max disp. is' ,{' '},num2str(Time(x_maxdisp)),{' '}, 'sec'))
text(.25,-1.25,strcat('Possible first bounce is ' ,{'
'},num2str(Time(x_firstbounce)),{' '}, 'sec'))
text(.25,-1.5,'Permanent contact after first bounce')

xlabel('Time (s)')
ylabel('Voltage (V)')
```

```
legend('LVT Output','Accelerometer Output')
```

```
Warning: The threshold must be a real scalar. No threshold will be used.
```

d. maximum velocity of core

```
LVT_Acc_In;



Max_Vel = max(abs(LVT_Acc_In)) %in/s

%%e
figure(13)
plot(Time,LVT_Force,Time,Force)
legend('LVT','Force Sensor','location','southeast')
xlabel('Time (s)')
ylabel('Voltage (V)')



Force_lbf = Force./.491; %lbf

for x = 1:100000
    if abs(LVT_Acc_In(x))== Max_Vel
        x_maxvel = x;
        break
    end
end

Force_maxvel = Force_lbf(x_maxvel)
Force_steady = mean(Force_lbf(end-1000,end))

total_mass = Force_steady/32.2
```