TERM PROJECT FOR STRUCTURAL DYNAMICS

Part a, Introduction:

This entry is about my term project for structural dynamics course. A model three storey shear building was built with the help of our professor and together with the other students, and accelerometers were placed on each floor to measure accelerations. We put braces on one direction of the building to make it mostly vibrate in a specific direction. On the top of the building, a battery powered motor was placed to simulate harmonic vibrations caused by a motor working inside a building. There was also another motor connected to the ground that shook the ground as it was rotating. The mass of each floor was arranged to be similar. So, additional masses were placed on the second and the third floor. We tried to make the second floor to not vibrate in second vibration mode.

After the completion of the building, accelerometers were hooked up to the lab computer and each student was asked to get the periods and mode shapes of the building by doing several tests on it.

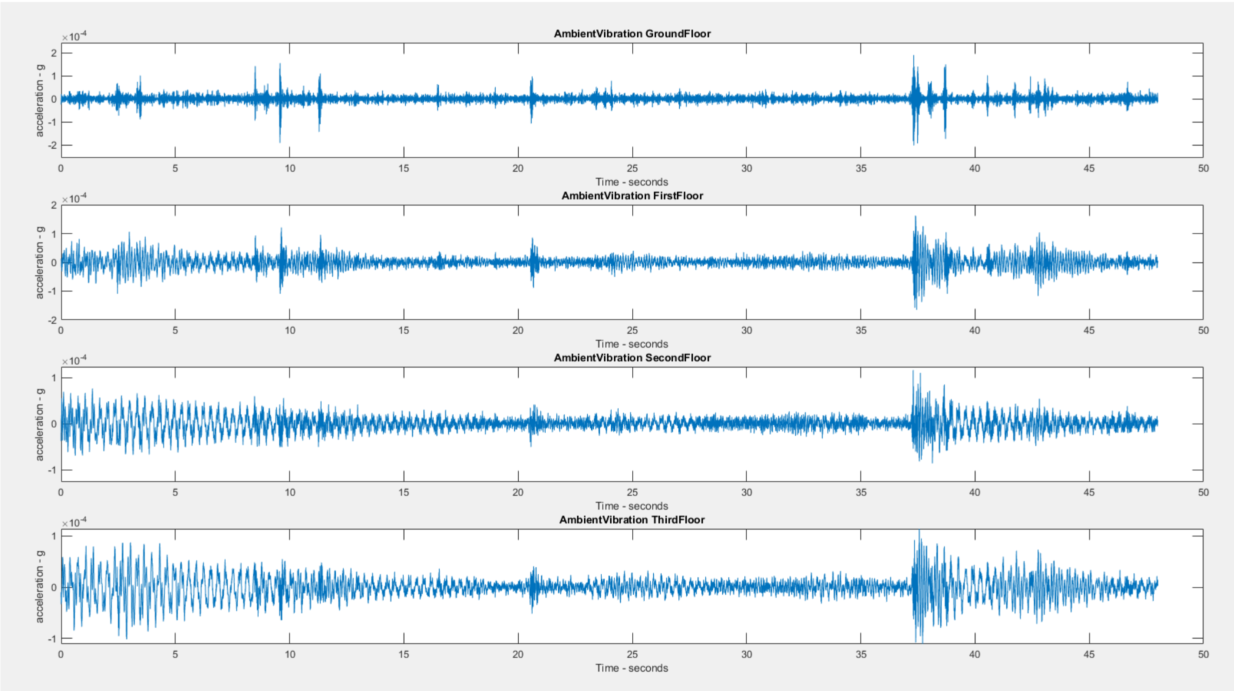
I first recorded the ambient vibration and later ran the motor connected to the ground. I changed the motor frequency to obtain the modes of vibration. Once the shaking of the building amplified, it became evident that it was vibrating in one of its modes. I kept the motor at that frequency for a while then changed to get the other modes. I wasn’t able to exactly get to the third mode because the motor frequency maxed out. From the type of the movement, it could be understood which mode the vibration belongs to. Then, I ran the small motor on the top and took some measurements. I finally hit the building quickly with my hand to take some measurements as it vibrated.

In the end, I analyzed the data and did some calculations using the program MATLAB to reach the obtained results below.

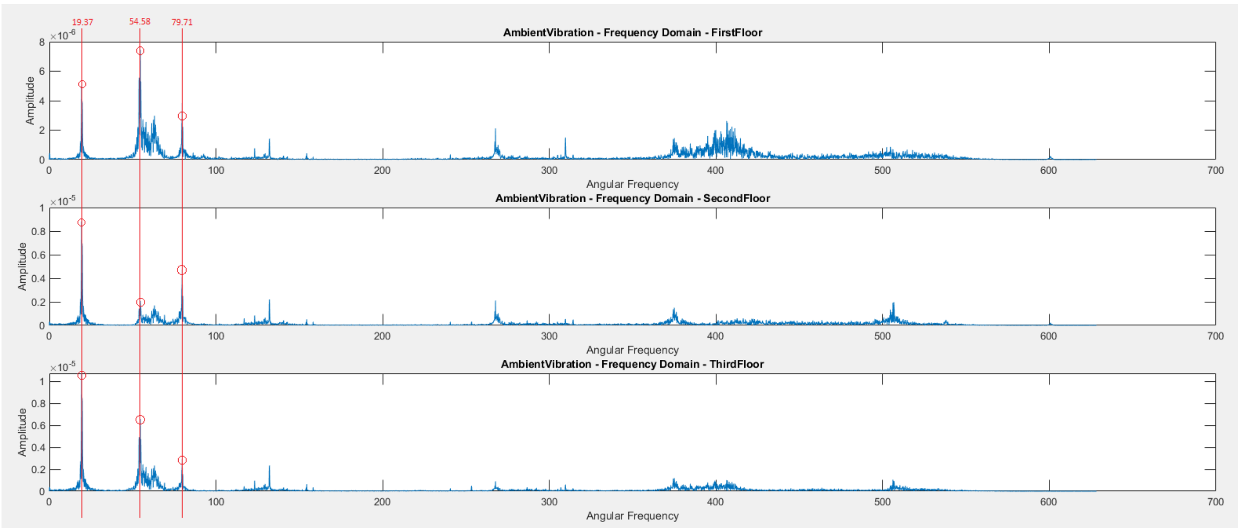
Part b, Project calculations:

Theory: The fact that the frequencies creating a signal can be found using complex plane is used in this project. If I can put the vibration around a circle in complex plane and calculate the centroid of the curve for each instant, I can find the dominating frequencies in the signal. When plotting frequency and signal frequency collide, the centroid moves unusually away from the centre in the complex plane. If I keep track of the length of centroid and keep changing the frequency, I can get the peaking values. Fourier Transform or Fast Fourier Transform does this in a machine friendly manner.

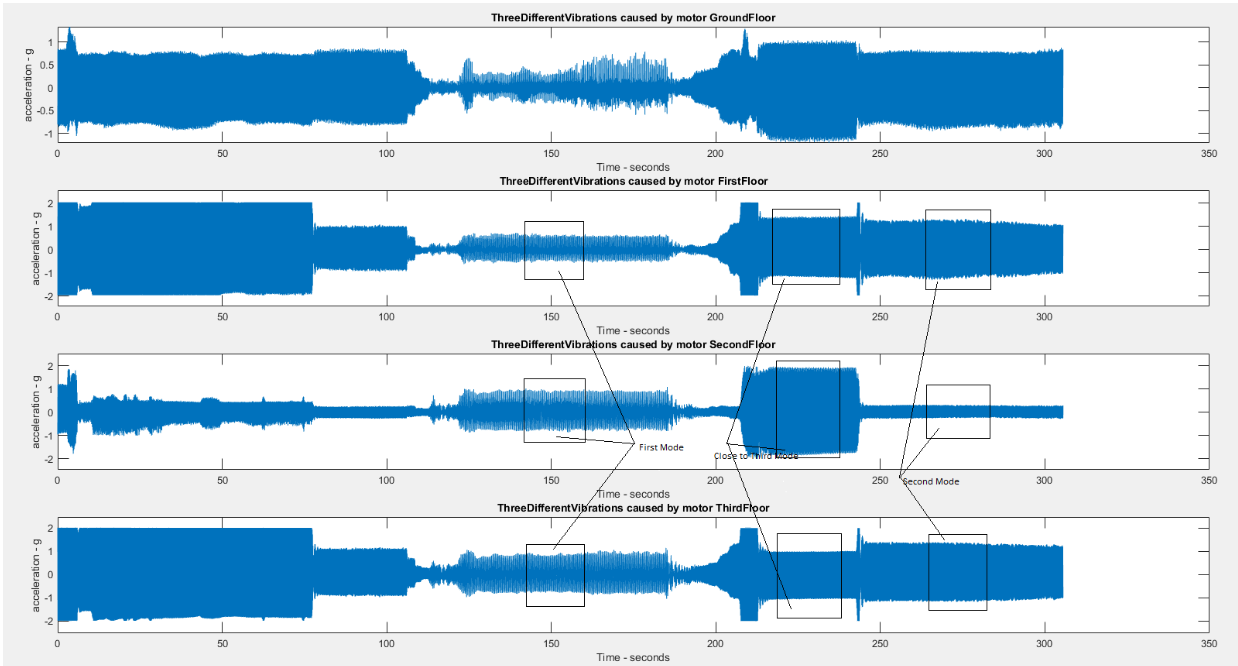
```
clear all;
close all;
clc;

load 'AmbientVibration_1g.txt';
load 'ThreeDifferentVibrations_g.txt';
load 'ForceVibration1_g.txt';
load 'ForceVibration2_g.txt';
load 'ForceVibration3_g.txt';
load 'HarmonicVibration_g.txt';

Dt = 0.005;

t1 = 0:Dt:48;
t2 = 0:Dt:305.495;
t3 = 0:Dt:33.995;
t4 = 0:Dt:24.995;
t5 = 0:Dt:23.995;
t6 = 0:Dt:143.995;

%Plot of the vibrations for each floor

%First the Ambient Vibration

for i=1:4

subplot(4,1,i);
plot(t1,AmbientVibration_1g(:,i));
title('AmbientVibration_1g');
ylabel('acceleration - g');
xlabel('Time - seconds');

end
```



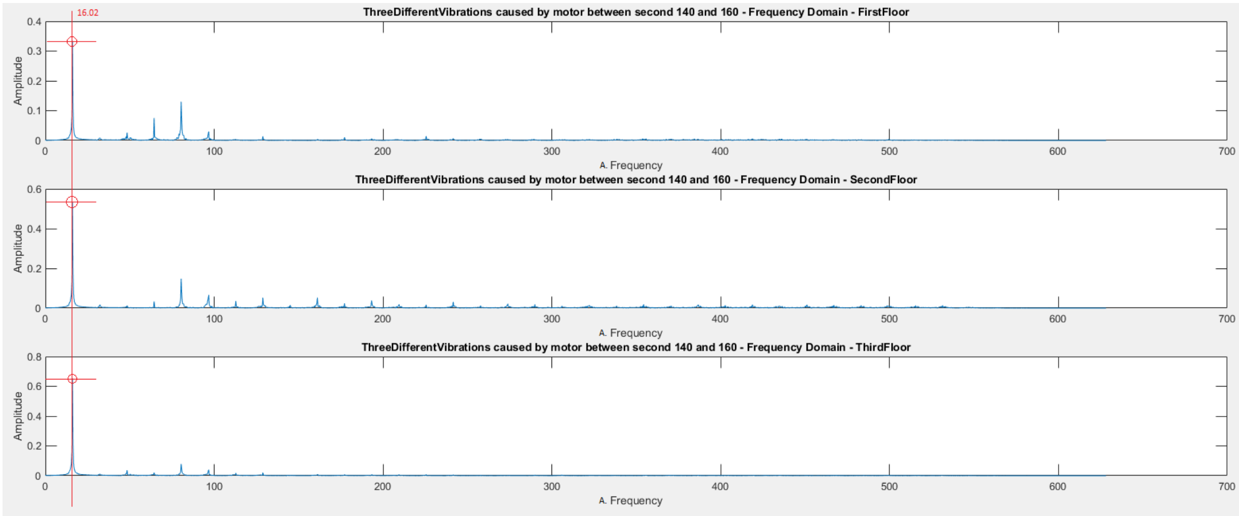

```
%Doing a Fourier Transformation to go in frequency domain to see the peaks in
f.
%Built in MATLAB Function fft is used.

for i=2:4

complex_num_result=fft(AmbientVibration_1g(:,i));
L=length(complex_num_result);
Dt=200; % 200 Samples/second
P2 = abs(complex_num_result/L); %two-sided spectrum
P1 = P2(1:L/2+1); %single-sided spectrum
P1(2:end-1) = 2*P1(2:end-1);
f = Dt*(0:(L/2))/L;
fft_result = (2*pi)*f;

subplot(4,1,i);
plot(fft_result,P1);
title('AmbientVibration_1g - Frequency Domain');
ylabel('Amplitude');
xlabel('Frequency');

%From here I have some information about frequencies and periods right
%away. Some of the significant peaks happen at 19.37, 54.58 and 79.71.
%So far these look like mode 1, 2 and 3 respectively. Further analysis with
%other data will make this clearer. Ts look like from here 0.32 sec,
%0.115 sec and 0.0787 sec.

end
```



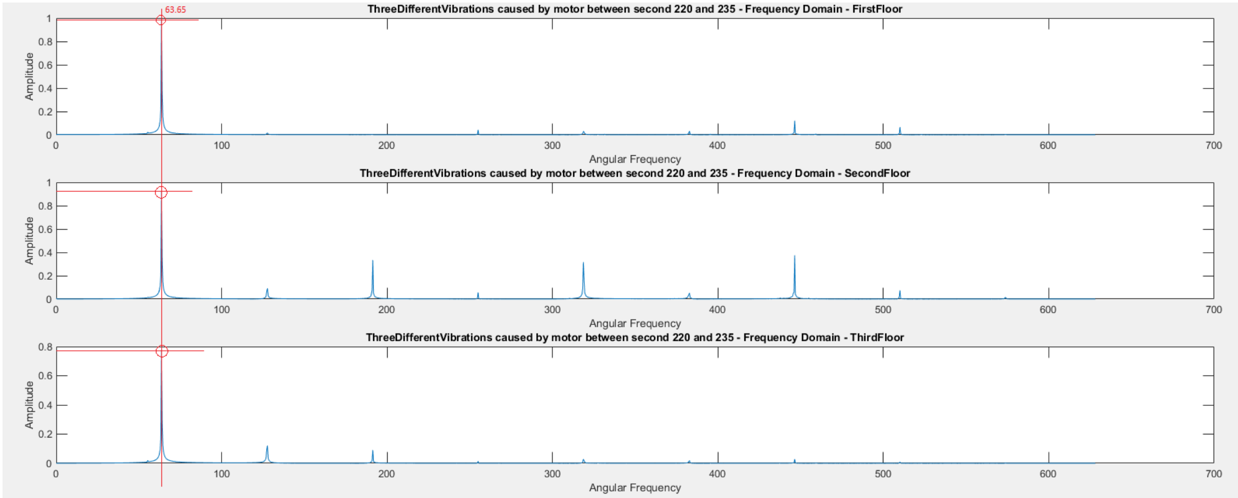

```
%Plot of the three different vibrations for each floor

for i=1:4

subplot(4,1,i);
plot(t2,ThreeDifferentVibrations_g(:,i));
title('ThreeDifferentVibrations_g');
ylabel('acceleration - g');
xlabel('Time - seconds');

%When data is examined closely, vibration patterns can be separated easily.
%To see which mode it is, the accelerations for each floor can be analysed.
%If they have similar sign mostly for all three floors, then it is most
likely
%first mode and so on. Also, I can work on frequency domain to verify further
%the assumptions made.

end
```



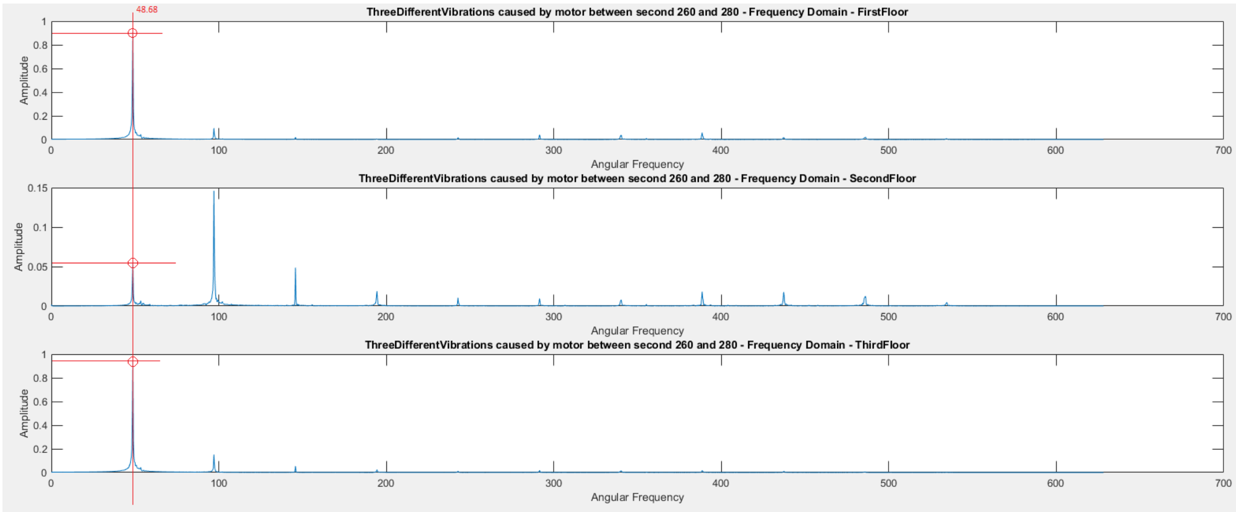

```
%Let's say I look at time between 140 and 160 seconds. It looks like mode 1
%from initial inspection steps described above. Taking the fft to see what
%happens in that interval:

for i=2:4

  %140*1/Dt = 140*200 = 28000
  %160*1/Dt = 160*200 = 32000

complex_num_result=fft(ThreeDifferentVibrations_g(28000:32000,i));
L=length(complex_num_result);
Dt=200; % 200 Samples/second
P2 = abs(complex_num_result/L); %two-sided spectrum
P1 = P2(1:L/2+1); %single-sided spectrum
P1(2:end-1) = 2*P1(2:end-1);
f = Dt*(0:(L/2))/L;
fft_result = (2*pi)*f;

subplot(4,1,i);
plot(fft_result,P1);
title('ThreeDifferentVibrations_g - Frequency Domain');
ylabel('Amplitude');
xlabel('Frequency');

%From this I know that this is mode 1 with frequency this time calculated as
% 16.02 period being 0.3922. There are other small peaks there but they
%are insignificant and they are there because of structural imperfections.

end
```




```
%The second interval that this time looks like mode 3 starts from
%approximately 210 sec and extends till 240 sec. But from experiment
%time I know that I couldn’t reach to mode 3 exactly due to limitations.
%So this data is expected to have mostly mode 3 response but together with
%the negligible influence of other modes. I will analyse between 220 and 235
sec
%with fft to see what happens.

for i=2:4

  %220*1/Dt = 220*200 = 44000
  %235*1/Dt = 235*200 = 47000

complex_num_result=fft(ThreeDifferentVibrations_g(44000:47000,i));
L=length(complex_num_result);
Dt=200; % 200 Samples/second
P2 = abs(complex_num_result/L); %two-sided spectrum
P1 = P2(1:L/2+1); %single-sided spectrum
P1(2:end-1) = 2*P1(2:end-1);
f = Dt*(0:(L/2))/L;
fft_result = (2*pi)*f;

subplot(4,1,i);
plot(fft_result,P1);
title('ThreeDifferentVibrations_g - Frequency Domain');
ylabel('Amplitude');
xlabel('Frequency');

%From this I know that my assumptions are correct, this is almost mode 3 with
frequency this time calculated as
% 63.65 period being 0.0987.

end
```



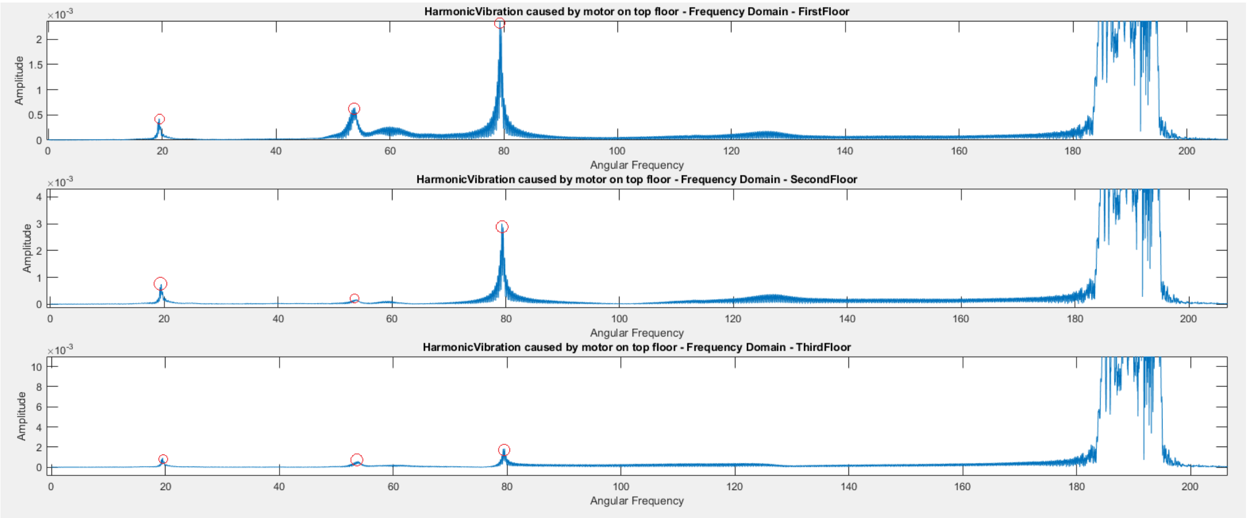

```
%From experiment time, I know that the last chunk of data was mode 2. The
%vibration starts and settles somewhere between 245 and 250 seconds and
continues
%until the motor is shut down. I will look between 260 and 280 seconds.

for i=2:4

  %260*1/Dt = 260*200 = 52000
  %280*1/Dt = 280*200 = 56000

complex_num_result=fft(ThreeDifferentVibrations_g(52000:56000,i));
L=length(complex_num_result);
Dt=200; % 200 Samples/second
P2 = abs(complex_num_result/L); %two-sided spectrum
P1 = P2(1:L/2+1); %single-sided spectrum
P1(2:end-1) = 2*P1(2:end-1);
f = Dt*(0:(L/2))/L;
fft_result = (2*pi)*f;

subplot(4,1,i);
plot(fft_result,P1);
title('ThreeDifferentVibrations_g - Frequency Domain');
ylabel('Amplitude');
xlabel('Frequency');

%From this I know that my assumptions are correct, this is mode 2 with
frequency this time calculated as
% 48.68 period being 0.129 sec.

end
```




```
%Mode shapes can be gathered both from frequency domain or time domain.

%If I look at the peak values in frequency domain where there are the
%modes, and proportion the peaks with each other I get the mode shapes. The
%reason for this is those frequencies are accumulated at that value of
frequency
%since the motor rotates very close or at the frequency of one of the modes
at the
%chosen points.

%Another way is to look at the proportion of relative accelerations in an
interval in time domain and
%get values. Both should give very close answers.


%From frequency domain, the mode shapes are found to be:
%For mode 1: 0.510; 0.818; 1
%For mode 2: 0.96; 0.0581; -1
%For mode 3: -1.227; 1.19; -1


%From time domain, the mode shapes are found to be:

%For mode 1:

for i=2:4

 %140*1/Dt = 140*200 = 28000
 %160*1/Dt = 160*200 = 32000

ModeShape1(i-
1)=mean(abs(ThreeDifferentVibrations_g(28000:32000,i)))/mean(abs(ThreeDiffere
ntVibrations_g(28000:32000,4)));

%The following values are calculated: 0.5410; 0.8973; 1
```

```
end

%For mode 2:

for i=2:4

 %260*1/Dt = 260*200 = 52000
 %280*1/Dt = 280*200 = 56000

ModeShape2(i-
1)=mean(abs(ThreeDifferentVibrations_g(52000:56000,i)))/mean(abs(ThreeDiffere
ntVibrations_g(52000:56000,4)));

%The following values are calculated: 0.96; 0.15; -1

end

%For mode 3:

for i=2:4

 %220*1/Dt = 220*200 = 44000
 %235*1/Dt = 235*200 = 47000

ModeShape3(i-
1)=mean(abs(ThreeDifferentVibrations_g(44000:47000,i)))/mean(abs(ThreeDiffere
ntVibrations_g(44000:47000,4)));

%The following values are calculated: -1.28; 1.26; -1

end

%For the calculations above, the more data is taken, the more it will
%approach to the real mode shapes observed. However, for the point of this
%project these are close enough.

%For Harmonic Vibrations Case, I can again do a fft and see the peaks:

for i=2:4

complex_num_result=fft(HarmonicVibration_g(:,i));
L=length(complex_num_result);
Dt=200; % 200 Samples/second
P2 = abs(complex_num_result/L); %two-sided spectrum
P1 = P2(1:L/2+1); %single-sided spectrum
P1(2:end-1) = 2*P1(2:end-1);
f = Dt*(0:(L/2))/L;
fft_result = (2*pi)*f;

subplot(4,1,i);
plot(fft_result,P1);
title('HarmonicVibration_g - Frequency Domain');
ylabel('Amplitude');
```

```
xlabel('Frequency');


%The unusual high peaks observed from these plots come from the harmonic
%excitation frequency. After some point, that becomes dominant in the
%vibration

end
```




```
%Forced Vibrations can also be analysed using similar procedures or by
%counting peak distances etc. Similar stuff will come at the end.
```

Summary of Results:

Periods from Ambient vibration:
0.32 sec | 0.115 sec | 0.0787 sec
Periods from Three Different Vibrations:
0.3922 sec | 0.129 sec | 0.0987 sec
Mode Shapes from Frequency Domain:
For mode 1: 0.510 ; 0.818; 1
For mode 2: 0.96 ; 0.0581; -1
For mode 3: -1.227; 1.19; -1
Mode Shapes from Time Domain:
For mode 1: 0.5410 ; 0.8973 ; 1
For mode 2: 0.96 ; 0.15 ; -1
For mode 3: -1.28 ; 1.26 ; -1