11/29/2021

AuE-608 Vehicle Testing

Vehicle Dynamics-

Ride Dynamics Laboratory

Name:

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Executive summary:

a. By using previous spring rate constant with recorded vertical load on right front tire estimate the un sprung mass of the wheel.
b. By using simplified derivative of undamped 2- mass quarter car model estimates the expected eigen frequencies of sprung and un sprung mass.
c. To perform Fourier-transform on recorded data and know the power spectral density for various runs.
d. To identify the eigenfrequencies of sprung and un sprung masses in the resulting frequency.
e. To distinguish vibrations caused by (harmonic) road irregularities and by rotational parts of the vehicle from the from the eigenfrequencies of the quarter car model.
f. To know the differences between the force data from the transducer wheel, the accelerometer readings, and the ride height information. What quantities constitute inputs, outputs, and states of the system.

Introduction:

- Purpose of testing:

a. To develop an understanding of the behavior of the dynamic vehicle in order to have better chance of optimizing future vehicles for ride comfort and for dynamic performance.

- General information of the topic:

➢ The motion of the vehicle generated by various input actions, through which the vehicle is capable of independent motion. This static measurement explains us about the motion of the vehicle for a given input (steer, weight, camber…), and explains us the mechanics of vehicle motion. • These measurements are used to calculate the weight to of a vehicle by placing four corner scales around.

- The measurements of the linear and angular dimensions of all categories are taken under testing.
- The spring rate of the vehicle is also calculated by placing different loaded sandbags in the trunk of the vehicle and weights that are indicated on four corner scales.
- The ride height of the vehicle is also calculated under static measurements.
- Even, the center of gravity of the vehicle is also considered under these measurements.
- The steering angles of a vehicle is also considered by placing vehicle onto front alignment plates of 4-post lift and then, all positions are taken to get the accurate angle.
- The widely used in determining the wheel dimensions and trackwidth of a vehicle.

Materials and Methods:

Materials:

1) The testing vehicle during Lab session given was **Mazda RX-8**.
2) The **Tape measurer** is used to calcite the different ride heights of a vehicle and to determine the C.G of a vehicle.
3) The **Four corner scales** are used to provide the vehicle weight under loading conditions.
4) The **accelerometers** let us to measure the forces caused by turning, accelerating or braking in the vehicle.
5) The **EDAQ** (data acquisition system) only data acquisition system on the market today that plugs directly into the vehicle network, while also allowing collection of additional analog signals including strain and acceleration.

Methods:

1) The instrumented Mazda RX8 vehicle is used for testing.

2) The vehicle is setup with the set of sensors:

   a. Accelerometers (2)
   b. Ride height sensor (2)
   c. Force transducing wheel (1)
   d. Velocity sensor

3) For the quarter car modeling, it is focused on the right front wheel. The two accelerometers are mounted on the lower control arm (un sprung mass) and on the strut tower (sprung mass).

4) Then, the setup of the car and the sensor configuration is pre-checked once again and all measurements is taken and all the information which is necessary to conduct is collected.

5) The data recording is done on the EDAQ (data acquisition system) system.

6) We should make sure that everything is working correctly and perform some basic tests to ensure the correct functionality of all sensors.

7) Also, we need to assure ourselves that data can be properly saved and ensure that the recorded data is used.

8) Now we split into two groups and each group need to perform driving tests and data recording on the parking provided lot around CGEC as well as on Research Drive.

9) While driving we need to ensure that the surface in the parking lot can be considered 'stochastic' where as the cobble stone surface of Research Drive will cause some structured inputs to the system. We need to record runs on different surfaces at different velocities.

10) During collecting the information, ensure proper recording and labeling of the data.

Results and discussions:

1. Utilize the previously determined spring constant, as well as the recorded vertical load on the right front tire. You will also need an estimate of the un sprung mass of the wheel. Perform a literature search to come up with an estimate of a typical un sprung mass on one wheel of a car such as the Mazda RX8. From this data, use the simplified derivation for an undamped 2-mass quarter car model (as performed in class) to estimate the expected eigenfrequencies of the sprung and un sprung masses.

   - A model with two masses and two springs is created with spring constants K1 and K2. K1 represents the spring constant of the vehicle's coil spring multiplied by the motion ratio. This is the effective spring rate of the wheel's motion. K2 is the spring rate of the tire. The wheel and tire combination were measured to be 21.5kg.

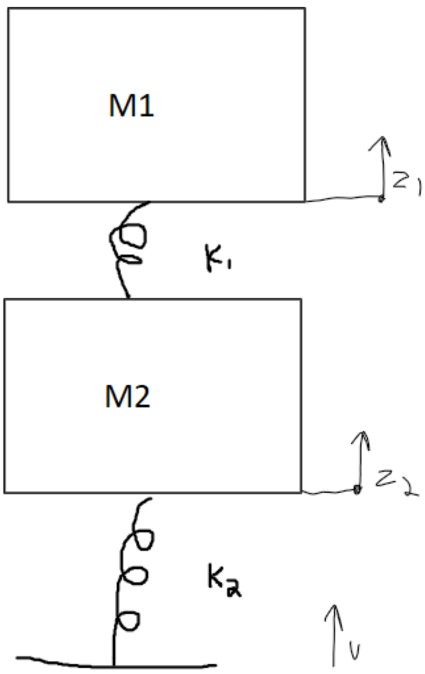


Figure 1

The equations governing the motion of mass 1 and mass two are as follows

$$m_1\ddot{z}_1 = k_1(z_2 - z_1)$$

Equation 1

$$m_2\ddot{z}_2 = k_2(u - z_1) \text{ -} k_1(z_2 - z_1)$$

Equation 2

The natural frequency for a similar problem with one mass and one spring is as follows

$$\omega = \sqrt{\frac{k}{m}}$$

Equation 3

Mass two can be thought of as an interface between two springs in series. The effective spring rate of two springs in series can be expressed as a function of each individual spring rate

$$k_{series} = \frac{k_1 k_2}{k_1 + k_2}`$$

Equation 4

W1 becomes:

$$\omega_1 = \sqrt{\frac{k_1 k_2}{k_1 + k_2} * \frac{1}{m_1}}$$

Equation 5

The front spring rate value of 39,000N/m obtained previously was used, and a tire spring rate of 264,000N/m at 2.4 bar. The tire spring rate was obtained from a Michelin engineer. The vehicle's weight was previously measured to be 1498kg when loaded with two passengers. This was divided by four to estimate M1 The calculation for the natural frequency. Given that M2 is much smaller that M1, the mass of M2 is neglected. The calculation is then as follows:

$$\omega_1 = \sqrt{\frac{10^3 * (39 * 264)}{10^3 * (39 + 264)} * \frac{1}{364.5}} = 0.523$$

Equation 6

The wheel, represented by M2, is pushed from above by the spring with constant k1, and from below from the tire with spring rate k2. These springs act in parallel. One assumption made is that M1 is fixed when calculating the natural frequency of M2. The spring can then be though of as springs in parallel. The equation to determine the natural frequency in this case becomes:

$$\omega_2 = \sqrt{\frac{k_1 + k_2}{1} * \frac{1}{m_1}} = \sqrt{\frac{10^3 * (39 + 264)}{1} * \frac{1}{21.5}} = 118.7hz$$

Equation 7

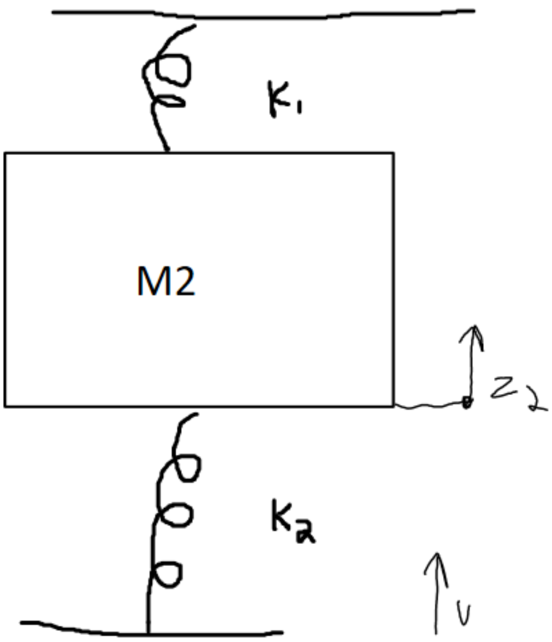
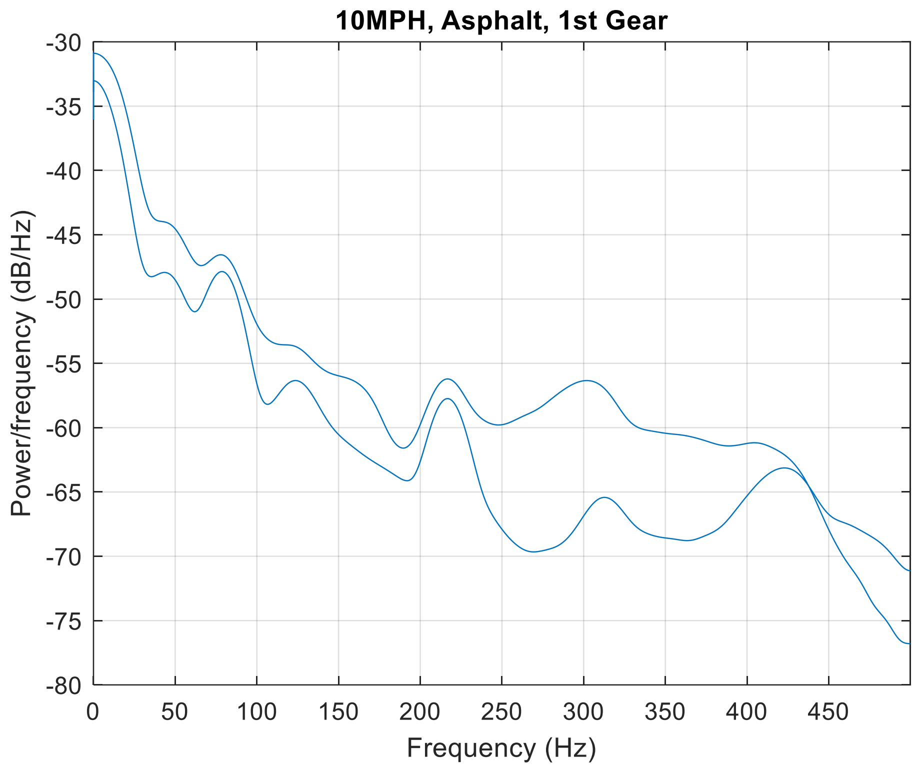


Figure 2

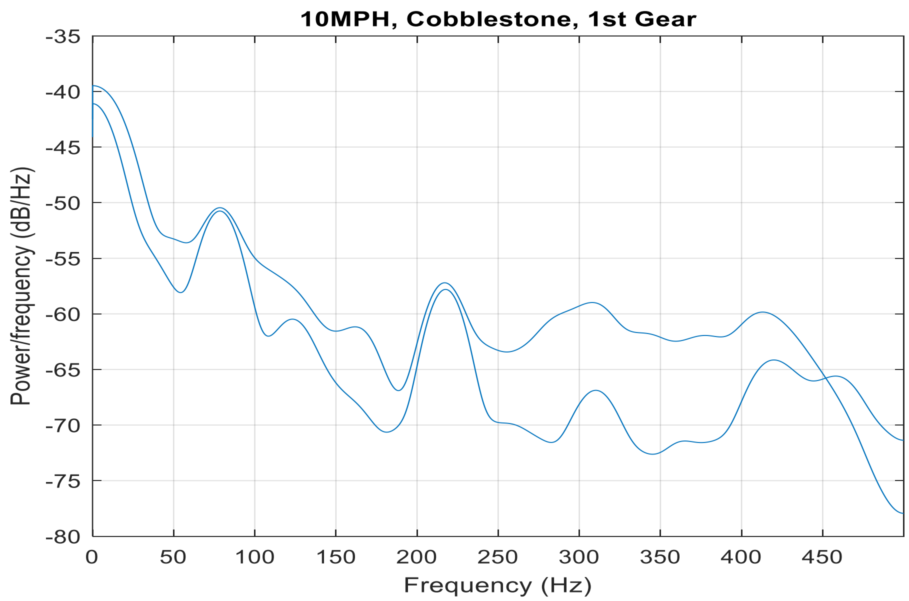
2. Perform a Fourier Transform on your recorded data and plot the Power Spectral Density for the various runs. You will have to match the sampling rate and number of output frequency bins to the recorded data (and the physical system). Perform the necessary prefiltering of the data before a discrete technique such as FFT is applied.

   - Power Spectral Density plots were created for the strut tower and control arm accelerations using MATLAB's PSD function from the signal processing toolbox. Only five out of six datasets were used because one of the datasets had three data modes instead of two. The source of the third data mode is unknown, so the dataset will not be used. In all plots, the PFD for the body acceleration is below the control arm acceleration. This is because of the damping from the shock absorber.

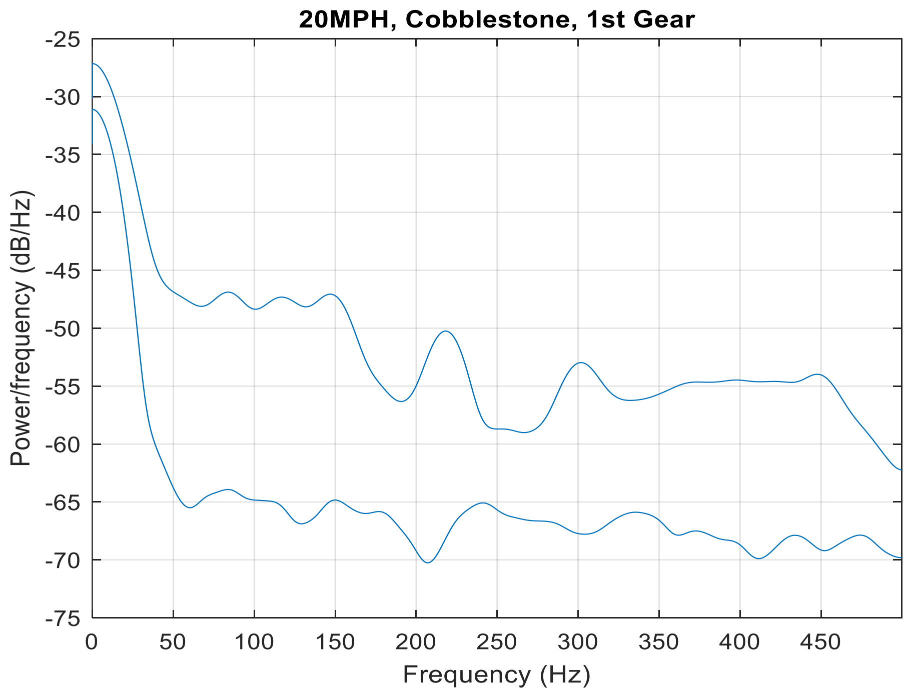
Plot 1


10MPH, Asphalt, 1st Gear
Power/frequency (dB/Hz)
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
0
50
100
150
200
250
300
350
400
450
Frequency (Hz)

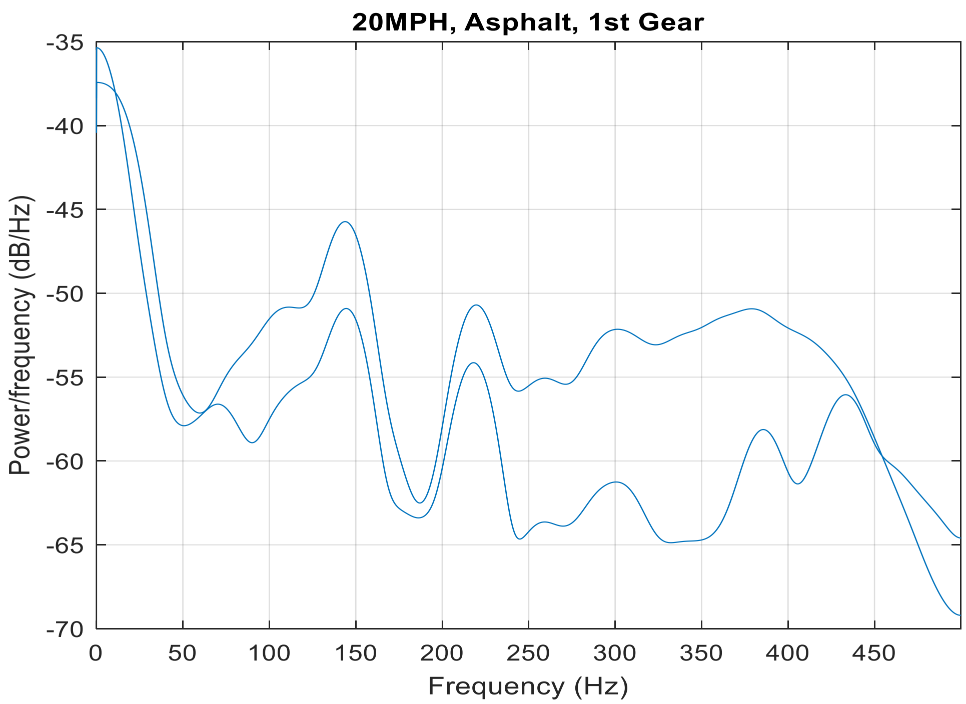
Plot 2


10MPH, Cobblestone, 1st Gear
Power/frequency (dB/Hz)
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
0
50
100
150
200
250
300
350
400
450
Frequency (Hz)

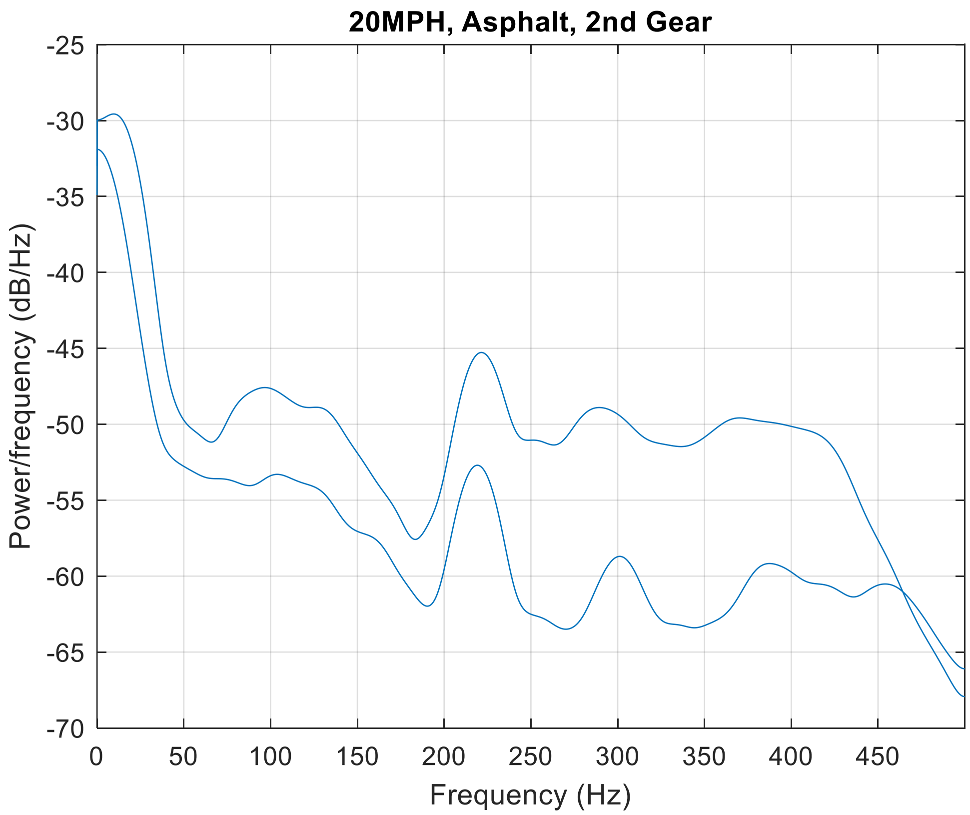
Plot 3


20MPH, Cobblestone, 1st Gear
Power/frequency (dB/Hz)
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
0
50
100
150
200
250
300
350
400
450
Frequency (Hz)

Plot 4


20MPH, Asphalt, 1st Gear
Power/frequency (dB/Hz)
-35
-40
-45
-50
-55
-60
-65
-70
0
50
100
150
200
250
300
350
400
450
Frequency (Hz)

Plot 5



3. Can you identify the eigenfrequencies of sprung and un sprung masses in the resulting frequency plot? Are they different from the previous estimates and if so, what would be the reasons for this? Which of the recorded data channels can you utilize to identify these frequencies? Which channel/sensor is most suitable for this analysis?

   - Every plot maintains large peaks below 10hz. This probably corresponds to the natural frequency of the wheel as calculated above. In all cases, there is a peak between 200 and 250hz. This frequency does not vary with rpm, speed, or road surface type. It is possible that this is the vehicle body natural frequency. Peaks around the theorized 118hz also exist, but they are not as abundantly clear as the ones between 200hz and 250hz. The difference between the theorized and actual frequencies is likely due to the simplifying assumptions made in the quarter car model and the difference in weight between the measured rx8 wheel and the wheel force sensor.

   - The Fz reading from the wheel force sensor is a much cleaner output than the one obtained from the accelerometers. It exhibits less random noise. This is expected given the relative cost of the devices. It tracks the control arm acceleration almost exactly because of the f=ma relationship. The Fz is likely the most suitable sensor to use for data analysis.

4. In your Power Spectral Density, you will likely encounter a variety of peaks. How can you distinguish vibrations caused by (harmonic) road irregularities and by rotational parts of the vehicle from the from the eigenfrequencies of the quarter car model? Demonstrate your answer with your recorded data.

   - The vibrations from the road surface vary in PSD plots when the road surface is changed but everything else is kept constant. For example, in the plots at 20mph in first gear on cobblestone and asphalt, one can see that the vibrations between 50hz and 150hz are more intense on cobblestone than they are on asphalt. These vibrations are likely due to the change in road surface. The peaks below 10hz and between 200hz and 250hz are present in all plots under all conditions and they are likely properties of the vehicle.

5. Comment on the differences between the force data from the transducer wheel, the accelerometer readings, and the ride height information. What quantities constitute inputs, outputs, and states of the system?

   - The acceleration from the control arm and strut tower tracks each other very closely, but the acceleration of the strut tower is lower over much of the data. This is due to the damping provided by the spring and shock absorber. The spring ideally does not dampen motion, but energy lost to friction internally is released as heat and has a small damping effect in reality. The suspension bushings undergo torsion and dampen the motion by converting kinetic energy in the wheel to heat in the bushings.
   - Fz is an input to the vehicle that results in a change in vehicle state. The control arm acceleration is an output given the input of the force, but it does not describe the state of the vehicle itself. The acceleration of the vehicle strut tower is a value that describes the state of the vehicle.

Conclusions:

1. The inherent vehicle natural frequencies can be found by varying test conditions and determining what doesn't change in the PSD plot.
2. The road frequencies can be found by varying the road surface and seeing what peaks do change.

References:

1. Lab - Vertical Dynamics.pdf
2. Static tests of vehicles, machines, equipment and parts (bosmal.eu) •
3. https://www.garageliving.com/blog/4-post-car-lift/
4. https://www.eng-tips.com/viewthread.cfm?qid=104278

Appendix:

Functions to run the MATLAB:

```
function [data] = processvd(filename)

data = readlines(filename);
file_length = length(data)-1;
data1_start = find(contains(data,'DM_Start='))+1;
data1_end = find(contains(data,'DM_DataMode2='))-2;
data = data(data1_start:data1_end,:);
data = split(data);
data(:,1) = split(data(:,1));
time = split(data(:,1),'T');
time = split(time(:,2),':');
time =
str2double(time(:,1))*3600+str2double(time(:,2))*60+str2d
ouble(time(:,3));
time = time-time(1);
%data(:,1) = time;
data = [time str2double(data(:,2:end))];

function [data] = processvd(filename)

data = readlines(filename);
file_length = length(data)-1;
data_start = find(contains(data,'DM_DataMode2='))+1;
data = data(data_start:file_length-1,:);
data = split(data);
data(:,1) = split(data(:,1));
time = split(data(:,1),'T');
time = split(time(:,2),':');
time =
str2double(time(:,1))*3600+str2double(time(:,2))*60+str2d
ouble(time(:,3));
time = time-time(1);
%data(:,1) = time;
data = [time str2double(data(:,2:end))];
```

```
MATLAB Run file:

run1_data1 = processvd('1_cobble_10kph_2400rpm.txt');
run1_data2 = processvd2('1_cobble_10kph_2400rpm.txt');

run2_data1 = processvd('2_smooth_10kph_2400rpm.txt');
run2_data2 = processvd2('2_smooth_10kph_2400rpm.txt');
```

```
run3_data1 =
processvd('3a_smooth_20kph_4200rpm_1strun.txt');
run3_data2 =
processvd2('3a_smooth_20kph_4200rpm_1strun.txt');

run4_data1 = processvd('4_high_smooth_high.txt');
run4_data2 = processvd2('4_high_smooth_high.txt');

run5_data1 = processvd('5_high_rough_low_4200.txt');
run5_data2 = processvd2('5_high_rough_low_4200.txt');

% run6_data1 = processvd('6_high_rough_high_2500.txt');
% run6_data2 = processvd2('6_high_rough_high_2500.txt');

%% PSD
figure(1)
plot(psd(spectrum.welch,run1_data2(:,5),'Fs',Fs,'NFFT',le
ngth(run1_data2(:,5))));
hold on
plot(psd(spectrum.welch,run1_data2(:,4),'Fs',Fs,'NFFT',le
ngth(run1_data2(:,4))));
title('10MPH, Asphalt, 1st Gear')

figure(2)
plot(psd(spectrum.welch,run2_data2(:,5),'Fs',Fs,'NFFT',le
ngth(run2_data2(:,5))));
hold on
plot(psd(spectrum.welch,run2_data2(:,4),'Fs',Fs,'NFFT',le
ngth(run2_data2(:,4))));
title('10MPH, Cobblestone, 1st Gear')

figure(3)
plot(psd(spectrum.welch,run3_data2(:,5),'Fs',Fs,'NFFT',le
ngth(run3_data2(:,5))));
hold on
plot(psd(spectrum.welch,run3_data2(:,4),'Fs',Fs,'NFFT',le
ngth(run3_data2(:,4))));
title('20MPH, Asphalt, 1st Gear')

figure(4)
plot(psd(spectrum.welch,run4_data2(:,5),'Fs',Fs,'NFFT',le
ngth(run4_data2(:,5))));
hold on
plot(psd(spectrum.welch,run4_data2(:,4),'Fs',Fs,'NFFT',le
ngth(run4_data2(:,4))));
title('20MPH, Asphalt, 2nd Gear')
```

```
figure(5)
plot(psd(spectrum.welch,run5_data2(:,5),'Fs',Fs,'NFFT',le
ngth(run5_data2(:,5))));
hold on
plot(psd(spectrum.welch,run5_data2(:,4),'Fs',Fs,'NFFT',le
ngth(run5_data2(:,4))));
title('20MPH, Cobblestone, 1st Gear')


%% FFT
Fs = 1000;              % Sampling frequency
T = 1/Fs;
L = 2080
t = (0:L-1)*T;
Y = fft(run5_data2(:,4))
P2 = abs(Y/L);
P1 = P2(1:L/2+1);
P1(2:end-1) = 2*P1(2:end-1);
f = Fs*(0:(L/2))/L;
plot(f,P1)
plot(Y)



%% Comparing given data
figure(1)
plot(run1_data1(:,6))
figure(2)
hold on
plot(run1_data2(:,5))
hold on
% plot(run1_data2(:,4))
legend('Fz','Strut Tower','Control arm')


%%%%%%%%%%%%%%%%%
%{
For data 1 files
1:time
2:Mz
3:theta
4:My
5:Fy
6:Fz

for data 2 files
```

```
1:time
2:Ride_height.RN_1
3:fx
4:control arm acc
5:StrutwrACC
6:Mx
%}
```