EM 406 Vibrations
LAB 4: Frequency Response for MDOF systems

In this lab you will be taking frequency response data for a 2-DOF and analyzing it in Matlab. Details of the equipment and what to do if you are not getting data are in previous lab descriptions and will not be included in this document.

<u>For you to do in lab</u>:

<u>Taking Data</u>
Input a swept sine for a 2-DOF system. The system should be configures as follows:

- Use the 1000 g on each cart
- Use 2 springs with the same stiffness spring (preferable the light spring) on the left side of cart 1 and the right side of cart 2 and the stiff spring between the masses as shown in Figure 1.

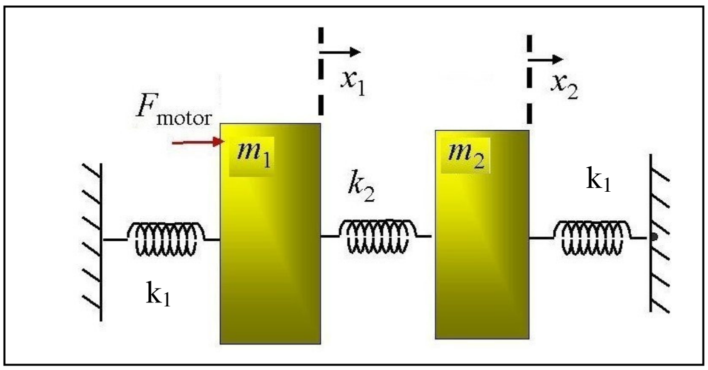

Figure 1 – Two DOF system

- Take swept sin data using “lab_four_2DOF_swept.mdl”
- **Watch the system closely during this test and record your observations.** Save your data for future analysis. Be sure to record any observations you will want to include you your lab write-up. For example, after the first resonance there is a frequency where the amplitude of the first mass gets very small. At what frequency did this happen?

<u>Analysis</u>
Task 1
Determine the FRF magnitude and phase for x_1 and x_2 using the built-in Matlab command tfestimate. You may just use all the data with no averaging. I would like results presented in two figures with subplots as shown below:

FRF magnitude for x_1 using semilogy. Frequencies from 0 to 7.5 Hz	FRF phase for x_1. Frequencies from 0 to 7.5 Hz
FRF magnitude for x_2 using semilogy. Frequencies from 0 to 7.5 Hz	FRF phase for x_2. Frequencies from 0 to 7.5 Hz

And

Real part of FRF for x_1. Frequencies from 0 to 7.5 Hz. Do not use log axes.	Imaginary part of FRF for x_1. Frequencies from 0 to 7.5 Hz. Do not use log axes.
Real part of FRF for x_2. Frequencies from 0 to 7.5 Hz. Do not use log axes.	Imaginary part of FRF for x_2. Frequencies from 0 to 7.5 Hz. Do not use log axes.

Note: the command to get the real part of a complex variable is real(Txy) and to get the imaginary part it is imag(Txy). The imaginary part will be used in Task 2 to determine the mode shapes.

Task 2
Identify the frequency and damping for each mode using the "peak-pick" method discussed in Lab 4. Fill out the table provided in the worksheet. The notes from Lab 3 are repeated below for your convenience.

If the magnitude plot looks like the curve shown in Figure 2, that is, it has small damping, then the damping ratio can be estimated from the half-power points as shown in Eq. 10.66 in the text. For convenience this equation is shown in Eq. 1.

$$\zeta_i \approx \frac{\omega_b - \omega_a}{2\omega_n} \tag{1}$$

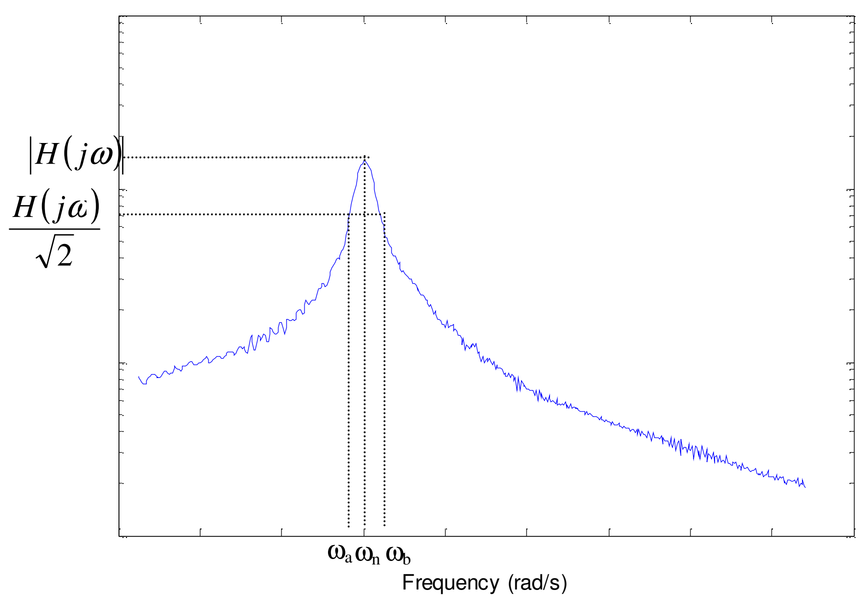

Figure 2 – Typical FRF magnitude

The natural modes can be determined from the imaginary part of the FRF. Assuming the first natural frequency is ω_1 then the first mode will be:

$$\{\phi\}_1 = \begin{Bmatrix} X_1 \\ X_2 \end{Bmatrix}_1 = \begin{Bmatrix} \text{imaginary part of the FRF for } x_1 \text{ at } \omega = \omega_1 \\ \text{imaginary part of the FRF for } x_2 \text{ at } \omega = \omega_1 \end{Bmatrix}$$

Questions to discuss: How do the frequencies and damping compare using the two different FRFs? How do the mode shapes compare to what you observed during the swept sin test?

Task 3 – Identify each frequency and damping assuming a SDOF model

Identify the frequency and damping for each mode using fminsearch for each FRF. Assume each individual peak can be considered a single-degree-of-freedom system. Select a band of frequencies that you will use to fit your model as shown in Figure 3. You should be able to use the same m-files used in lab 5 or lab 4 once you save your data in the appropriate format.

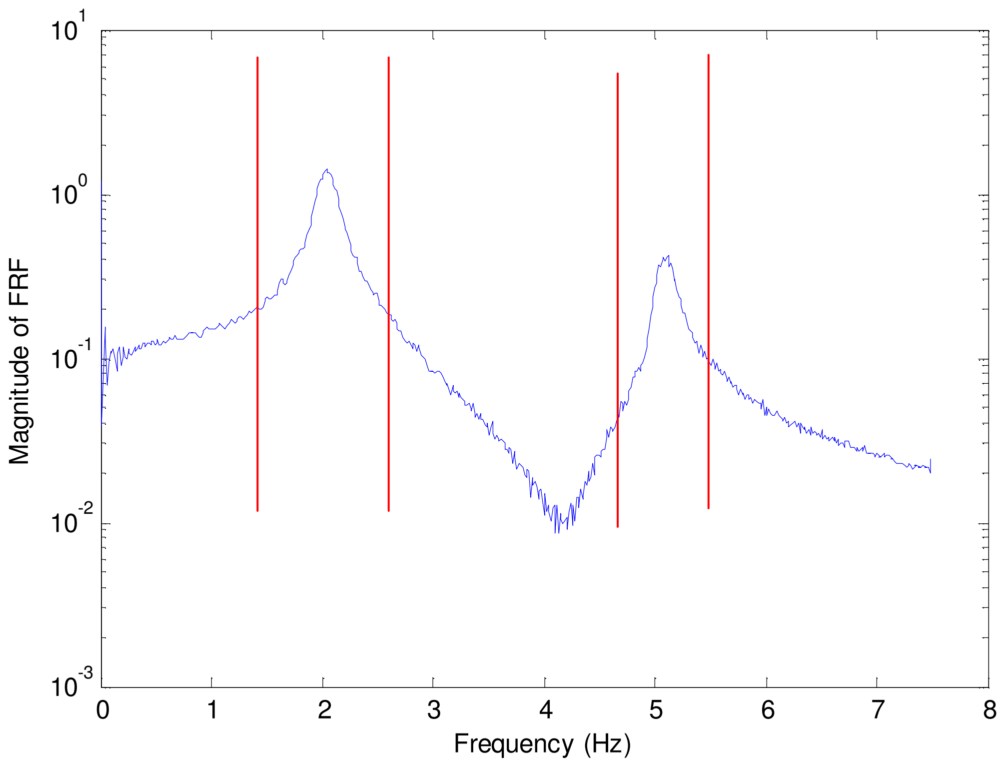

Figure 3 – Typical FRF for a 2-DOF system and frequency bands used for fitting.

Task 4 – Fit both modes together.

Rather than selecting a frequency band let try to identify both modes at once. You still may want to eliminate the low frequency data (below about 0.3 Hz). As a transfer function let's try to use a fairly general one as shown in Eq. 2.

$$G(s) = \frac{K_1 + K_2 s + K_3 s^2}{\left(s^2 + 2\zeta_1\omega_1 s + \omega_1^2\right)\left(s^2 + 2\zeta_2\omega_2 s + \omega_2^2\right)} \tag{2}$$

We will use Eq. 1 to try and identify all of our parameters. To generate the theoretical magnitude plot we will use the built-in Matlab command called “bode”. Therefore your function routine called by fminsearch should look something like the code shown in Figure 4.

```
function J = lab8(x)
% I’m assuming the inputs are
% x(1) = omega1
% x(2) = omega2
% x(3) = zeta1
% x(4) = zeta2
% x(5) = K1
% x(6) = K2
% x(7) = K3
% the experimental data is in the file twoDOF_freq_resp_x2.mat I’m assuming
% the frequency is in Hz and the variables are called “freq” and “mag”
Load twoDOF_freq_resp_x2
s=tf(‘s’)
TF = (x(5)+x(6)*s+x(7)*s^2)/((s^2+2*x(1)*x(3)*s+x(1)^2)*(s^2+2*x(2)*x(4)*s+x(2)^2))
ww = freq*2*pi;    % be sure to convert freqs. to rad/sec
maggie = bode(TF,ww);  % the calculates the magnitude of the FRF at ww
maggie = maggie(:);  % converts maggie to a vector
J = norm(mag - maggie);
```

For mass 1 your result should look similar to Figure 4. Your initial conditions are very important, **so will want to look at your initial guess to see if it looks fairly close to your experimental data**. You do this by plotting your theoretical curve with your initial parameters verses your experimental data. My initial guess was around of K_1 = 15,000, K_2 = 10 and K_3 = 30. You may need a different initial guess for your system.

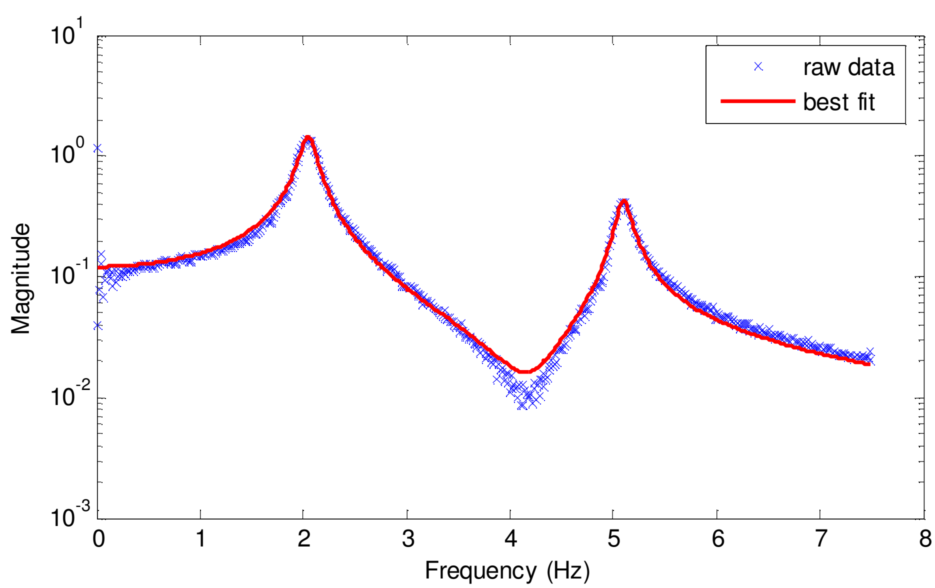

Figure 4 – Typical FRF magnitude plot and a best fit curve for mass 1.

Use this transfer function for mass 2 and identify the system parameters. Your result should look similar to Figure 5.

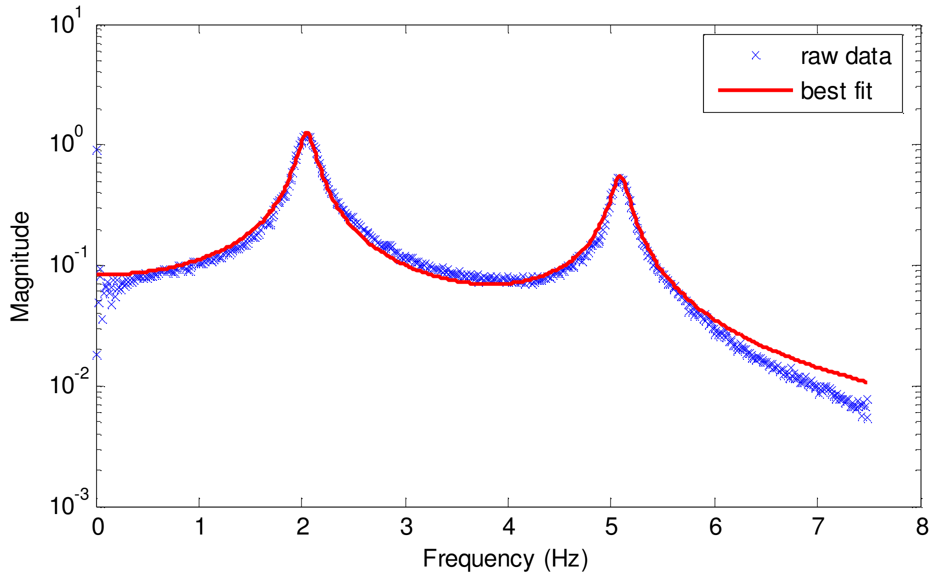

Figure 5 – Typical FRF magnitude plot and a best fit curve for mass 2.

In the field of experimental modal analysis there has been considerable work done in the area called "curve fitting", which is basically determining frequencies, damping and mode shapes using frequency response data. We will discuss some of these techniques in lab next week, but conceptually they are really no different from what we are doing with fminsearch. The main difference is that these techniques will fit the complex data rather than just the magnitude of the FRF.

I would like you to report your results in the form of a memo.

Listing of common mistakes I've seen in the past:

Formatting/Style

1. The first sentence/paragraph of the memo is very important. It should tell the reader the purpose of the memo and the lab and should provide a roadmap to the rest of the memo.
2. Use the equation editor for all equations.
3. Discuss the figures immediately after they are presented.

Figures and Tables

1. All figures and tables should be embedded in the text and should appear after the reference to them.
2. All figures need to have a figure number and a title (both below the figure) and need to be referred to by number in the text.
3. Size of text should be readable.

4. No gray area in a figure, i.e. do not use the Excel default or a screen capture in Matlab.
5. Do not put figures in an appendix – I want them embedded in the text.
6. All tables need a table number and title (above the table) and need to be referred to by number in the text.

General comments on why memos are poor:

1. All results not reported.
2. Poor discussion of results.
3. Poor quality of writing.

Since this memo requires a memo it will be with twice as much as a worksheet lab.

Lab #4 Worksheet – System Identification of MDOF systems

Names: ____________________ ______________________ ______________________

Date: _____________________________

Table 1 – Summary of results for 2-DOF system using the peak-pick method						
Task	data	ω_1	ω_2	ζ_1	ζ_2	Mode 1 = $\{\phi\}_1=\left\{ \quad \right\}$
Task 2 (Peak pick)	x_1					
	x_2					Mode 2 = $\{\phi\}_2=\left\{ \quad \right\}$

Table 2 – Summary of results using fminsearch (Note: The K_1 and K_2 for Task 3 are different than the K_1 and K_2 for Task 4.)								
	data	ω_1	ζ_1	K_1	ω_2	ζ_2	K_2	K_3
Task 3 (using fminsearch treating each mode as a SDOF)	x_1							NA
	x_2							NA
Task 4 (using fminsearch using a 2-DOF model)	x_1							
	x_2							

Observations: In the memo be sure to discuss any observations you made while performing this lab. Be sure to answer any questions asked in the lab handout and include all necessary plots and tables. You discussion should be THOROUGH!! Comment on an make observations from your results.