DO NOT REMOVE FROM LABORATORY

Operating Instructions for the Vibration Experiment

MAE171a/MAE175a

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> **NOTE**: *make sure to handle the accelerometers attached to your structure with care. They are sensitive devices and dropping them on the table or the ground will damage them due to exposure to accelerations beyond the operating range.*

1 Powering up equipment

Please follow the following procedure when turning on the equipment. Improper start-up will result in an automatic shutdown of the LDS amplifier that drives the shaker table.

1. Turn the **dial gain button on the front of the LDS amplifer all the way left (counter clock wise)** for zero gain amplification.
2. Turn on power strip on the back of the table.
3. Wait till the LDS amplifier displays `08` on the LED screen
4. Push the white control button to enable the LDS amplifier to 'ready'. If the LDS is ready, LDS amplifier displays `00` on the LED screen and both 'on' and 'ready' green LED's are on.
5. Turn on the Piezotron Coupler boxes that are connected to the accelerometers placed on your structure
6. Check if the SOURCE output of the HP analyzer is connected to the BNC input 1 of the LDS amplifier on the back using a BNC cable.
7. Now turn on the HP Analyzer with the on/off button on the front.

2 Powering down equipment

1. Turn the **dial gain button on the front of the LDS amplifer all the way left (counter clock wise)** for zero gain amplification.
2. Push the white control button to disable the LDS amplifier. If the LDS is disabled, LDS amplifier displays `07` on the LED screen and the 'ready' green LED is off and the red 'interlock' LED in on.
3. Now turn off the HP Analyzer with the white button on the front.
4. Turn off the power strip on the back of the table.
5. Turn off the Piezotron Coupler boxes that are connected to the accelerometers placed on your structure

3 Sinusoidal experiments (week 1)

With the HP Analyzer you can create an excitation (source) signal for the LDS amplifier and measure the response of the structure via accelerometers on 2 different channels. You are now ready to perform your experiments. For details on how to use the HP Analyzer to perform your experiments, see the instructions below.

This section tells you how to set up the HP Analyzer[1] to generate sinusoidal signals as excitation (source) signal for the LDS amplifier. Follow the instructions carefully, as improper use of excitation signals may result in an automatic shutdown of the LDS amplifier that drives the shaker table and/or damage to the equipment.

1. Before you start your experiment, make sure the **floors in the small-scale building has been set to the right distance**. Every group works with a different building configuration, so ask your instructor/TA for the right floor distances.

2. Turn on the equipment as described in Section 1.

3. Make sure the **dial gain button on the LDS amplifer is turned all the way left (counter clock wise)** for zero gain amplification before changing the source signal!

4. With the HP35670A Dynamic Signal Analyzer turned on, press the Source and then F1 button to toggle the source **ON** or **OFF**. Make sure to set the source to **OFF** before setting up the source signal.

5. Press the Source and then F2 button to set up the level of the source. Make sure the source level is set to **0.1 Volt peak to peak** by typing the level .1 and then pressing the F1 button.

6. Press the Source and then F8 button to select a **Fixed Sine** as a source. Immediately after this you need to select the frequency of your sine. This can be done by typing the frequency (say 10) and then pressing the F2 button for a 10 Hz sine. Alternatively, you can also use the dial on the HP35670A Dynamic Signal Analyzer to 'dial-in' the desired frequency.

   NOTE: *the frequency resolution (step size in which you can change the frequency) depends on the record length. Typically, a record length of 8 sec will give you a resolution of 1/8 = 0.125 Hz. For more information on specifying the record length, see Section 4 below.*

7. Again press the Source and then F1 button to toggle the source **ON**.

8. Slowly and slightly turn the dial gain button on the LDS amplifer to the right (clock wise) to increase the gain amplification to see the effect of the sinusoidal source signal. **Do not increase the gain on the LDS amplifier too much, as this leads to excessive vibrations**.

4 Displaying time domain data

This section tells you how to set up the HP35670A Dynamic Signal Analyzer to measure time domain signals via the Piezotron Coupler boxes that are connected to the accelerometers placed on your structure. You can place the accelerometers at different locations on your structure due to the wax connection, but be careful not to drop them!

[1] In particular, the Hewlett Packard HP35670A Dynamic Signal Analyzer

NOTE: *make sure to handle the accelerometers attached to your structure with care. They are sensitive devices and dropping them on the table or the ground will damage them due to exposure to accelerations beyond the operating range.*

1. Turn on the equipment as described in Section 1.
2. Make sure the Piezotron Coupler boxes are turned on and have enough battery power (test with flipping switch to top position).
3. With the HP35670A Dynamic Signal Analyzer turned on, press the Meas Data and then the F2 button to select both channels 1 and 2.
4. Press the Meas Data and then the F5 button to display the time signals of channel 1 and 2.
5. Press the Scale and then the F1 to toggle **Autoscaling** ON or OFF. Best to turn **Autoscaling ON**. You should now see the signals on your screen after a measurement record has been completed.
6. To display data over a specific (shorter) time interval, you can press the Freq and then the F8 to specify the record length. For example, type in .5 and then press the F1 button for a record length of 0.5 seconds.

   NOTE: *Changing the record length influences the frequency resolution (step size in which you can change the frequency). A record length of T sec will give you a resolution of $1/T$ Hz. Example: record length of 0.5 seconds will lead to a resolution of only 2 Hz.*

5 Saving Data

The data measured on HP35670A Dynamic Signal Analyzer can either be saved on a floppy disk interface or directly loaded into Matlab on host computer with a GP-IB to COM/USB interface and the KE5FX GPIP toolkit properly installed. The procedure described below allows you to save the top and bottom figure displayed on the screen of HP35670A Dynamic Signal Analyzer and is applicable to saving either time domain data (time traces of Channel 1 and Channel 2) or frequency domain data (estimated Magnitude and Phase response).

1. First make sure you display the desired **time domain data** or **frequency domain data** on the screen of the HP35670A Dynamic Signal Analyzer. In case of time domain data, you typically should have Channel 1 in the top figure and Channel 2 in the bottom figure (see Section 4). In case of frequency domain data, the top figure should contain the magnitude and the bottom figure the phase of the frequency response data (see Section 6.3). In addition (optional) you can display the Coherence data in the bottom figure to get a idea on the quality of your frequency response estimate at each frequency.
2. The HP35670A Dynamic Signal Analyzer saves data in so-called **traces**. Typically the top figure on the screen is **Trace A**, the bottom figure on the screen is **Trace B**. When measuring time domain data **Trace A** (top figure) is a time trace of Channel 1 and **Trace B** (bottom figure) is a time trace of Channel 2. When measuring frequency domain data **Trace A** (top figure) is a magnitude response and **Trace B** (bottom figure) is the phase response.

5.1 Saving data on Floppy Drive

Make sure you display the desired **time domain data** or **frequency domain data** on the screen of the HP35670A Dynamic Signal Analyzer as indicated above. Make sure you have an empty formatted floppy (formatted on one of the computers in the lab) before saving data and one can follow the following procedure to save data on a floppy:

1. Press the Active Trace and then the F1 button to select **Trace A** (typically top figure). Press the Active Trace and then the F2 button to select **Trace B** (typically bottom figure).
2. Press the Save/Recall, the F1 and the F2 button to toggle saving data in ASCII format that can be read by Matlab or Excel. Make sure you select **ASCII format**, otherwise you will not be able to read the data.
3. Then press the F1 and then the F9 button (modify the filename if you like) to **save the selected trace** in an ASCII file onto the floppy. Make sure the filename has a **.txt** extension, as this indicates you are saving your data in **ASCII** format.
4. Write down the name of the file and the conditions of your experiment. When you are writing your report you will need this background information to explain your data.
5. If the floppy is full, use (any) computer the lab to copy data from the floppy to your memory stick. To log in, use the username and password provided to you at the beginning of the lab.

5.2 Loading data into Matlab

Make sure the computer has been connected to HP35670A Dynamic Signal Analyzer with the GP-IB to COM/USB interface. Log into the computer with the username and password provided to you during the beginning of the lab. With Matlab and the KE5FX GPIP toolkit properly installed, you can follow these steps to load data directly into Matlab:

1. Start up Matlab from the Matlab icon on the desktop. You will have a working directory located at `C:\labcourse\%username%` wehere `%username%` should be replaced by the username given to you for log in purposes.
2. In the Matlab command window, type in `pwd` and verify that you are indeed in your working directory under `C:\labcourse\%username%`.
3. You can now the `gettrace` Matlab function to download your data as follows, type `help gettrace` for more help on how to use `gettrace`.

   <u>Time domain data</u>

   With trace A displaying time domain data of Channel 1, use

   ```
   >> [ch1,t]=gettrace(1);
   >> plot(t,ch1)
   ```

   to load the data from the HP35670A Dynamic Signal Analyzer and display the measured time domain data of trace A in a Matlab figure. Similarly, with trace B displaying time domain data of Channel 2, use

   ```
   >> [ch2,t]=gettrace(2);
   >> plot(t,ch2)
   ```

to load the data from the HP35670A Dynamic Signal Analyzer and display the measured time domain data of trace B in a Matlab figure. To save the data, use

```
>> save mytimedata t ch1 ch2 -V6
```

to save the data in the Matlab (binary) file `mytimedata.mat`. Be aware of the fact that Matlab does not issue a warning message if `mytimedata.mat` already exists and simply overwrites the file. You can reload this data at any time with

```
>> load mytimedata
```

Frequency response data

With trace A displaying the transfer function (either magnitude or phase) between Channel 1 and Channel 2, use

```
>> [G,f]=gettrace(1);
```

to get the complex numbers `G` as a function of the frequency `f`. A nice Bode plot of the same frequency response date can be created typing the commands

```
>> subplot(2,1,1),loglog(f,abs(G));
>> subplot(2,1,2),semilogx(f,180/pi*unwrap(angle(G)))
```

whereas the data can be saved again via

```
>> save myfreqdata G f -V6
```

in the binary Matlab file `myfreqdata.mat`. Be aware of the fact that Matlab does not issue a warning message if `myfreqdata.mat` already exists and simply overwrites the file. You can reload this data at any time with

```
>> load myfreqdata
```

6 Frequency Response Estimation (week 2 & 3)

This section tells you how to set up the HP35670A Dynamic Signal Analyzer to estimate a *frequency response between two signals*.
The frequency response is used to investigate the transfer function $H(s)$ that relates the Laplace transform $y_1(s)$ of Channel 1 and the Laplace transform $y_2(s)$ of Channel 2 via $y_2(s) = H(s)y_1(s)$. The frequency response is simply an estimate of magnitude $|H(s)|$ and the phase $\angle H(s)$ when $H(s)$ is evaluated over $s = j\omega$ over a frequency grid $\omega \in \Omega$. The signals measured at Channel 1 and Channel 2 should be all combinations of accelerations of floors that one can measure. The different combinations are found by placing the accelerometers at different locations on your structure due to the wax connection, but be careful not to drop them!

NOTE: *make sure to handle the accelerometers attached to your structure with care. They are sensitive devices and dropping them on the table or the ground will damage them due to exposure to accelerations beyond the operating range.*

In order to perform a frequency response estimation two main steps have to be taken:

- Select a broad-band excitation (source) signal to move the shaker table. Typically we will use a **random noise source**.

- Set up the HP35670A Dynamic Signal Analyzer to perform **frequency response estimation via averaging**.

These two steps are explained in more details below. Follow the instructions carefully, as improper use of excitation signals may result in an automatic shutdown of the LDS amplifier that drives the shaker table and/or damage to the equipment.

6.1 Random noise excitation

1. Before you start your experiment, make sure the **floors in the small-scale building has been set to the right distance**. Every group works with a different building configuration, so ask your instructor/TA for the right floor distances.

2. Turn on the equipment as described in Section 1.

3. Make sure the **dial gain button on the LDS amplifer is turned all the way left (counter clock wise)** for zero gain amplification before changing the source signal!

4. With the HP35670A Dynamic Signal Analyzer turned on, press the Source and then F1 button to toggle the source **ON** or **OFF**. Make sure to set the source to **OFF** before setting up the source signal.

5. Press the Source and then F2 button to set up the level of the source. Make sure the source level is set to **0.1 Volt peak to peak** by typing the level .1 and then pressing the F1 button.

6. Press the Source and then F5 button to select a **Random Noise** as a source. Random noise excitation will randomly excite the structure and will excite all resonance modes (frequencies) so we can compute a frequency response estimate.

7. Press the Freq and then F1 button to set up the frequency span. Type in 50 and then the F2 button to set up a 50Hz span. This should be enough to see all resonance modes of your structure.

8. Again press the Source and then F1 button to toggle the source **ON**.

9. Slowly and slightly turn the dial gain button on the LDS amplifer to the right (clock wise) to increase the gain amplification to see the effect of the random noise source signal. **Do not increase the gain on the LDS amplifier too much, as this leads to excessive vibrations**.

6.2 Measuring frequency domain data

Frequency domain data or estimate of the frequency response of the transfer function $H(j\omega)$ in $y_2(j\omega) = H(j\omega)y_1(j\omega)$ is found by averaging and dividing Fourier transforms of Channel 1 and Channel 2. The HP35670A Dynamic Signal Analyzer can be set up to this automatically for you by the following instructions:

1. Make sure you have set up the equipment with the proper level of **random noise excitation source**, see Section 6.1.

2. Make sure the Piezotron Coupler boxes are turned on and have enough battery power (test with flipping switch to top position).
3. With the HP35670A Dynamic Signal Analyzer turned on, press the Meas Data and then F1 button to toggle the channel select and make sure to **select channel 2**.
4. Again press the Meas Data and then F6 button to enable the **frequency response measurements**. This will estimate the frequency response between **Channel 1 as an input** and **Channel 2 as an output**.
5. Now press the Avg and then the F1 button to enable averaging of the frequency response measurements. Default the number of averages is 10, which should be enough to get a smooth estimate of the frequency response. the **frequency response measurements**.
6. Now press the Start button to start the measurements. After the averages have completed you will have an estimate of the frequency response between Channel 1 (input) and Channel 2 (output).

6.3 Displaying frequency domain data

To make sure you have the amplitude plot $|H(j\omega)|$ in the top figure and the phase plot $\angle H(j\omega)$ in the bottom figure before inspecting and/or saving data please follow these instructions.

1. Use the HP35670A Dynamic Signal Analyzer to estimate a frequency response as decribed in Section 6.2.
2. For the top figure: press the Active Trace and then the F1 button to select **Trace A** (top figure). Then press the Trace Coord and then the F2 button for a **Log Magnitude** display and press the F9 button for a **Log x scale**.
3. Press the Scale and then the F1 to toggle **Autoscaling** ON or OFF. Best to turn **Autoscaling ON**. You should now see the magnitude plot of the frequency response on your screen after a measurement has been completed.
4. Similarly for the bottom figure: press the Active Trace and then the F2 button to select **Trace A** (top figure). Then press the Trace Coord and then the F4 button for a **Phase** display and press the F9 button for a **Log x scale**.
5. You can save the frequency domain data according to the instruction in Section 5.

7 Models of building (week 3, MAE171b students)

As explained before, a frequency response is simply the magnitude $|H(s)|$ and the phase $\angle H(s)$ of a transfer function $H(s)$ evaluated over $s = j\omega$ over a frequency grid $\omega \in \Omega$. The transfer function is the relation between two signals (Channel 2 and Channel 1) in the Laplace domain. In the laboratory handout, the transfer functions between the different floors are described in more detail and you are asked to construct transfer function models $H_{ij}(s)$ that explain the measured frequency responses from floor i to floor j.

As an example, consider the frequency response between the first and second floor. In that case, $y_2 = q_2$, $y_1 = q_1$ and the transfer function $H_{21}(s)$ from first floor acceleration $\ddot{q}_1$ to second floor acceleration $\ddot{q}_2$ will be given by

$$q_2(s) = H_{21}(s)q_1(s),\ H_{21}(s) := \frac{G_2(s)}{G_1(s)} = \frac{k_1(m_3s^2 + k_2)}{m_2m_3s^4 + (k_2m_2 + (k_1 + k_2)m_3)s^2 + k_1k_2} \tag{1}$$

It can be noted that the values of m_1 and k_0 are irrelevant, whereas the value of the other parameters k_1, k_2, m_2 and m_3 can be lumped into a transfer function model

$$H_{21}(s) = K \cdot \frac{\omega_2^2 \omega_3^2}{\omega_1^2} \cdot \frac{(s^2 + \omega_1^2)}{(s^2 + \omega_2^2)(s^2 + \omega_3^2)}$$

where ω_1 and ω_3 are the *resonance frequencies*, as they appear in the denominator, and $omega_2$ is the *anti-resonance frequency*, as it appears in the denominator. It is obvious that if $\omega = \omega_2$, $|H_{21}(j\omega)| = 0$, modeling the 'dip' in the frequency response. If $\omega = \omega_1$ or $\omega = \omega_3$ then $|H_{21}(j\omega)| = \infty$, modeling the 'spike' in the frequency response.

Obviously, the measured frequency response does not spike to ∞ and dip to 0 and the model $H_{ij}(s)$ can be refined by adding damping terms. Considering again the frequency response between the first and second floor as an example, we may model this as

$$H_{21}(s) = K \cdot \frac{\omega_2^2 \omega_3^2}{\omega_1^2} \cdot \frac{(s^2 + 2\beta_1\omega_1 s + \omega_1^2)}{(s^2 + 2\beta_2\omega_2 s + \omega_2^2)(s^2 + 2\beta_3\omega_3 s + \omega_3^2)}$$

where now β_1, β_2 and β_3 are *damping ratios* between 0 and 1 that model damping.

Using this concept of modeling transfer functions with (anti-)resonance frequencies ω_1, ω_2 and ω_3 and corresponding damping ratios β_1, β_2 and β_3 you are asked to perform these tasks:

- On the basis of the measured frequency response data obtained in week 2, propose a transfer function H_{21} from floor 1 to 2, H_{31} from floor 1 to 3 and H_{32} from floor 2 to 3.
- Determine the (anti-)resonance frequencies ω_1, ω_2 and ω_3 and corresponding damping ratios β_1, β_2 and β_3 for each transfer function H_{21}, H_{31} and H_{32}.
- The above estimates should be validated by plotting the measured frequency response and the modeled frequency responses in the same Bode plot. An example was given in the lecture notes (slides 49-51, lecture notes MAE171a vibration experiment, Winter 2010)

8 Helicopter rotor (Week 3, MAE175a students)

Using the time and frequency domain estimation tools learned in the first two weeks, the idea is to find the different resonance frequencies and modes of the helicopter blade. This can be done by mounting the helicopter blade on the shaker table and attach the accelerometers to different places on the helicopter rotor. When performing your experiments, keep track of the following:

- Estimate the frequency of the first 3 resonance modes as explained in the lecture (movies).
- Keep in mind the general shape of the different resonance modes of the helicopter rotor blade as explained in the lecture (movies) for deciding where to place the accelerometers for your measurements.
- Location of accelerometers will determine the location of the "anti-resonance modes" of your structure. Use this information to see if you can find the mode shapes of the helicopter rotor blade by keeping one accelerometers on Channel 1 fixed and move the second accelerometers on Channel 2 till you find a significant 'dip' in the frequency response measurement at the frequency of the second resonance mode.
- Record and save the frequencies of the resonance modes you observe up to approximately 200 Hz. Also carefully record the location of both accelerometers for each measured frequency response.