ME220 Lab #5 Characterize Accelerometer and PZT Stack Response

Due: 5/16/08, before 5:00 pm.

Goals of this Lab:

This is the second part of a two-part lab. We'll use the LabVIEW VIs created last week to characterize an accelerometer and the PZT stack actuator used to excite it. We will look at both the amplitude and phase of the accelerometer response compared with the actuator drive voltage. Finally, we will look for non-linearities in the response of the system.

Acknowledgement:

Zachary Nelson of National Instruments orchestrated a donation of the LabVIEW Software and the National Instruments Data Acquisition hardware that we'll be using in the lab this quarter. Zach will visit sometimes during the quarter, so please be nice to him!

Part 1 - Connect the accelerometer and piezoelectric actuator

Your first task is to connect the physical apparatus we will be using. There is one actuator/accelerometer setup for each lab workstation. The accelerometer (ADXL105) is glued on top of the actuator, which in turn is glued down to a piece of acrylic, which is clamped to the table. Make sure the whole set-up is clamped to the table, so that the actuator movement is coupled entirely to the accelerometer. The devices are very fragile, so after you are done with them, please *gently remove the devices and place them carefully on the top shelf.*

The next step is to set up the piezo actuator drive voltage from the function generator. We want to acquire this in LabVIEW, too. The function generator can drive a sine wave at +/- 10 Volts, which fortunately we can (just barely) measure with LabVIEW (otherwise we'd need to hook up something to attenuate the physical signal (*e.g.,* a resistive divider) before connecting it to the connector block and LabVIEW). So: hook up the leads from the function generator (via the BNC → alligator clip connector) directly to the two leads attached to the piezo actuator. Also connect these to the connector block to the pins corresponding to analog input channel ai3 (again, just like last week). Please be careful with the leads that are soldered to the piezo actuator - they are fragile. You should also connect the ground of the function generator to the ground of the power supply. Don't turn on the function generator yet. That comes later…

You now want to connect the accelerometer. Following Figure 17 in the data sheet should work for us. Read the VDD section on page 6 to know a little more about what you're hooking up. You can either build your circuit on the included interface breadboard--which will have to be taken down for the next group--or add long jumpers from this breadboard onto yours which has the circuit then connect V_{DD} to the 5-volt power supply and Gnd to the power supply ground with the two banana jacks at the station. You can leave the connection to ST (self-test) unconnected.

We will connect the V_{out} (A_{out} in the data sheet) pin to analog input channel 1 (ai1) just as in previous labs. However, the accelerometer data sheet recommends low-pass filtering the signal first to eliminate high-frequency clock noise (from the accelerometer's internal clock). So connect the raw V_{out} signal to a low-pass filter consisting of a 1.5kΩ and a 0.01 µF capacitor (the cutoff frequency of this filter is about 10 kHz). Then connect the filtered output signal to the pins corresponding to channel ai1 on the connector block (look at the connector block reference sheet or over past labs if you've forgotten which they are). Be sure to connect the appropriate wire from the connector block to ground since you'll be using ai1 in differential mode just as we have in previous labs.

A word before we start hooking up physical wires and creating the LabVIEW interface: you may want to use what you created as Part 5 of Lab #4 as a starting point for the LabVIEW part. This is because we're doing what you set up - reading in two voltages and separating them so they can be manipulated separately.

In the DAQ Assist block that interfaces with the input, set the sampling frequency to 10 kHz and take data for 1 second (you may wish to change these settings later). Since the accelerometer will only output between 0 and 5 volts, you can safely set ai1 to these limits. You should set ai3 to range from +/- 10 volts.

The filtered V_{out} of the accelerometer should now be accessible within LabVIEW on ai1 - verify this before proceeding (you can simply add a time-domain graph to the output of the DAQ Assist block). If you turn on the power supply and just look at the filtered V_{out}, it should be centered somewhere near 2.28 V (plus some noise of a few to tens of mV, depending on what your sampling frequency is). (*Why is this?* The accelerometer output is nominally specified as 2.5 V at 0g; but, we are exposing it to -1g from the earth's gravity, at the specified 250 mV/g nominal sensitivity the resulting value is ~2.25V).

I've noticed that some of the function generators aren't doing a good job of driving the piezo actuator. If this happens, first try connecting the scope up to the function generator output without removing the other connections. Somehow a common ground connection between these devices seemed to remedy the situation a few times.

Now to test our whole apparatus! (Note: unless otherwise specified, we will keep these settings for the remainder of the lab). Turn on the function generator and set it to a sine wave at about 100 Hz. Turn the amplitude knob to about the middle. Now grab the offset knob and (gently) pull it towards you (this enables the offset control). Now turn the knob about halfway to the right. Look at the sine wave with LabVIEW (or on the scope). Keep fiddling with the knobs until you have a sine wave with about 5-volt amplitude centered at about 5 volts. In summary, we want a sine wave that goes from ~0 to ~10 volts. Just be sure that the output doesn't exceed LabVIEW’s threshold of 10 volts, otherwise it won't be able to see it.

For the curious, we adjusted the DC offset because the piezo actuator doesn't actuate well in the reverse direction; positive voltages lead to expansion but negative voltages don't result in contraction (not much anyway, and you can ruin the piezo (a ~$100 part) by applying too much negative voltage). This way we have a sine wave input to the actuator that should result in a sine wave motion of the top of it. Also, do not forget that the voltage measurement is relative so the offset is easily accounted for.

Once you have the drive voltage set up, look at the output of the accelerometer. The time-domain signal should move at the same frequency as the drive signal. *What will we see in the frequency domain?* This is just the FFT (its magnitude if not otherwise specified), which will give a clear peak at the drive frequency.

For the write-up:
- Include 4 plots from LabVIEW:
  - Time-domain plot of the first 0.10 seconds of the drive voltage
  - Time-domain plot of the first 0.10 seconds of the accelerometer output voltage
  - Frequency-domain plot from 10 Hz to 1000 Hz of the drive voltage

- Frequency-domain plot from 10 Hz to 1000 Hz of the accelerometer output voltage

Part 2 - Look at the accelerometer output with no drive

Now that you've verified that the setup is working, turn off the function generator. Here we will look at the accelerometer output when we apply no actuation, so be sure to leave the accelerometer power supply turned on.

Collect data at 10 kHz for at least one second. Take the FFT (linear scale, peak amplitude setting) and look at the frequency range from 10Hz to 5000Hz. If the noise were white noise, like we generally assume, the spectrum would be flat (in other words, all frequency components are present in nearly equal proportions). In the signal coming from the accelerometer when the actuator is undriven, do you observe white noise? We've seen 60 Hz noise in other labs (60 Hz noise is common because all the AC electrical wires in the US operate at 60 Hz). Why might there be certain preferred frequencies in this noise spectrum? (Hint: the sensor has a mechanical basis). Is there some other "type" of noise we should be considering?

For the write-up:

- Include a frequency-domain plot from 10 Hz to 5000 Hz of the accelerometer output voltage when the actuator is undriven
- Answer the question: Why might there be certain preferred frequencies in this noise spectrum?

Part 3 - Characterize the accelerometer response vs. frequency

Now for the core of the lab! This will be much like the low-pass filter characterization of Lab #4, where we will apply a signal at a given frequency (here the actuator drive voltage) and then measure the resulting output signal (here the accelerometer output voltage). The ratio output/input is the transfer function. Even though we generally think about it in terms of a magnitude, the transfer function also has an associated phase, which we will also measure.

You should collect data at 10-15 different frequencies, spaced between about 10 Hz and about 4 kHz. At each point, record the magnitude of the transfer function (amplitude of the output divided by the amplitude of the drive signal), the relative phase of these two signals, and the exact frequency at which you collected each data point. (Be sure to pick data off of the FFT at this exact frequency; if you set the function generator to about 1 kHz and the actual signal is at 1023 Hz, pick off the FFT value at 1023 Hz. Your VIs from lab 4 should help). I recommend saving this data in a spreadsheet. Pleae read the next few paragraphs though before starting to collecting data.

First, you will need to do a little LabVIEW manipulation to collect this data, not unlike what you did for the low-pass filter last week. Make generous use of the “library” of VIs you created in previous labs; This was the primary reason for lab 4!

One small issue that you might run into and need to resolve: now that we have a large DC offset of the drive frequency, the block that you build for part 3 of last week's lab may tell you that the dominant frequency is 0 Hz, or DC. In that case, modify your VI so that it doesn't consider the point at 0 when it picks out the frequency where the FFT amplitude is at a maximum.

In all these data collection steps, make sure to sample at least 5-10 periods of the sine wave data, otherwise the FFT will not be able to do a good job of extracting the amplitude at that frequency.

Now, make sure the sampling rate is fast enough to handle the signals you put in. Remember “aliasing” from last week’s lab (part 1)? Collecting 4 kHz data means you need to sample at 8 kHz or faster. On the other hand, don't make the sampling rate ridiculously high either (explanation next paragraph). Sampling at 10 kHz seems like a good number.

For those who would like to know why we can't sample arbitrarily fast: our particular A/D card has a single A/D converter that is shared between all the channels. That A/D is specified to sample up to 333 kHz, so in theory running two channels each at 100 kHz shouldn't be a problem. The basic process is to sample one channel, digitizing it, sampling the other channel, digitizing it, and repeating. The sampling process involves storing the voltage on a capacitor, and between sampling steps this capacitor is in theory discharged to start afresh the next sample. However, it doesn't discharge infinitely fast. This is more of a problem when dealing with multiple channels, so that's why fancier (and pricier) D/A cards will often have a dedicated A/D converter for each channel.

OK, collect your data! Remember, make note of the relative amplitude of the two signals, the relative phase, and the exact frequency.

Compare the magnitude of the noise you observed in part 2 with the magnitude of the data you collected in part 3. Does the noise call any of your measurements into question? Are measurements at any of the frequencies susceptible to noise "contamination" as determined from the measurements in part 2, or are they all safe? To do this part, you probably want to look at the absolute amplitude of the signal at your frequency of interest, not the relative amplitude compared with the drive signal.

For the write-up
- Answer the questions above.

Part 4 - Plot your data

Take the ratio of the output voltage of the accelerometer, corrected for noise, to the input voltage of the actuator. This can be accomplished simply by dividing the FFT peak amplitudes you recorded.

Plot the observed transfer function from the actuator input voltage to the accelerometer output voltage. Note that this is expressed in output voltage / input voltage, or accelerometer output divided by the actuator input. Also note that the full transfer function is complex-valued, so include a pair of plots, one showing the magnitude and the other the relative phase (both plotted versus driving frequency).

For the write-up:

- Include the plot of your transfer function, both magnitude and phase.

Part 5 - Analyze your data

For the write-up:

- Comment on the phase of the measured transfer function. Relate it to the transfer function of the accelerometer (as given in lecture) at least in the two frequency limits (of low and high frequencies).
- Does the output amplitude of the accelerometer indeed increase as the square of the input frequency? If not, comment or conjecture why not. If there are different trends in different regions, comment on why that might be the case. Some hints: What is the advertised bandwidth of the accelerometer from the datasheet? From the plots in class, how do you expect the accelerometer output to be related to the frequency assuming the same acceleration? How do you expect it then to be related to the actual acceleration experienced by the accelerometer (which goes as frequency squared)?

Part 5 - A quick look at non-linearity

If an actuator or sensor is not perfectly linear, then a sine wave input won’t exactly map to a sine wave output. By Fourier analysis (that is beyond the scope of this lab), one can show that non-linearities manifest themselves at overtones of the fundamental frequency. For example, if you drive a perfectly linear actuator/sensor with a pure sine wave at 70 Hz, the output will be a pure sine wave at 70Hz (with a possible phase shift plus any noise). However, if there are non-linearities in the sensor/actuator, then the output will have components at 140 Hz, 210 Hz, and so forth. These conceptually correspond to the non-linear terms in the Taylor series expansion. So the take-home message is that non-linearities in the response of elements manifest themselves as components in the FFT at integer multiples of the fundamental frequency.

In this part of the lab you will look at the non-linearities of the piezo actuator and accelerometer by looking for peaks at overtone frequencies of the drive frequency.

Pick an excitation frequency at which you obtained a large signal in the previous parts of the lab. However, you should pick it low enough that you can see the first few overtones. I suggest picking about 500 Hz - 1000 Hz, but feel free to pick any other reasonable frequency. You should not pick a frequency at which there was a lot of “undriven noise” at as determined in part 2.

Now drive the actuator with the function generator at the frequency you picked.

NOTE: When looking at the frequency spectrum in the following paragraphs, experiment with viewing in dB to see if this helps. However, the linear view will probably help you get peak values more accurately

First, look at the frequency spectrum of the drive voltage. Because of non-linearities in the function generator’s output stage you can see small by measurable overtones of the fundamental or drive frequency (looking at the FFT of the function generator output). Look for the first two overtones and make at note of how large they are relative to the fundamental frequency (in terms of a ratio). If you have two nearby peaks and aren't sure which one is the overtone from the function generator and which is from the undriven noise, then turn off the function generator and see which peak disappears.

Now look at the frequency spectrum of the accelerometer output. How big are the first two overtones relative to the fundamental frequency? Measure and note how large they are relative to the fundamental frequency (in terms of a ratio). Can you detect noticeable non-linearity in the actuator/sensor?

Remember that the overtone frequencies of the function generator are subject to the transfer function you measured in part 3. An example to clarify: say your fundamental frequency is 750 Hz and the first overtone is at 1500 Hz. If the ratio of 1st overtone to the fundamental in the function generator output is 1/123 but the transfer function magnitude at 1500 Hz is twice as big as at 750 Hz, then with a perfectly linear system we would expect the ratio of the overtone to the fundamental on the output to be 2/123 instead of 1/123.

Correct your recorded ratios to account for the transfer function you recorded in part 3. Feel free to interpolate points on your transfer function if you didn't happen to take transfer function data near the frequency of the overtones.

For the write-up:

- Include your results for the relative amplitudes of the overtones (as a fraction of the amplitude of the fundamental) for both the output of the function generator and the output of the accelerometer.
- Include these ratios corrected for the transfer function.
- Answer the question "can you detect noticeable non-linearity in the actuator/sensor?" in a semi-quantitative way based on these numbers (no more calculations needed).

Congratulations, you are done (with the experiments at least)!