Strain measurements

Caution

The strain gauges and the wires attached to them are very fragile. The solder connections are very small. Make sure you do not pull on, smash, pinch, or break any of the strain gauges or the connecting wires. We really need them to last through all of the sections. If the wires get pulled off, please tell us and we can repair the beam. Do not leave it broken for the next team to deal with.

Intro

In this lab, you will make measurements of strain in steel beams as you stand on them in different configurations. You will convert your voltage readings to strain measurements and compare your measurements to the simple beam theory discussed in class.

The strain gauge

The strain gauge is nothing more than a resistor whose value changes when it is elongated or compressed. When elongated, the thin wires which make up the strain gauge are elongated and the resistance goes up. When compressed the wires get shorter and fatter and the resistance goes down. When a strain gauge is stretched, its resistance changes according to the following formula

$$\frac{\Delta R}{R} = G_F \epsilon$$

where G_F is the gauge factor (it is 2.1 for our sensors), ϵ is the mechanical strain, R is the starting resistance (120 ohms in our case) and ΔR is the change in resistance. Since a strain is usually quite small, the change in resistance is also quite small. The mechanical strain is defined as the change in length of an object when a force is applied divided by the length with no load. To measure the small changes, we need a circuit with an output close to zero with no strain, and a high gain to amplify the change in resistance to a reasonable value which can be read by the DAQ.

Measuring the change in resistance

The classic circuit for measuring the resistance change of a strain gauge is the Wheatstone bridge, shown below in Figure 1. In our case, the nominal resistance of the strain gauge is 120 ohms, so we show an example bridge with these values. If all the resistances are precise, and

the variable resistance is adjusted to exactly 5 ohms, the bridge is balanced (all four resistors are equal) and you measure 0 volts. If the resistance of the strain sensor then changes, a voltage is created at V_{meas} which is related to the resistance change of the strain gauge.
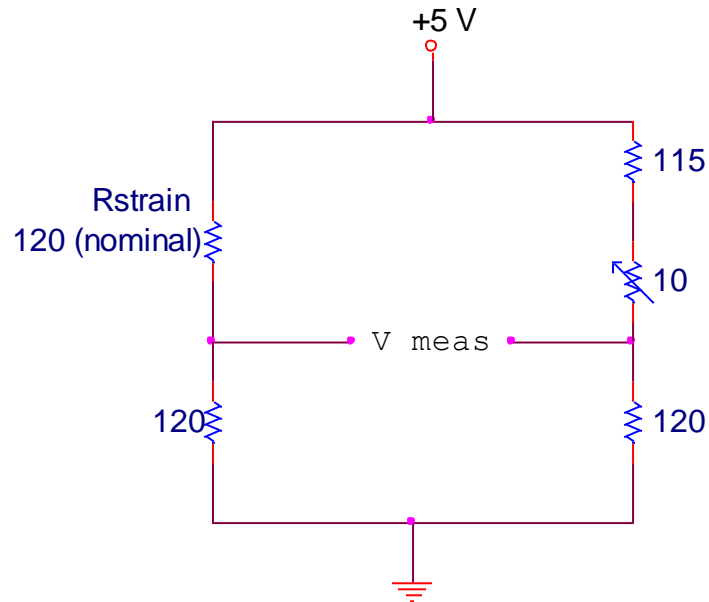

Figure 1: Classic Wheatstone bridge for sensing small changes in resistance. We won't use this circuit, so don't build it, just keep reading.

The variable resistor (potentiometer) is used to balance the bridge. Since resistors have some error, this variable resistor can manually set the equilibrium, no load condition to 0 measured volts. Once balanced, we can sense small changes in resistance at the strain gauge. The changes in voltage from the Wheatstone bridge (due to the change in resistance) are very small and must be amplified. One could amplify the voltage with three op-amps to create a classic instrumentation amplifier as you did last week.

Rather than using the Wheatstone bridge in its classic configuration, we will do something equivalent, but will use software and the DAQ to balance the bridge so that there is no need for the manual potentiometer. If you look at the circuit in Figure 1, you will see that the right side of the bridge does nothing other than provide a constant (but adjustable) voltage reference to measure the left side of the bridge against. We will implement our equivalent to the bridge circuit as shown in Figure 2, using the DAQs analog output as the right side of the bridge.
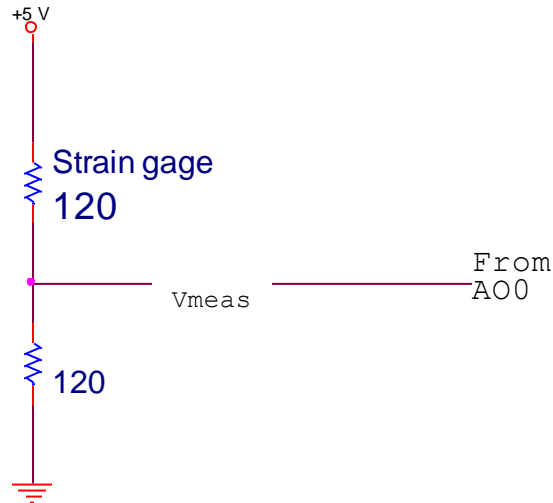
Figure 2: Our implementation of the Wheatstone bridge.

In our version, the bridge will be adjusted in software by adjusting the DAQ analog output. We will amplify and measure Vmeas shown in Figure 2 and adjust the DAQ output until the bridge is balanced. We provide a MATLAB code for tuning your bridge automatically, which you can use. The voltage output to balance the bridge will be close to 2.5 V, but not exactly. Since our amplifier gain is large, the bridge must be precisely balanced.

In the previous lab you built the 3 op-amp instrumentation amplifier. You probably found that building the circuit was feasible but a little bit complicated and that the circuit did not work perfectly due to mismatched resistors within the amplifier. Conveniently, these three op-amp circuits are also sold as individual chips with all the internal pieces inside a tiny little chip. We will use the AD623 built by Analog Devices. The connection diagram is shown in Figure 3. It is very easy to use and you will probably hate us for making you build your own with 3 op amps last week. The amplifier has an adjustable gain which is set by a single resistor which connects pins 1 and 8. The amplifier has a positive and negative input, pins 3 and 2. The output voltage at pin 6 is equal to the gain times the difference on the inputs.
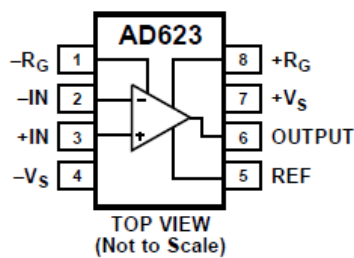
Figure 3: Connection diagram for AD623.

The complete circuit that you will build is shown in Figure 4. It incorporates the bridge (using the analog output to tune it to zero), the AD623 instrumentation amplifier, a low pass filter, and a buffer. If not for the filter we could hook the AD623 directly to the DAQ.
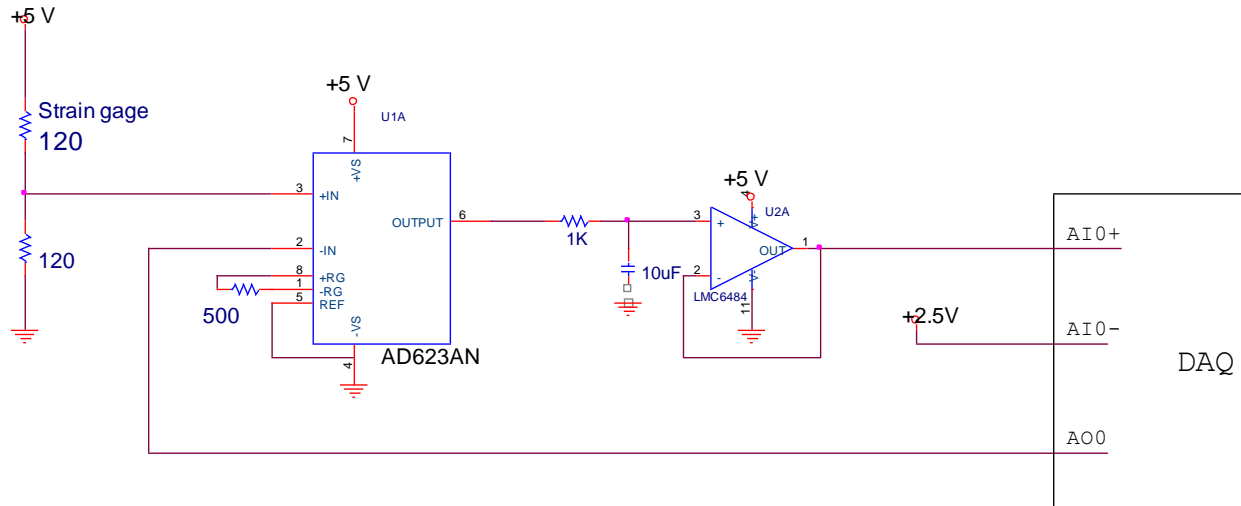

Figure 4: Circuit you should build.

If you read the data sheet you will find the gain is set by the gain resistor, here 500 ohms. The formula the chip follows is the gain is, $G = 1 + \frac{100000}{Rg}$. Thus our gain is 201. This seemed to work well for us, but you may want to increase or decrease the gain if you need to change the sensitivity.

The software we provide for tuning the bridge, simply reads the voltage difference at the analog input. The analog output starts at 2.5 Volts and then a simple control loop runs to set the analog output such the measured voltage is zero. This program is run once at no load to determine the balance point.

The experiment

In the experiment you will breadboard one of the circuits. First, test your circuit with a 120 Ohm resistor in place of the strain gauge. You will run the program, bridge_tune.m which will find and return the value of the voltage needed to zero the bridge. We will demo this program in class. If you do not get a value close to 2.5 volts then something is probably wrong. Once you have the value needed for the analog output to zero the bridge, you can run the Strain_template.m program to acquire the data. When this program runs you should be able to touch the resistor and see the voltage output fluctuate just a little bit. If you see this, everything is probably working. In your MATLAB program (Strain_template.m), you will want to convert the voltage that you measure with the DAQ into the resistance of the strain gauge. This is easy

to do and you have already done this in a previous lab. As in that previous lab, if you want a more precise measurement of the resistance, you will want to measure the value of the 5V supply on your DAQ as they are all not perfectly consistent (typically closer to 5.05 V). You can do this measurement of the 5 V reference once and then use the value as it will not change.

Now you will want to try the real experiment with the strain gauge. Before getting too far you might want to use a multi-meter to measure that each strain gauge is about 120 Ohms (at the free ends of the connecting wires) before connecting it to your circuit. The connections to the gauges are fragile and can come loose if the previous user wasn't careful. Once you determine the strain gauge is good, remove the 120 Ohm resistor that you used for testing and insert the strain gauge like in Figure 4. You will need to run the program to auto tune the bridge once again. Once you have tuned the bridge, run the Strain_template.m program. Push on the beam so it deflects and make sure that the resistance changes. The resistance should decrease if the strain is compression and increase if it is in tension. The beam is in compression if you stand on the beam and the strain gauge is on the top and tension if the gauge is facing down and you stand on the beam.

For the experiment you need to set up the beam and calibrate it as a scale (weight measurement device). Even though each person in the class should do their own circuit and work, you will need a volunteer to help with the experiment to be a mass (and a mass who is willing to report to you their real approximate mass). You will setup the beam as shown in class. Before taking strain measurements you will want to determine/specify the distance between the two supports, the location of the load (i.e. your volunteers foot) and measure the location of the strain gauges. Modify your program so it runs for about 5 seconds and computes the mean value of the strain gauge resistance over the experiment. Now;

1) With nobody standing on the beam, run the program to tune the bridge for the strain gauge of interest.
2) Run the program to measure the average resistance with nobody standing on the beam. Record the value and note which strain gauge it was.
3) Run the program to measure the average resistance with a volunteer standing in the center of the beam. Record the value.
4) Have your volunteer step off, repeat the unloaded and loaded measurement of the resistance. Record the values.
5) Unhook the strain gauge in plug in the next one.
6) Return to step 1.

Try at least two spatial configurations, as shown below.
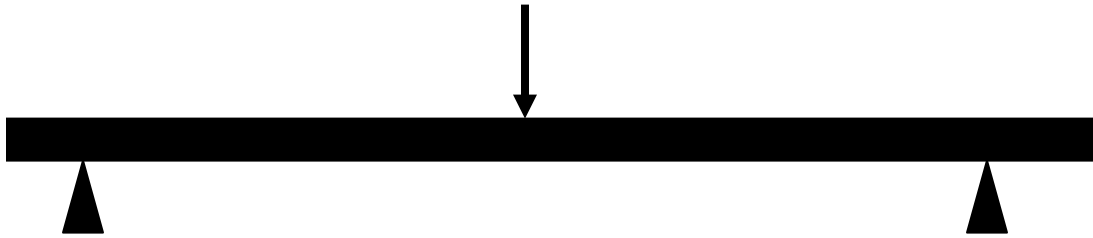
For the first configuration, you can mark an X with a marker in the center of the supports and stand with one foot on the spot. For this configuration you will measure the distance between the supports as the location of the inner edge of the wood blocks.

And

In this configuration you will want to move the supports closer and your volunteer can place one foot on the outer edge of the support. Mark the spot they stand with an X. For this configuration, you will measure the distance between the supports as the location of the outer edge of the wood blocks.

Make absolutely certain that you don't step on the strain gauges or the wires and that the strain gauges and wires are not sandwiched directly between the beam and the support to avoid damaging anything. Avoid pulling on the wires. Try to avoid permanently deforming the beams. The longer the lever arm from the applied weight to the support the more deflection you'll observe, but the more risk there is of permanently deforming the steel. Choose a reasonable compromise between deflection/signal amplitude and permanent damage.

Calculations

The calculations for this lab will be done mostly after the Wednesday class where we will cover the basic aspects of solid mechanics that will allow you to interpret your data. For the first step, you should convert your measurements of resistance (loaded and unloaded) to the change in resistance divided by the initial resistance. Scale these data by the gauge factor to get a plot of mechanical strain vs. distance from one of the supports. Plot the average of the three measurements that you took at each location. Note on your graph where the other support is located and where the load was applied.

After Wednesday, we will explain what the theoretical profile should look like and how to quantitatively calculate it. Now include on your graph with your data points, the theoretical prediction. They should match reasonably well.

Your final lab report should contain two figures. One for each loading configuration and each graph should contain the experiments compared to the theory. Your lab report should also include a short description of the equations used and the constants you used in the theory (i.e the modulus of elasticity for steel, the size of the beam, the length of the beam, the moment of inertia, etc). Include a few comments about how well the theory and experiment compared.