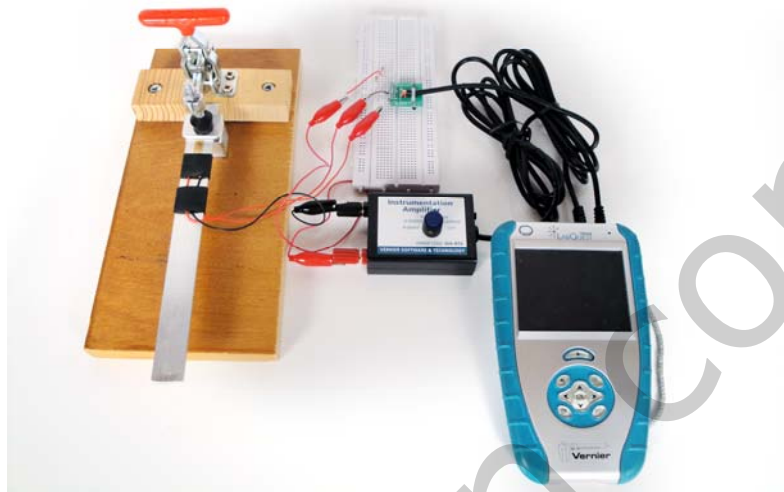


Strain Gage Measurement



When a force is exerted on an object, the length of the object will change. The ratio of the change in length to the original length is called *strain*. A strain gage is a small section of very fine wire that changes electrical resistance when its dimensions are changed. Two leads (wires or terminals) are available to connect the gage to measuring instruments. In use, a strain gage is attached to the surface of the object to be measured in such a way that when the mechanism is deformed, the conducting material is also deformed. Consider two strain gages that are glued to the top and bottom of a metal cantilever beam. When a force is applied to the beam, it bends down in proportion to the force (Hooke's Law). As the bar bends downward, the top of the bar stretches as it is placed in tension. The top strain gage is also stretched, and its resistance increases slightly because the length of gage wire increases while the width of the wire decreases. For the strain gage on the bottom of the bar, all of these effects are reversed—the bottom of the beam is placed in compression and the gage decreases in resistance. These changes in resistance are small, but they can be measured accurately with the proper circuit. A well-known circuit designed to convert small changes in resistance to changes in voltage is a Wheatstone bridge circuit.

PROJECT DESIGN REQUIREMENTS

Build a Wheatstone bridge circuit with two strain gages, and use it to measure the strain on a cantilever beam as a load is applied to the end of the beam. You will write a LabVIEW program to measure the output voltage of this circuit and convert it to strain. Both voltage and strain should be displayed on the front panel as Waveform Charts. Your apparatus should incorporate a Vernier Instrumentation Amplifier to magnify the voltage readings.

MATERIALS

SensorDAQ or LabQuest or LabQuest Mini	glue for strain gages
LabVIEW	aluminum bar (1/8" x 3/4" x 8")
computer	set of small weights (100–500 grams)
USB cable	breadboard
Vernier Instrumentation Amplifier	jumper wires
Vernier Breadboard Cable	two 120 Ω ($\pm 1\%$) precision resistors
two 120 Ω strain gage (e.g., Omega #SG-6/120-LY11)	clamp to secure bar at one end

PROJECT SETUP

Mount the strain gages and lead wires

1. Obtain an aluminum beam of rectangular cross section.
2. Follow the strain gage installation instructions provided by your instructor to adhere one strain gage to the beam, about 2 or 3 cm from the point where it will be clamped. Center the gage mid-width and align the lead wires or terminals so that they are extending toward the end of the beam that will carry the load.
3. Glue a second strain gage to the opposite side of the beam in the same location and with the same orientation. Make sure the leads or terminals on both gages project in the same direction.
4. If the gage has pre-attached metal leads, make sure that they do not touch the metal bar. Bend them away from the bar and wrap electrical tape around the bar, under the leads. Then tape the wire leads firmly to the taped bar so that if the leads are pulled they will not break off of the strain gage.
5. Three wires should be coming from the apparatus. A single wire must extend from one terminal or lead of each of the two strain gages. A third wire must extend from the junction of the other two lead wires (one from each strain gage) as shown in Figure 1. One method of creating the three leads is to use bondable terminal pads. Leads from the strain gages are soldered to the terminals. Then longer wires are soldered to these terminals and secured to the bar with tape.

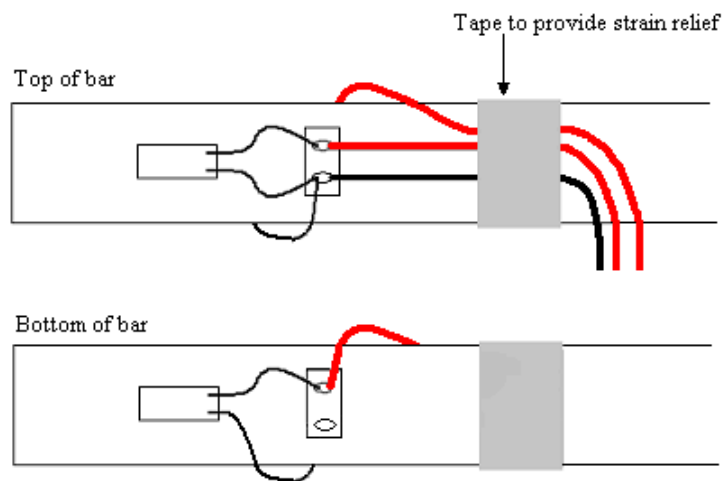


Figure 1 Strain gage lead wires

6. Clamp the end of the beam with the strain gage to the table. In our device shown in the picture above, we created a fixture for the metal beam using a vertical t-handle toggle clamp.

Build the Wheatstone bridge circuit

1. Use a breadboard to connect the various parts of the circuit shown below. Connect the Vernier Breadboard Cable to the breadboard, you will see a +5V and GND pin on the cable that you will use in the circuit. Add the two 120 Ω resistors to the breadboard as required for the circuit. Now connect the single wire from each strain gage to your breadboard circuit.

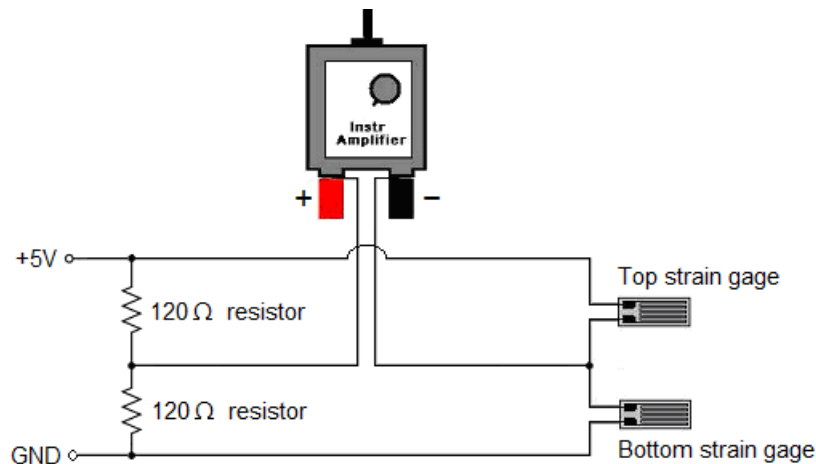


Figure 2 Strain gage connection to Vernier Instrumentation Amplifier

2. The wire from the junction of the two strain gage leads should be connected to the negative (black) terminal on the Instrumentation Amplifier.
3. A wire should connect the point between the two resistors to the positive (red) terminal on the Instrumentation Amplifier.

Connect the sensor to the interface

1. Connect the Instrumentation Amplifier to Channel 1 on the interface. Adjust the knob to ±20mV.
2. Connect the Vernier Breadboard Cable to Channel 2 on the interface.

Tip: If you are using a SensorDAQ, you can make the +5V and GND connection to the screw terminal on the side of the SensorDAQ. This way, you do not need the Vernier Breadboard Cable. Use screw terminal 6 for the +5V power source and use screw terminal 5, 8, or 10 for Ground.

3. Connect the interface to the computer.

PROJECT BACKGROUND INFORMATION

The Wheatstone bridge circuit contains four resistances and a constant voltage excitation source. In a half-bridge circuit, two of the four resistors are strain gages (see Figure 1).

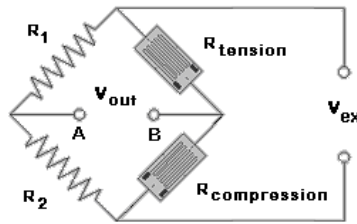


Figure 3 Wheatstone half-bridge circuit

The two resistors and two strain gages are arranged in a diamond pattern. The resistors should have approximately the same resistance as the two strain gages. A DC excitation voltage (V_{ex}) is applied across the top and bottom of the diamond and the output voltage (V_{out}) is measured across points A and B. The two strain gages are mounted on a test specimen (see Figure 4).

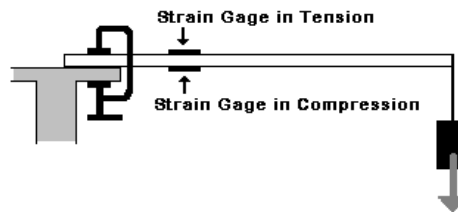


Figure 4 Strain gage mounting

As the figure above shows, the strain gages are mounted at the location where the strain is to be measured. The two gages are mounted on opposite sides of the bar. When the circuit is balanced, the voltage at both points A and B in Figure 3 above will be one-half of the excitation voltage. Therefore, the output voltage will be approximately zero. When a force is applied, the resistance of the strain gage in tension increases and the resistance of the gage in compression decreases. This change in resistance creates a voltage change at point B. The voltage at point A has not changed and is still equal to one-half the excitation voltage. Therefore, a small voltage difference will appear across points A and B. The voltage between these points (V_{out}) can be monitored, and is proportional to the amount of bending or strain in the structural member.

In our circuit, the excitation voltage (V_{ex}) of the circuit can be supplied by the +5V terminal on the Breadboard Cable. The circuit's output voltage (V_{out}) is never very large—rarely as large as a millivolt. Therefore, the output voltage must be amplified so that it can be measured. The Instrumentation Amplifier is used to provide this amplification (see Figure 5).

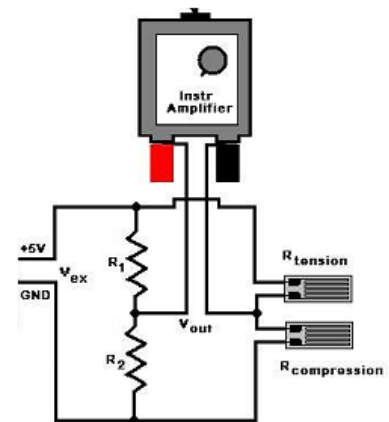


Figure 5 Apparatus setup

If the bridge resistances are not exactly balanced, there will be a nonzero output voltage when no load is applied. Taking this into account, the output voltage (V_{out}) of the half-bridge circuit can be determined using the following equation:

$$V_{out} = V_{measured} - V_{offset}$$

where $V_{measured}$ is the measured voltage of the Instrumentation Amplifier and V_{offset} is the output voltage measured when no load is applied.

The output voltage of the half-bridge circuit is related to the excitation voltage (V_{ex}) by the following relationship:

$$V_{out} = \frac{V_{ex} \times GF \times \varepsilon}{2}$$

where ε is the strain, V_{ex} is the excitation voltage, and GF is the nondimensional “gage factor” of the strain gage.

The strain in the beam is therefore represented by the following equation. Notice that the strain varies in a linear way with the output voltage.

$$\varepsilon = \frac{2 \times V_{out}}{V_{ex} \times GF}$$

You will use the interface’s output voltage terminal (which supplies about 5 volts) as the excitation voltage (V_{ex}). For this Project, you can use 5 volts for the excitation voltage. Most strain gages have a gage factor of about 2, so you can use 2 for GF.

In addition, V_{out} can be replaced with the first equation above that takes the offset voltage into account. The resulting equation, shown below, should be used in your LabVIEW program to calculate the strain in the beam.

$$\varepsilon = \frac{2(V_{measured} - V_{offset})}{V_{ex} \times GF}$$

PROJECT TIPS

1. The Vernier Instrumentation Amplifier provides readings in units of millivolts. You will need to convert this reading to volts to match the units of the excitation voltage.
2. The aluminum bar should flex, but not deform permanently, when a small load is applied.
3. The strain gages should be aligned with the longer, straight sections of wire inside the gage running along the length of the bar. The gages should be mounted about 2 or 3 cm from the clamped end.
4. Attaching the strain gages to the bar can be tricky at first. It may take a few trial runs to adhere the gage without bubbles between the gage and bar. It is recommended that you use a strain gage adhesive and follow the directions closely. Make sure the gage is glued flat against the surface of the bar with a thin, even layer of glue between the gage and the bar.

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5. While it is strongly recommended that you use an adhesive specifically designed for strain gages, the strain gage can be attached using household cyanoacrylate glue (e.g., Super Glue[®]). Do not use the gel-type Superglue. Make sure to use a small amount (one drop) and to use a technique that minimizes bubbles between the gage and bar.
6. The leads on the strain gages are very fragile, so you need to make sure they are not ripped out by a pull on the wires. Create some strain relief by taping the wire leads firmly to the metal bar so that if the wires are pulled, the force is not delivered to the strain gage leads.
7. A good data-collection rate for the Instrumentation Amplifier is 50 samples per second.
8. The Analog Express VI collects data for a fixed amount of time. For an indefinite data collection length, check the Repeat option in the Analog Express VI's Set Timing configuration window.
9. The gage factor for your strain gage can be found from your manufacturer's published data. Typical values are slightly greater than 2.
10. Some strain gages are sold with long lead wires already connected to the strain gage. This would be an option to avoid the need to solder wires onto the strain gage.
11. Refer to *Appendix E* for more information about the Instrumentation Amplifier and Breadboard Cable.

PROJECT TROUBLESHOOTING

1. The Project calls for setting the Instrumentation Amplifier to the ± 20 mV setting. This assumes that all 4 resistors in the Wheatstone bridge circuit are the same when no load is applied. However, if your resistor resistance is not precise, the no-load output may be outside of this range, and the setting will have to be changed. Try using the ± 200 mV setting. The instrument should still work, but the resolution of the measurements will be reduced.
2. If your voltage readings keep fluctuating, you may need to shield your device from the surrounding electrical interference. Place a sheet of paper and then a sheet of aluminum foil over the sensor, interface, and circuit (the paper prevents the foil from inadvertently creating a short circuit between electrical components). The aluminum bar should remain exposed.
3. A nice addition to the circuit is to replace one of the static resistors with a variable resistance (potentiometer). This way, the resistance on that leg of the bridge can be fine-tuned in order to balance the bridge when no load is applied.

CHALLENGE DESIGN REQUIREMENTS

Note: Do not attempt the Challenge until you have completed the Project Design Requirements.

Modify your VI created in the Project to use your strain gage device as a penny counter. When a stack of pennies is placed on the end of the cantilever beam, the program should be able to determine the number of pennies in the stack and display this value on the front panel.

ADDITIONAL MATERIALS

pennies

CHALLENGE TROUBLESHOOTING

1. To make a reliable penny counter, you will need to eliminate noise on your strain gage force measurement system built for the Project. Shielding the circuit and keeping it away from the computer, the monitor, and power supply lines is important.
2. Be aware that pennies minted before 1983 have more mass than those minted after 1983 due to significantly different proportions of copper and zinc. Also be sure that your pennies are clean and free of tarnish.

Vernier Lab Safety Instructions Disclaimer

THIS IS AN EVALUATION COPY OF THE VERNIER STUDENT LAB.

This copy does not include:

- **Safety information**
- **Essential instructor background information**
- **Directions for preparing solutions**
- **Important tips for successfully doing these labs**

The complete *Engineering Projects with NI LabVIEW™ and Vernier* manual includes 12 projects as well as essential teacher information. The full lab book is available for purchase at: <http://www.vernier.com/cmat/epv.html>



Vernier Software & Technology
13979 S.W. Millikan Way • Beaverton, OR 97005-2886
Toll Free (888) 837-6437 • (503) 277-2299 • FAX (503) 277-2440
info@vernier.com • www.vernier.com