**Objectives**

1. Analyze the static characteristics of the cantilever beam load cell, and predict its performance.
2. Investigate the use of the load cell using an empirical calibration to infer the applied force.
3. Extend your knowledge of LabVIEW.

As part of this lab, you write a LabVIEW vi to:
- Perform a static calibration of the load cell.
- Evaluate the load cell precision.
- Use the load cell to measure the weight of an “unknown” object.

**Introduction**

A cantilever beam and electronic motion transducer are to be used as a static force-measuring device: a load cell. The system as shown, consists of a rectangular cross-section beam, a means of applying the force (we will use hanging weights), and a DCDT (DC displacement transducer).

![Figure 1: Cantilever beam load cell](image)

The input to this instrument is the downward force $F$ exerted at the end of the beam. For small deflections, the ideal relationship between the applied force $F$ and the displacement $y$ of the beam at that point is

$$ F = \frac{Ebh^3}{4L^3}y $$

(1)

where $E$ is the elastic modulus of the material, $b$ is the beam width, $h$ is the beam thickness, and $L$ is the beam length.

The output voltage of the DCDT is proportional to the displacement $y$ of its “core” that contacts the beam at the position of the applied force. Therefore, the load cell output is the DCDT voltage:

$$ e_o = k_d y $$

(2)

where $k_d$ is static sensitivity of the DCDT.

**Analysis**

**Static Sensitivity** – Using equations 1 and 2, derive an equation for the output of the load cell $e_o$ as a function of its input force $F$. From this relationship determine the static sensitivity $K$. In the lab, measure the dimensions of the beam using appropriate instruments for each: the micrometer for the thickness $h$, the vernier caliper for the width $b$, and the ruler for the length $L$. The $3\sigma$ values for the uncertainties of these instruments are:

$\Delta b = 0.001\text{ in}$, 
$\Delta h = 0.0005\text{ in}$, 
$\Delta L = 1/32\text{ in}$.

Additionally, the elastic modulus $E$ of the aluminum beam is $69 \pm 0.35 \text{ GPa}$. The manufacturer’s specifications indicate that the static sensitivity $k_d$ of the DCDT is $332.3 \pm 1.6 \text{ V/m}$.

From these data compute both the value of the load cell static sensitivity $K$ in units of $\text{V/N}$, and the $3\sigma$ uncertainty of that calculation. Of the parameters that determine $K$, which contributes the largest portion of the uncertainty? In the lab, you will compare the measured sensitivity to the result of your analysis.

**Load Cell Uncertainty** – Once the load cell is calibrated you will use it to measure the weight of an unknown object. Although, the geometry and elastic modulus of the beam remain constant during use, the load cell output is subject to statistical variations due to noise in the DCDT. The standard deviation $\sigma$ of DCDT output is $6.66 \text{ mV}$. Predict the load cell input standard deviation. Again, you will compare a laboratory measurement of this value to your analysis.
LabVIEW

The LabVIEW vi will record calibration data for the load cell, fit a linear calibration curve to the data, and apply the resulting calibration model to infer the weight of any unknown object. Below, the operation and implementation of the vi are described.

Operation

The vi runs continuously. While it runs, the user hangs a series of lab weights from the load cell. The vi records and plots the corresponding voltage. The front panel will have a numeric control for the equivalent mass of the lab weight, a numeric voltage indicator, a boolean button to signal that a data point (force and voltage) are to be recorded, and an xy graph containing the current recorded data (Voltage vs Force).

A portion of the front panel is shown in Figure 3. For each data point, the user will place a combination lab weights on the load cell, record its mass in grams in the “Mass - gm” control, and press the “Take Data Point” button, causing the corresponding DCDT output voltage to be recorded. This process is repeated until sufficient points have been recorded for the calibration curve. The graph will continuously display all of the data taken, as discrete points.

Implementation

The Main Loop – Part of the vi block diagram is shown in Figure 4. This is not the entire diagram. You will have to expand and add more elements to complete this exercise. However, this figure does illustrate many key concepts.

Figure 4: Code fragment: the main loop

Notice that the “Wait Until Next ms Multiple” timer causes the “while” loop to execute 10 times per second (forever). The calibration data points (force and voltage) are stored in arrays (thick lines) that circulate around the loop in “Shift Registers” (triangles, at the loop edges). Each time time the loop executes, the Mass value is read from the from panel, and the dcdt voltage is measured in the “DCDT Voltage” vi. When the “Take Data Point” button is pressed the Case Structure becomes TRUE (as shown). Inside the Case Structure “Build Array” functions add the current values of the force and voltage to the arrays, increasing their lengths by one.

Each time time the loop executes, the current contents of the arrays are passed to the Calibration Graph. Notice also the use of the “Expression Node” to convert the mass into an equivalent force.

Voltage Measurement/Simulation – The “DCDT Voltage” subvi supplies the current value of the dcdt voltage. This subvi provides the voltage in one of two ways, depending on the boolean input “Real Data”. See Figure 5.

If Real Data is TRUE, the subvi should return voltage connected to the analog input Channel #0. As shown, use the AI Sample Channel function, located in the functions palette at Functions/NI Measurements/Data Acquisition/Analog Input. Specify device number 1.

If Real Data is FALSE, your subvi will simulate the voltage output, based on the calibration model that you
develop in the above analysis. Notice that one of the inputs DCDT Voltage subvi is “Weight”. Using this value, have the FALSE frame of the case structure compute the corresponding dcdt voltage. Use an arbitrary value for the intercept voltage (e.g. 0.5 V). Add Gaussian random noise, with standard deviation equal to that given above, to computed voltage.

You might ask: Why bother simulating the dcdt voltage when the purpose of LabVIEW is to measure real data? Two reasons: First, with Real Data set to FALSE, you will be able to completely develop, debug, and test your vi on any computer running LabVIEW (not just the experiment computer). Second, with Real Data set to TRUE, you will be able to compare the results of your analysis to the experimental results in the lab.

Hint: I suggest that you code, debug, and test the portion of your vi described above before proceeding on to the remaining two sections.

Least Square Linear Fit – During each cycle of the main loop use the “Linear Fit” function to fit a line to the data in the calibration arrays. Using the outputs of Linear Fit, display on the front panel the slope and intercept of the least squares fit to the data, and the standard deviations of both the input (force) and output (voltage).

The Linear Fit vi also provides a “Best Linear Fit” line that you should plot on the Calibration Graph along with the calibration data. Find Linear Fit on the functions palette at Functions/Analyze/Mathematics/Curve Fitting.

Using the Load Cell – Your vi should also continuously apply the calibration parameters (slope and intercept) to infer the applied force. Plot this measured force on a Waveform Chart on the front panel. Note: A LabVIEW Chart differs from a Graph in that it accepts one data point at a time, and scrolls the waveform to the left to make room.

Finally, you will also plot a running average of the measured force on this chart. Use the “Mean PtByPt” function that you will find on the functions palette at Functions/Analyze/Point by Point/Probability and Statistics PtByPt. Also, display this inferred force in a front panel numerical indicator.

Laboratory Procedure
1. In the lab, measure the thickness $h$, width $b$, length of the beam $L$, using the appropriate instruments. Accuracy is essential. If you are unfamiliar with using a micrometer to make measurements ± .0001 inch, see the course web site under “additional resources”. Predict the load cell static sensitivity.
2. As described above, code, debug, and test your vi.
3. In the lab, use the vi to calibrate the load cell. Do this by applying a series of weights, from 0 to 2 kg. Even steps are not necessary, but use at least 10 different weights in the 2-kg range.
4. Measure the weight of the unknown object.

Answer the following questions:
1. From your analysis, what is the static sensitivity?
2. What is the uncertainty in that estimate?
3. What parameter contributed the largest portion of the uncertainty?
4. Does the experimental static sensitivity agree with your analysis?
5. Is it within the predicted uncertainty?
6. What is your analytical prediction of the load cell output standard deviation?
7. How does that prediction compare with the experimentally measured value?

Report
Be certain to include any figures and data necessary to support your analysis and conclusions, although you may choose to put details in an appendix. This brief report is to be written at a level midway between a homework assignment and a formal report. Handwritten work is acceptable, but must be neat and legible. Binding is not required.

Please include a printed copy of your vi front panel and block diagram in your report.