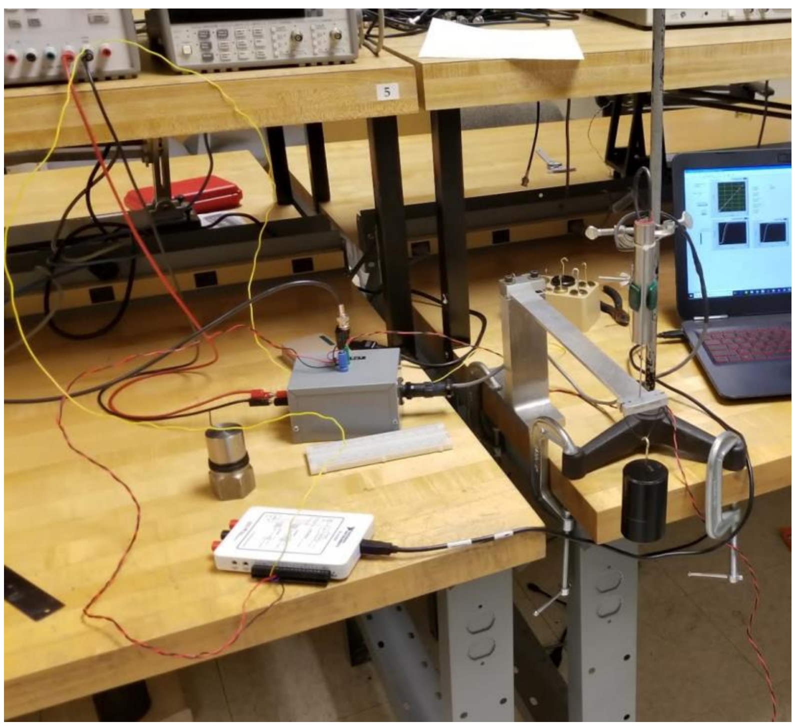
ME 473 Instrumentation

Project 4:
A Cantilever Beam Load Cell



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Laboratory Procedure

1. **Measure h, b, and L**

```
b=1.177 in;
h=0.1878 in;
L=11.875 in;
```

By equating y in:

$$F = \frac{Ebh^3}{4L^3}y \quad \text{and} \quad e_o = k_d y$$

We can obtain:

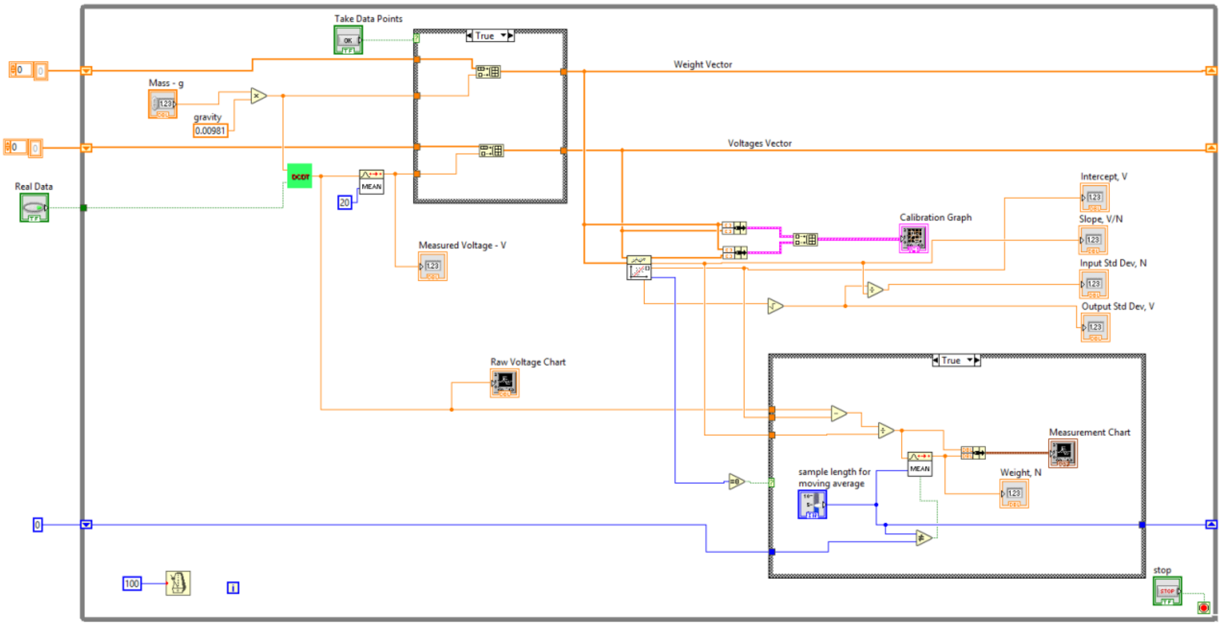
$$\epsilon_0 = \frac{4K_d L^3}{Ebh^3}F$$

Where:

$$K = \frac{4K_d L^3}{Ebh^3}$$

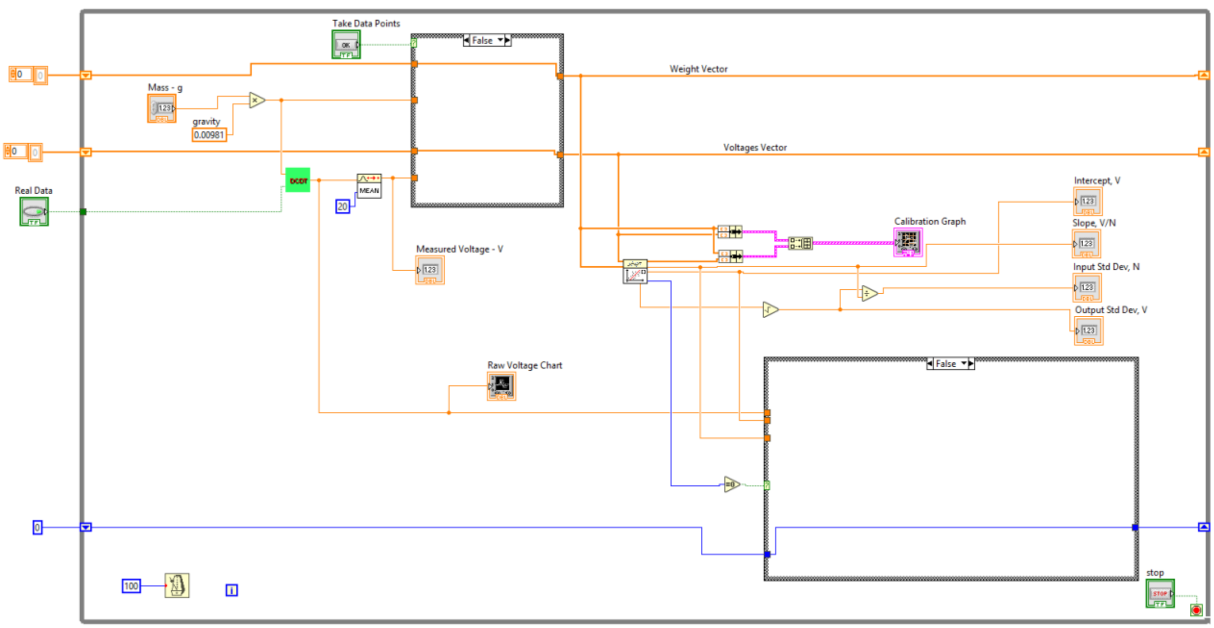
In which K is the static sensitivity

2. VI



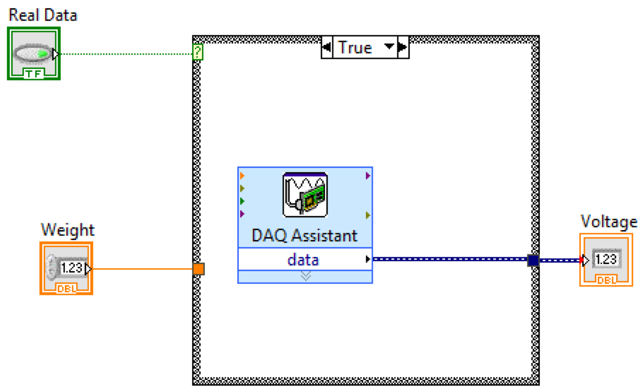
Calibration VI (True Case)

The true case is used to record the input measurements and converting them into weights and measured voltage.



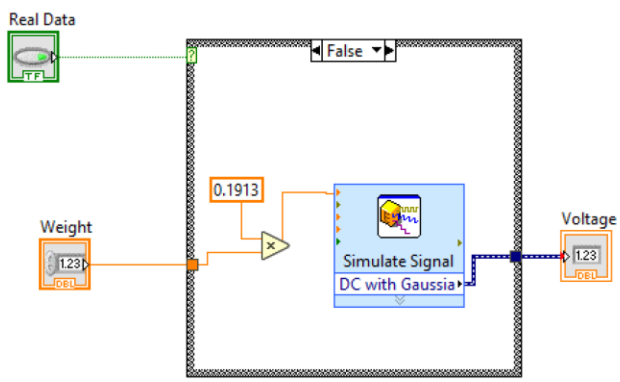
Calibration VI (False Case)

The false case is used when the VI is idling and therefore the user can switch the mass in the cantilever while not continuously taking data points.



DCDT Voltage VI (True Case)

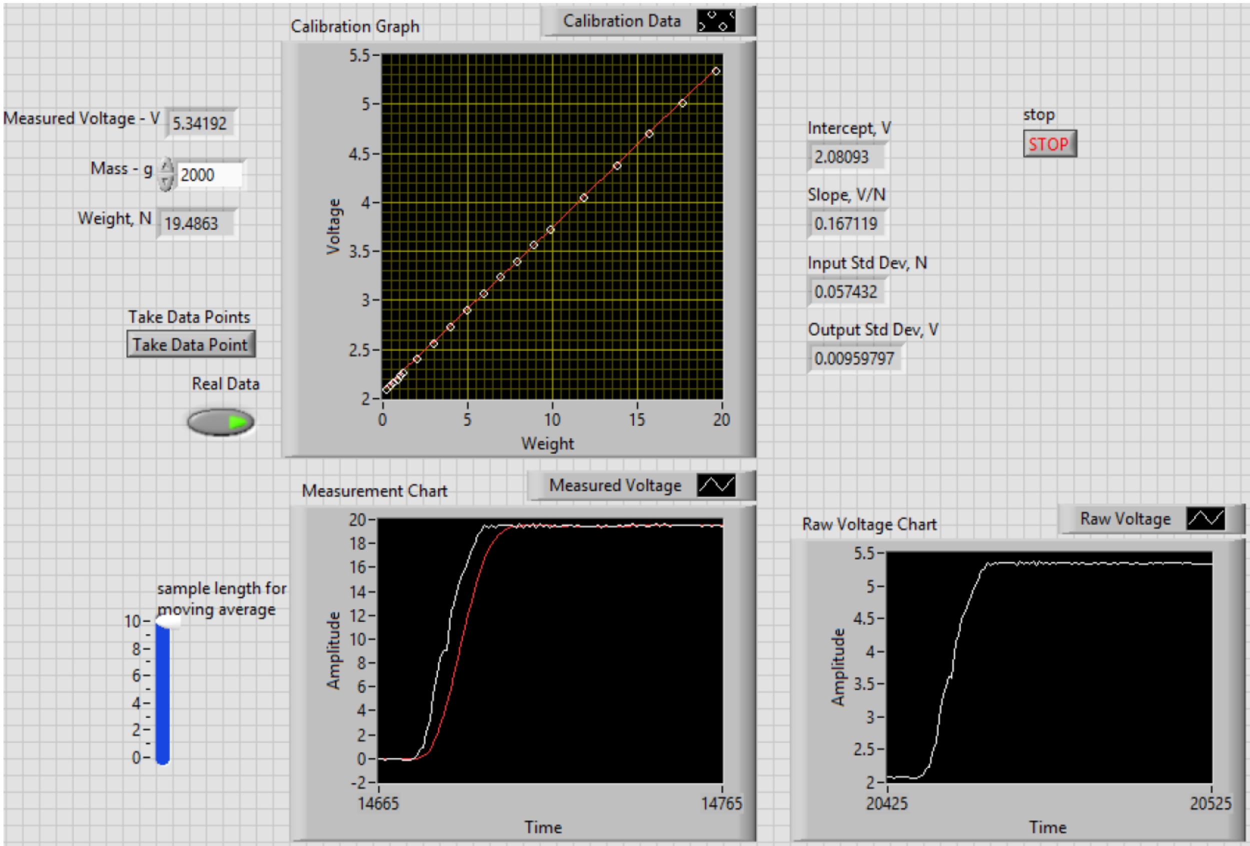
The true case is used to measure the measurement voltage acquired from the load cell apparatus.



DCDT Voltage VI (False Case)

The false case is used to test the VI by generating random DC signal with Gaussian Noise which will give a certain value with a simulated noise that has a certain variance. The DC signal is multiplied by the static sensitivity calculated in MATLAB.

3. Calibrate the load cell



Calibration Front Panel

To take the calibration data, we would first need to toggle the real data button on. Then, for every known mass, input the value in the mass numerical input, then press the take data point button in order to record it in the calibration curve. Continue doing this until all the data has been acquired.

The result of the calibration can be accessed in the numerical indicator and will provide:

a) Intercept voltage (V)
b) Slope (V/N) or the static loading factor
c) Input standard deviation (N) or the standard deviation of the force measured
d) Output standard deviation (V) or the standard deviation of the noise

4. Measure the weight of the unknown object

The voltage measured by myDAQ upon hanging the load is:

$$\varepsilon = 3.302\ V$$

Applying the formula obtained from the calibration,

$$F = \frac{1}{slope} * (\varepsilon - intercept)$$

$$\boxed{F = \frac{1}{0.167119}(3.302 - 2.08093) = 7.31\ \mathrm{N}}$$

Answer the following questions:

1. From your analysis, what is the estimated static sensitivity of the load cell you have created?
2. What is the uncertainty of that estimate?
3. What one parameter contributes the most to the uncertainty of that estimate?
4. To what extent does the the experimentally determined static sensitivity of your load cell agree with your analytical prediction?
5. Is it within its predicted uncertainty?
6. What is your analytical prediction of the standard deviation of the measurement error for your load cell (N)?
7. To what extent does that prediction agree with what you observed experimentally?

Answers:

1. The estimated static sensitivity (K) of the load cell is: (calculation performed in MATLAB)

$$K = \frac{4K_d L^3}{Ebh^3}$$

$$\boxed{K = 0.1913 \text{ V/N}}$$

2. The uncertainty of the estimate is: (calculation performed in MATLAB)

$$\boxed{dK = 0.006736 \text{ V/N}}$$

by using the formula:

$$\delta K = \sqrt{(\frac{\delta K}{\delta b}\Delta b)^2 + (\frac{\delta K}{\Delta E}\Delta E)^2 + (\frac{\delta K}{\Delta h}\delta h)^2 + (\frac{\delta K}{\delta L}\Delta L)^2 + (\frac{\delta K}{\delta K_d}\Delta K_d)^2}$$

3. The uncertainty that contributes the most should be the highest partial derivative term in the equation above.

$\frac{\delta K}{\delta b}\Delta b$ = -1.625686879493520e-04

$\frac{\delta K}{\Delta E}\Delta E$ = -9.705821884164571e-04

$\frac{\delta K}{\Delta h}\delta h$ = -0.001528301483358

$\frac{\delta K}{\delta L}\Delta L$ = 7.553026804594233e-04

$\boxed{\frac{\delta K}{\delta K_d}\Delta K_d = 0.006441843614433}$

Judging from the values of each uncertainty components, **Kd contributes to most of the uncertainty.**

4. We can calculate the percent error of the static sensitivity with respect to the theoretical value.

   The static error obtained from the slope of the data calibration is:

   K = 0.167119 V/N,

   Therefore, the percentage error is:

$$\%error = \frac{0.167119 - 0.191343}{0.191343}$$

$$\boxed{\%error = -12.66\ \%}$$

This percentage error is significant with respect to the theoretical K value. One possible reason for this decrease in the measured static loading sensitivity (K) is due to the nonlinearity in static loading since the displacement is high enough to cause the cantilever beam to bend horizontally as well on top of the assumed vertical bending.

5. The theoretical K value is 0.1913 and the theoretical standard deviation for K is 0.0067358. Therefore, **the range of K value should be within 0.1846 and 0.19804**.

   The measured K value is 0.167119 which is not in range of the predicted K value.

   One possible reason for this inaccuracy is due to the fact that the cantilever beam does not bend purely vertically since it also will bend laterally since the strain is large enough that the relationship between the displacement and force is no longer linear.

6. The analytical prediction of the standard deviation is:

$$\boxed{\sigma_F = \frac{\sigma_\varepsilon}{K} = \frac{0.0067358\ V}{0.1913433\ V/N} = 0.0352\ N}$$

7. The percentage error of the standard deviation of the load cell can be calculated by:

   The standard deviation in the measurement is:

$$\sigma_{F,measured} = 0.057432\ N$$

   Therefore, the percentage error is:

$$\boxed{\%error = \frac{\sigma_{F,measured} - \sigma_F}{\sigma_F} * 100\% = \frac{0.0574 - 0.0352}{0.0352} * 100\% = 63.1\ \%}$$

   There is a huge difference between the expected standard deviation and the theoretical standard deviation. One clear explanation for this case is due to the myDAQ used in this experiment. From my experience in completing project 4, my myDAQ is especially noisier than my classmate's myDAQs judging from the potentiometer calibration and the rolldown data acquisition. Since the theoretical standard deviation does not take into consideration the noisiness of the myDAQ itself, I expect the measurement to have higher standard deviation.

Secondly, the cantilever beam itself is subject to vibrations from the building and from the table, which would contribute to the increase in the standard deviation. Also, when applying the load to the cantilever beam, it was difficult to keep the load stable without moving, which would contribute to the increase of the measurement standard deviation.

MATLAB Code

```
%ME 473 - Project 4
%Khrisna Kamarga
clear all; close all; clc;

%Variables
E = 69e+9;
Kd = 390.3;

%Measurements
b=1.177*0.0254;
h=0.1878*0.0254;
L=11.875 *0.0254;
%Calculate K
k = 4*Kd*L^3/(E*b*h^3);
display(k);

%Uncertainties
dKd = 13.14;
dE = 0.35e+9;
db = 0.001*0.0254;
dh = 0.0005*0.0254;
dL = 1/64 *0.0254;
values = [E b h L Kd];

%Uncertainty of K
syms E b h L Kd;
K = Kd/(E*b*h^3/(4*L^3));
dK = sqrt((diff(K,b)*db)^2 + (diff(K,E)*dE)^2 + (diff(K,h)*dh)^2 ...
           + (diff(K,L)*dL)^2 + (diff(K,Kd)*dKd)^2);
symbolic = [E b h L Kd];
dK = subs(dK, symbolic, values);
dK = double(dK);
display(dK)

% Uncertainty Contribution
UE = (diff(K,E)*dE);
UE = double(subs(UE, symbolic, values))
Ub = (diff(K,b)*db);
Ub = double(subs(Ub, symbolic, values))
Uh = (diff(K,h)*dh);
Uh = double(subs(Uh, symbolic, values))
UL = (diff(K,L)*dL);
UL = double(subs(UL, symbolic, values))
UKd = (diff(K,Kd)*dKd);
UKd = double(subs(UKd, symbolic, values))

% Analytical Percent Error
err_K = 100*(0.167119 - K)/K;
err_K = double(subs(err_K, symbolic, values))
```