University of New Haven

Department of Mechanical Engineering

To: Dr. Dieckman
December 2, 2022
From: Semih Akyuz, Raymond Pagan Jr.
Re: Load Cell and Strain Gage Evaluation for Measurement System

Readings from a LC201 load cell and a CEA strain gage were collected in two individual experimental setups. The load cell was attached to an aluminum rod that suspended load vertically and returned mV values. The strain gage was attached to a 6061-aluminum cantilever beam and returned strain values along the length of the beam. The outputs were collected over incrementally varying loads to obtain an experimental calibration line. Load cell readings were plotted as mV vs lbs and compared to the calibration information provided in documentation [1]. Strain gage readings were used to calculate the load on the cantilever beam through the equations shown in the 'Calculations Attachment' and the results were plotted as calculated load vs placed load. The load cell had a drastic slope error of 60.7% and an offset error of 3.82 ± 1.13 mV [95%] while the strain gage had a slope error of 4.10% and an offset error of 0.0595 ± 0.0223 kg [95%]. Comparison of experimental and expected calibration lines are shown in Figure 1. for the load cell and in Figure 2. for the strain gage.

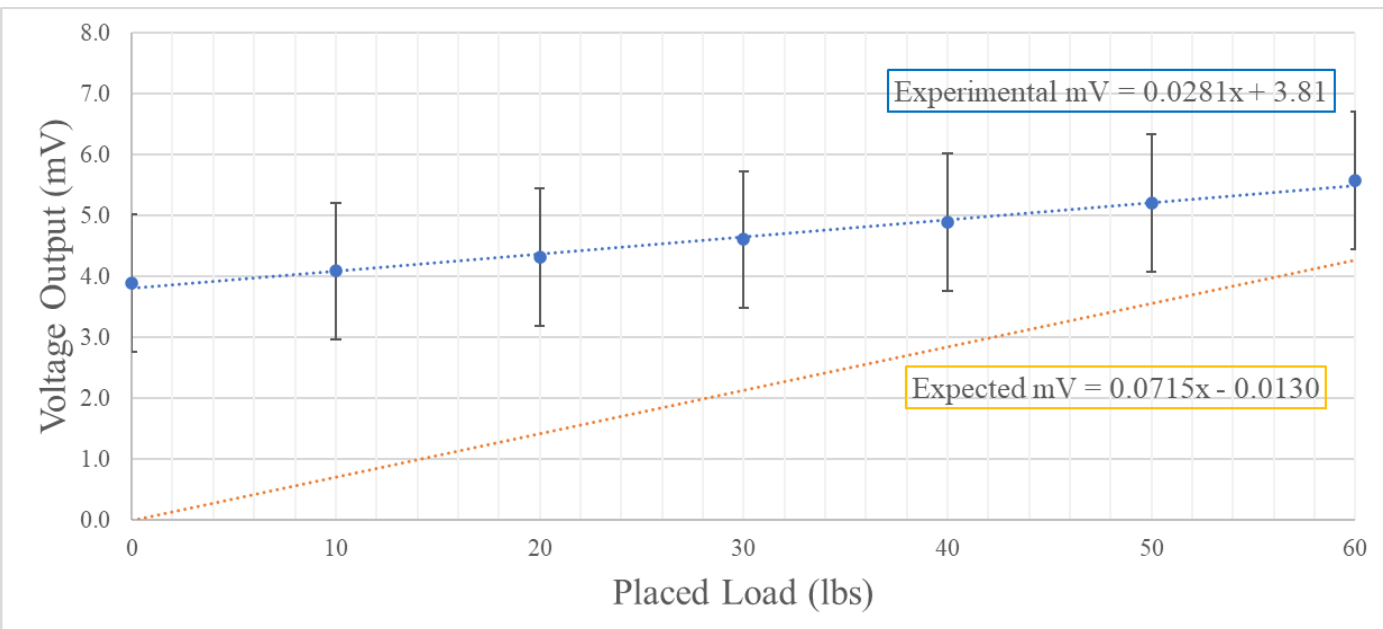


Figure 1. The load cell had a 60.7% slope error and an offset error of 3.82 ± 1.13 mV [95%]. After verifying the experimental setup, the sensor was deemed inoperable.

The LC201 load cell was wired to an NI Elvis board and received a voltage of 10V[1]. Output voltage values were recorded in sets of seven from 0 to 60lbs in 10lb increments. The expected line was found by plotting mV output vs placed load. After the collection of what was assumed to be faulty data from the load cell, the experimental setup was verified with a multimeter. The 10 volts provided for the excitation of the load cell was confirmed to be within ±0.02V. The outputs at various loads used in the trial were checked manually to verify their equivalency to data collected through LabView. It was concluded that the setup returned the outputs of the

[1] LC-201 Load Cell Calibration Sheet

load cell properly. The load cell is faulty beyond expected operational errors and should not be relied upon in the proposed measurement system.

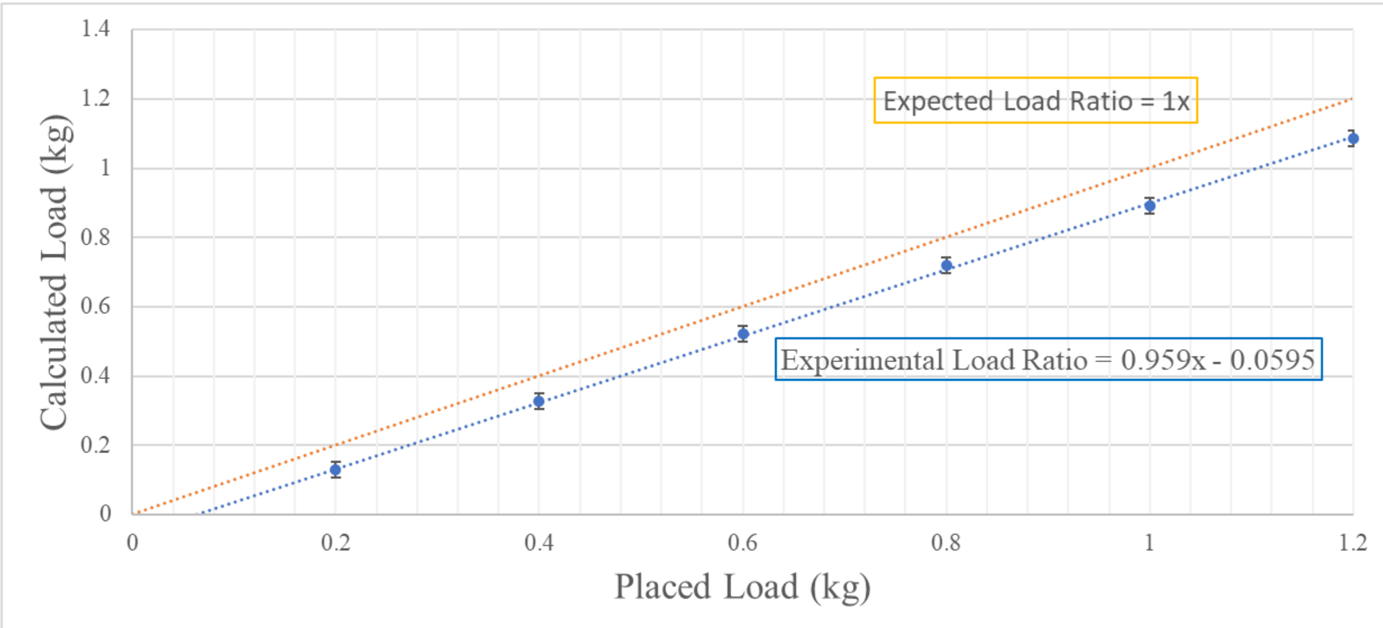


Figure 2. The strain gage had 4.10% slope error and an offset error of 0.0595 ± 0.0223 kg [95%].

The CEA strain gage was mounted on a 6061-aluminum cantilever beam and wired in a quarter bridge configuration. An NI-9945 120Ω resistor and a NI-9237 bridge hub were used as shown in the 'Experimental Setup Attachment'. Strain values were recorded in sets of seven from 0 to 1.2kg in 200-gram increments. The outputs were averaged and used to calculate the load applied on the cantilever beam using equations in the 'Calculations Attachment'. Calculated load from measured axial strain was plotted against placed load in Figure 2. Calculated load and applied load are expected to have a 1:1 ratio which would indicate that the sensor is perfectly accurate. Potential causes of error are the measurement for the strain gage position on the beam, and compounding error caused by the variance in multiple weights.

The uncertainties reflected in Figures 1 and 2 were calculated though a combination of obtained bias and precision uncertainty. The bias uncertainties for the strain gage and load cell were set as half of the largest difference between the maximum and minimum output values at no load. The precision uncertainty was calculated at a 95% confidence interval for each set of seven readings. Equations used to determine the uncertainty for both sensors are shown in the 'Uncertainty Attachment'.

The load cell had a drastic slope error of 60.7% and an offset error of 3.82 ± 1.13 mV [95%] while the strain gage had a slope error of 4.10% and an offset error of 0.0595 ± 0.0223 kg [95%]. The load cell is deemed to be faulty as the sensor returns a load value and does not involve calculations using other experimental measurements. The strain gage has an expected amount of error considering the multitude of experimental variables involved in the calculations to obtain a load value.

The proposed LabVIEW programming for the requested scale is shown below in Figure 3. The system makes use of the calibration lines to output a load value. Outputs of the strain gage are converted to kg load and displayed while the strain gage indicator is turned on. After the limitations of the strain gage are met at 5% of its length, the system starts using the load cell outputs. Conversion steps and the programming logic are displayed in Figure 3 along with annotations.

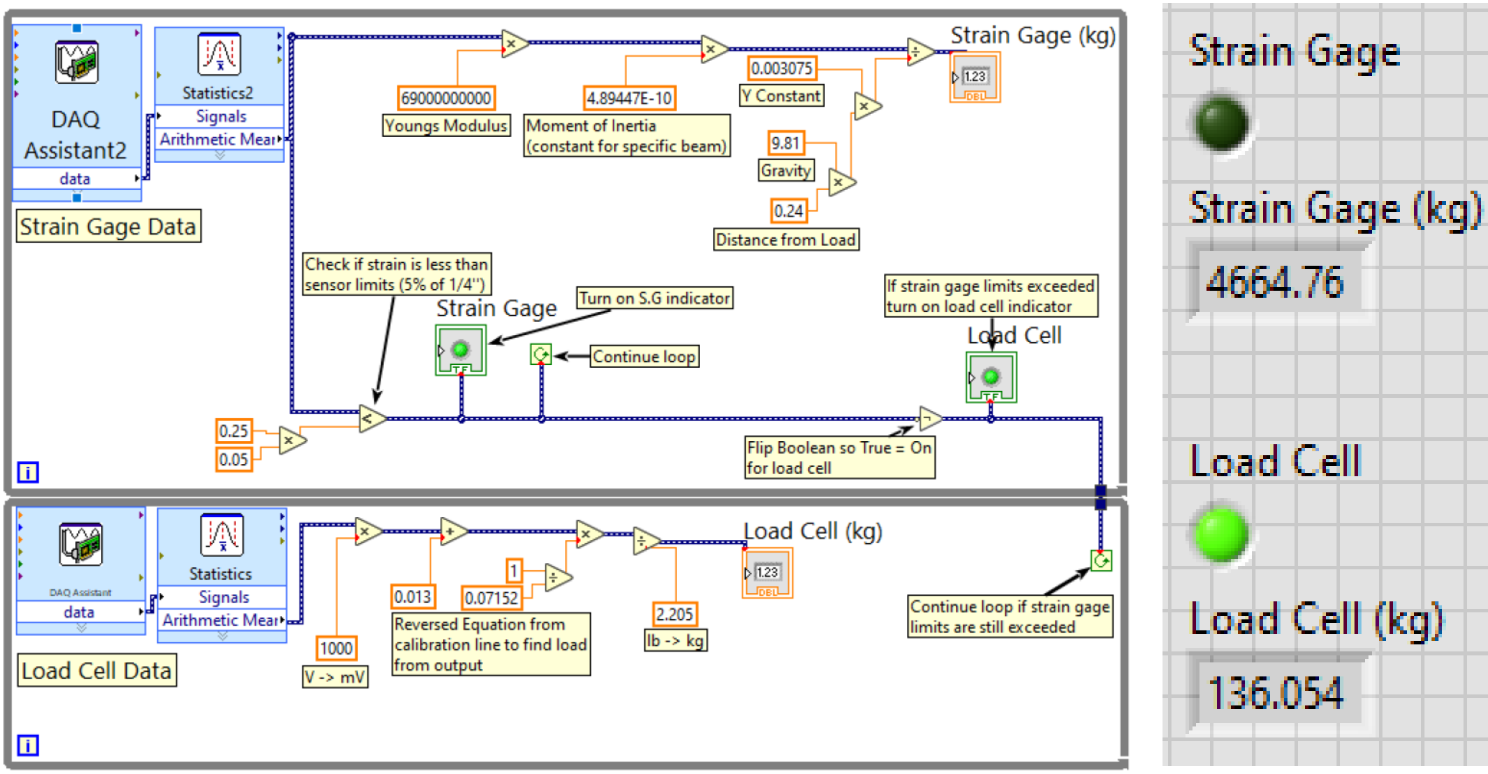


Figure 3. The proposed LabView scale system features two numeric indicators displaying the outputs of the sensors at varying loads. The LED indicators are used to show which sensor is in active use at the time.

The experimental calibration line is used for the strain gage to obtain a load value as the strain gage had relatively low error during the trials. The expected calibration line is used for the load cell as it was determined to be faulty and needs replacement. Experimentation for the load cell will need to be repeated upon acquiring a functional one. The LabVIEW program will require the substitution of the new experimental calibration line. It is currently not recommended to use the current scale above loads which exceed the limitation of the strain gage as the load cell will return highly inaccurate values.

Following replacement of the load cell, the system can be used by applying the load in question and taking the reading presented below the LED that is turned on. A mechanical system will need to be designed to take the load off of the strain gage and apply it only to the load cell. Over stressing the strain gage must be avoided to ensure proper future operation.

Attachments: Expected Values, Experimental Setup, Calculations, Uncertainty

EXPECTED VALUES

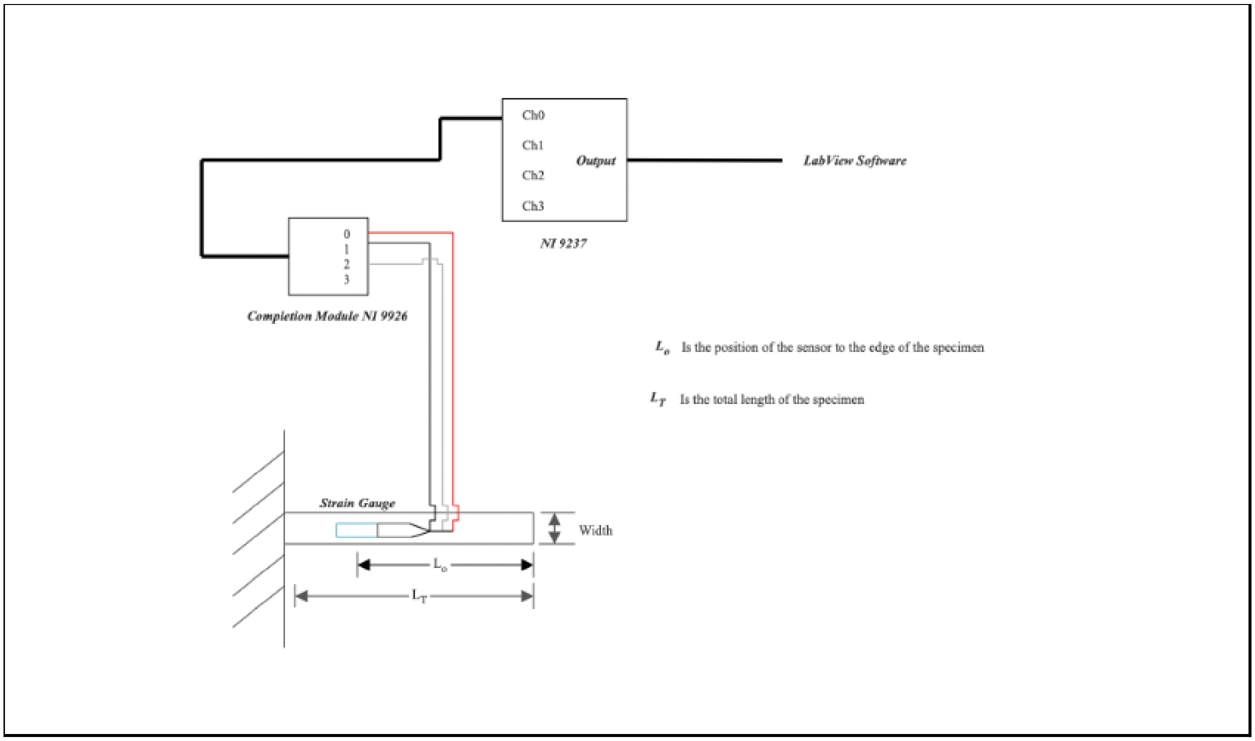
This attachment shows the expected calibration lines for each sensor. The reading at the experimental limit is also calculated for reference. Note that the calibration line of the strain gage is not used in this report and is only included for reference. A comparison for strain gage readings is provided through the expected 1:1 ratio between the placed load and the calculated load.

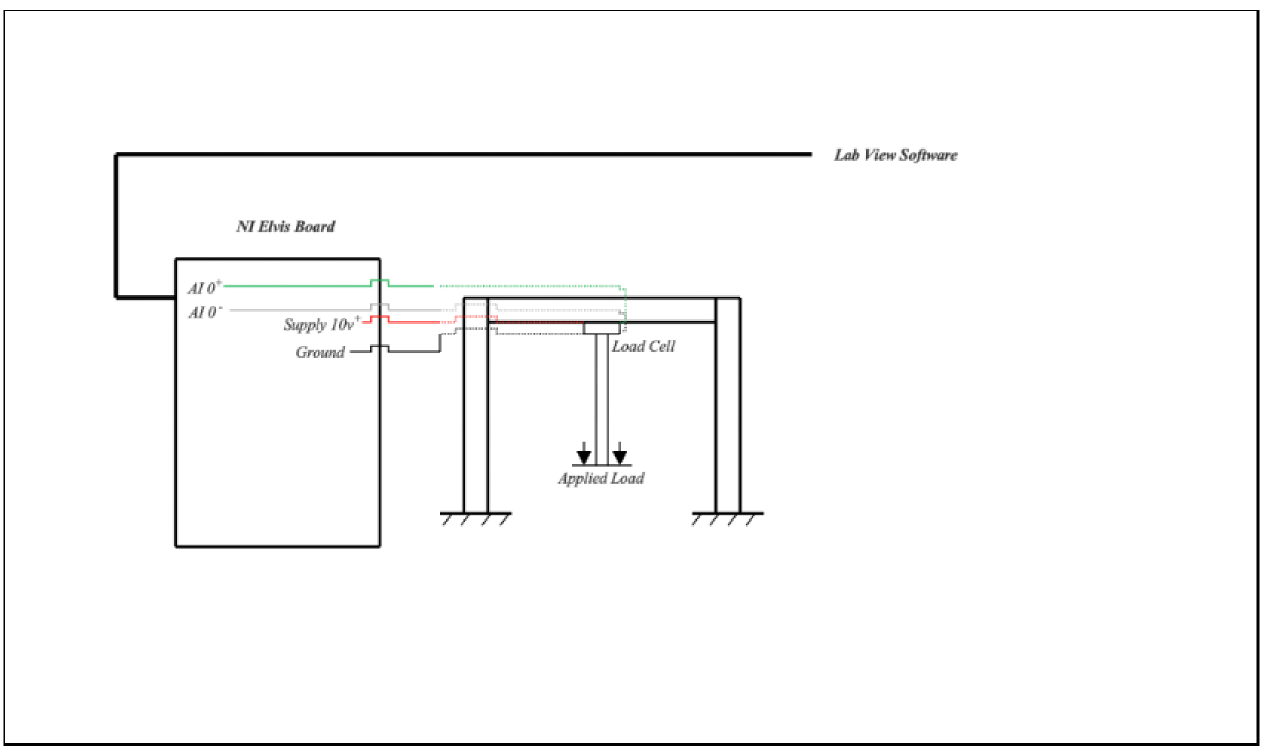
Load Cell - Voltage at Experimental Limit		
	Load lbs	Voltage mV
Sensor Min	0	-0.013
Experimental Limit	60	4.277
Sensor Max	300	21.44
Calibration Line (mV vs Load)	y = 0.0715x -0.013	

Strain Gauge - Expected Calibration Line		
	MicroStrain	Load kg
Sensor Min	0	0
Experimental Limit	257.25	1.25
Calibration Line (Strain vs Load)	y = 214.37x	

EXPERIMENTAL SETUP

This attachment shows both the strain gage and load cell experimental setups. The first image is the strain gage, and the last image is the setup up for the load cell.





CALCULATIONS

Bending Stress

$$\boldsymbol{\sigma_b = \frac{My}{I}}$$

where

σ_b is bending stress applied to the cantilever beam

M is the bending moment

y is the vertical distance away from the neutral axis (thickness/2)

I is the moment of inertia around the neutral axis

Bending Moment, M

$$\boldsymbol{M = mgx}$$

where

m is the suspended mass on the cantilever beam

g is the gravitational constant (9.81 m/s^2)

x is the distance from the suspended end of the cantilever beam to the center of the strain gage

Moment of Inertia Around Neutral Axis, I (for rectangular prism)

$$\boldsymbol{I = \frac{1}{12}wt^3}$$

where

w is the width of the cantilever beam

t is the thickness of the cantilever beam

Strain, $\boldsymbol{\epsilon}$

$$\boldsymbol{\epsilon = \frac{\sigma_b}{E}}$$

where

σ_b is the bending stress applied to the cantilever beam

E is Young's modulus for the material of the cantilever beam (Aluminum 6061 at 69 GPa)

UNCERTAINTY

Standard Deviation - (Sample)

$$\boldsymbol{\sigma = \sqrt{\frac{\sum(x_i - \overline{x})^2}{N-1}}}$$

where

x_i is each measurement in individual groups of seven points from the two sensors

$\overline{x}$ is the mean of each group of seven measurements

N is the number of data points in each data set

Standard Error of the Mean

$$\boldsymbol{\sigma_M = \frac{\sigma}{\sqrt{N}}}$$

where

σ is the standard deviation

N is the number of data points

Uncertainty - Precision

$$\boldsymbol{U_{xP} = \frac{Z * \sigma_M}{\sqrt{N}}}$$

where

Z is the z-score used for the desired confidence interval (1.96 for 95% CI)

σ_M is the standard error of the data set

N is the number of data points in each data set

Uncertainty - Combined

$$\boldsymbol{U_x = \sqrt{u_{xB}^2 + u_{xP}^2}}$$

where

U_{xB} is the bias uncertainty of the individual sensors

U_{xP} is the precision uncertainty of the individual sensors