LOAD CELL CALIBRATION

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Table of Contents

Introduction *3*
Equipment and Instruments 3
Methodology and set up procedure *4*
Justification of this methodology 6
Analysis of Results *6*
Conclusion: *9*
Methodology reflection and Future suggestions 9

Introduction

Load cell calibration involves the exact measurement of weight or force with the use of a scale. For accuracy of these measurements, the weighing scale must be properly calibrated and taking into consideration the uncertainty of the weights and multimeter calibration. An instrumentation amplifier or "in-amp," is a type of differential amplifier that is used to amplify small signals like the output signal of a load cell with large common-mode signals as load cells are overwhelmed by common-mode noise. In-amps have a high input impedance and a low output impedance. To use an in-amp to amplify the small output signal of a load cell, the IA must first be properly configured. This involves setting the gain of the in-amp, which determines the amount of amplification applied to the input signal.

A load cell is a type of transducer that measures weight or force producing an output signal that is proportional to the applied load. The output signal from a load cell ranges in the millivolt unit, which is too small to be measured or read precisely by most electronic devices hence the use of an in-amp for amplification. An instrumentation amplifier amplifies the difference between the non-inverting and inverting inputs, and rejects said any common-mode signals that may be present. This eliminates any interference from external sources.

With the gain of the in-amp, the output signal of the load cell can be amplified so that a voltage of 5v is produced for the maximum range of the load cell which is 1Kg. To do this, the load cell is connected to the in-amp and with the chosen of the gain resistor after several adjustments in the amplifier circuit to achieve the desired output. This will allow for accurate measurements and analysis of the weight of the load using the amplified output signal. This allows the load cell to be used in a wide range of applications, such as weighing scales, force sensors, and other systems that require accurate measurement of mechanical forces.

Equipment and Instruments

- The INA118P is the instrumentation amplifier used. It is uses low-power and is used for instrumentation applications. It has a high common-mode rejection ratio with a low input offset voltage that rejects unwanted noise and offset errors in the input signal. INA118P has a gain bandwidth product of 10kHz, allowing it to accurately amplify signals with frequencies up to 10kHz. This makes it well-suited for use in applications where higher frequency signals are present such as in load cells that are designed to measure rapid changes in weight, used in medical and scientific instrumentation, as well as industrial sensors and measurement. INA118P can operate on a single supply voltage as low as 2.7 V.

- Cantilever Load Cell is a type of load used in applications where weight is measured at a single point. It is anchored at one end and extends outwards, perpendicular to its support. This weight being measured is applied to the end of the cantilever beam, which then deflects according to the magnitude of the force. When a force is applied to the free end of the cantilever beam, it deflects or bends in proportion to the magnitude of the force. The change in resistance is then converted into an electrical signal that can be read by a device.

- Multimeter measures electrical properties, such as voltage, current, and resistance, in this case the voltage.

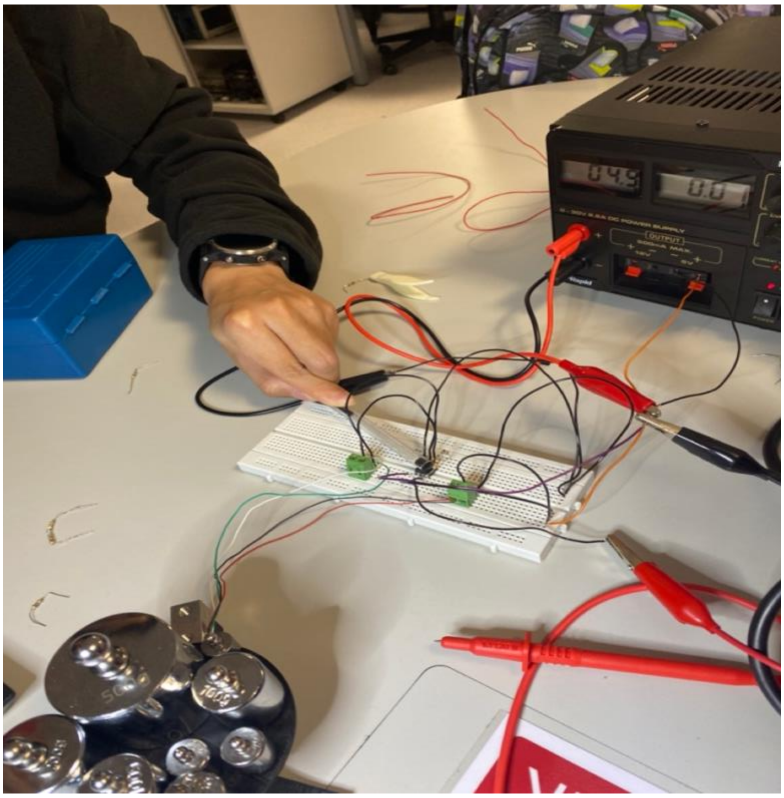
- Breadboard connects electronic components together using jumping wires.
- Sets of calibration weights
- Terminal blocks are electrical connectors that are used to connect wires together in a circuit. The wires are inserted into the terminals and held in place by a screw.
- Power supply

Methodology and set up procedure

Multi-point calibration is a methodology that involves using multiple reference points to accurately calibrate a device.

1. Set up the load cell: Four strain gauges was attached in a Wheatstone bridge configuration, using four wires. The red for the supply voltage, black for ground connection, and white and green for signal output as seen in figure 1 below.
2. Measure the output voltage when there's no weight.
3. Measure the output voltage when there's maximum weight.
4. Connect the breadboard with the instrumentation amplifier. The INA118P in-amp used needs +/-5v supply voltage and a power supply is connected as the one given in the lab. The INA118P is placed on the central divider of the breadboard and connected by the terminal blocks that help with the connection to the power supply and the cantilever load cell. The INA118P's input is connected to the load cells output. The INA118P output is then be connected to a suitable load, the multimeter to measure the amplified signal from both terminals relative to ground. The in-amp's common-mode rejection ratio is high enough to reject common-mode signals in the output such as ground-level offsets. This ensures accuracy of the load cell output. The in-amp has a low input offset voltage for accuracy of this amplified signal. The INA118P is configured by setting the appropriate gain with the use of resistor(s). This determines the amount of amplification applied to the input signal. The bridge output for the maximum load for the cantilever load cell is measured to get this gain resistor.
5. The power supply was then turned on after being connected accordingly in order to obtain +/- 5v. The 10g weight was added, the output voltage was measured three times as that was the decided amount of readings to be taken per measurement for accuracy purposes. Then the 20g replaced the 10g weight and the same procedure was repeated, then the 10g weight was added back to measure 30g until 100g was reached with the use of 10g, 20g, 20g and 50g. From 100g it went up in 100's until 1000g was reached.
6. Measure the output of the load cell with every weight.
7. Record data and calculate uncertainty.

Figure 1 showing The Setup of Apparatus:



Gain is the calculated as the ratio of the target voltage to the voltage at maximum weight. An estimated calculation was done as shown below:

Voltage measured with no weight = 0.0009V

Voltage measured at maximum weight = 0.0055V

Target Voltage = 5V

Gain = Target voltage/Voltage at maximum weight: $\frac{5}{0.0055}$ = 909

Resistor Gain = $\frac{50k}{Gain-1}$ = 55Ω

Voltage = 4.912V

Justification of this methodology

This method gives accuracy over a range of load values, which helps correct nonlinearities in the load cell's response.

In addition to that, a multi-point calibration is used to account for any drifts in the load cell's functioning over time. With continuous multi-point calibrations, any changes in the load cell's performance can be identified and corrected, so that the load cell will give accurate measurements.

The Wheatstone bridge circuit is used as it amplifies and measures small changes in resistance due to external factors. The Wheatstone circuit is good in trying and a wide range of temperature conditions which is good for measurement correctness.

In-amps have high input impedance, allowing them to precisely measure the small voltage output of the load cell without loading the circuit. It does not load the load cell, allowing it to operate at maximum sensitivity. This is necessary because the load cell's output is proportional to the weight being measured, and any loading of the circuit can result in an inaccurate measurement. Instrumentation amplifiers are designed to have high gain and low noise, which makes them well-suited for amplifying small signals. This is important because the output of a load cell is a few millivolts, and it needs to be amplified significantly.

Analysis of Results

The accuracy of the load cell is followed by comparing the measured output voltage to the known value by calculating the percentage error.

Percentage error:

$$\frac{\text{Measured output voltage} - \text{target voltage}}{\text{target voltage}} * 100\%$$

$$\frac{4.912 - 5}{5} * 100 = -1.76\%$$

This is a low percentage error indicating that the load cell measurement is accurate as it is close to the known value(5V) of weight being measured.

As seen in the Excel Spreadsheet below, the precision of the load cell has been critically analysed with the output voltage measurements of several weights next to their standard deviation (column K) and uncertainty values (column F). The smaller the standard deviation, the closer it is to the mean value indicating a more precise measurement and the bigger means the values are more dispersed indicating variability of the data. To calculate the standard deviation, the average value of the voltage for a particular data set was found then this said average value was subtracted from each data value. This new value was squared and averaged, then the square root of that average is the standard deviation.

Figure 2 showing Excel Spreadsheet showing Results and Uncertainty

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1															
2															
3					weight	weight uncertainty +/- g	1st voltage	2nd voltage	3rd voltage	average voltage	standard deviatio	variance	Type A	Uncertaintity	Type B
4					0		0.9391	0.9383	0.9392	0.938866667	0.000493288	2.43333E-07	0.0002848		
5					10	0.006	0.9796	0.9805	0.9806	0.980233333	0.000550757	3.03333E-07	0.0003180	0.0034641	0.0094
6					20	0.008	1.0228	1.0225	1.0234	1.0229	0.000458258	2.1E-07	0.0002646	0.0046188	0.01121
7					30	0.014	1.0649	1.0647	1.0648	1.0648	1E-04	1E-08	0.0000577	0.0080829	0.01736
8					40	0.016	1.106	1.1056	1.1056	1.105733333	0.00023094	5.33333E-08	0.0001333	0.0092376	0.01953
9					50	0.01	1.1465	1.1462	1.1462	1.1463	0.000173205	3E-08	0.0001000	0.0057735	0.01317
10					60	0.016	1.1874	1.1871	1.1869	1.187133333	0.000251661	6.33333E-08	0.0001453	0.0092376	0.01953
11					70	0.018	1.2267	1.2259	1.2255	1.226033333	0.00061101	3.73333E-07	0.0003528	0.0103923	0.02174
12					80	0.024	1.267	1.2673	1.2668	1.267033333	0.000251661	6.33333E-08	0.0001453	0.0138564	0.02843
13					90	0.026	1.3074	1.3075	1.3074	1.307433333	5.7735E-05	3.33333E-09	0.0000333	0.0150111	0.03068
14					100	0.012	1.3485	1.3484	1.3485	1.348466667	5.7735E-05	3.33333E-09	0.0000333	0.0069282	0.01523
15					200	0.024	1.76	1.7601	1.7602	1.7601	1E-04	1E-08	0.0000577	0.0138564	0.02843
16					300	0.036	2.1706	2.1704	2.1702	2.1704	0.0002	4E-08	0.0001155	0.0207846	0.04205
17					400	0.048	2.5823	2.5822	2.582	2.582166667	0.000152753	2.33333E-08	0.0000882	0.0277128	0.05579
18					500	0.056	2.9928	2.9426	2.929	2.9548	0.033604166	0.00112924	0.0194014	0.0323316	0.07568
19					600	0.068	3.404	3.4038	3.2036	3.337133333	0.115643302	0.013373373	0.0667667	0.0392598	0.15504
20					700	0.08	3.8154	3.8152	3.8159	3.8155	0.000360555	1.3E-07	0.0002082	0.046188	0.09259
21					800	0.092	4.229	4.228	4.227	4.228	0.001	1E-06	0.0005774	0.0531162	0.10643
22					900	0.104	4.638	4.64	4.639	4.639	0.001	1E-06	0.0005774	0.0600444	0.12026
23					1000	0.136	4.905	4.906	4.907	4.906	0.001	1E-06	0.0005774	0.0785196	0.15717

Column F above is the weight uncertainty of each weight. Weight uncertainties for 10, 20, 50, 100, 200 and 500 were provided, the other weights were calculated by adding the uncertainty value for each weight used in addition.
Columns G, H and I shows the three measured voltages per weight and column J averages the voltages.
Column K shows the standard deviation of columns G, H and I (the three voltages).
Column L shows the variance which is the square of the standard deviation calculated.
Column M shows the Type A which is presented as the standard uncertainty calculated using the formula $u = \frac{\sigma}{\sqrt{N}}$

Row 16 Column M shows the standard deviation divided by square root of 3
$u = \frac{0.0002}{\sqrt{3}} = 0.0001155$

Column N shows when the uncertainty is rectangularly distributed therefore
$u = \frac{\text{weight uncertainty}}{\sqrt{N}}$.
Row 16 Column N: $u = \frac{0.036}{\sqrt{3}} = 0.0207846$

Column O shows the (U) Type B evaluation in which the uncertainty is hard to determine or estimate and the combination of the standard uncertainties. The Type B evaluation gives a range of values that include the true quantity and gives a measure of the uncertainty with the range.

Combining standard uncertainty formula goes as (U) = kUc
$Uc = \sqrt{(3.162\text{m})^2 + M^2 + N^2}$

The multi meter calibration uncertainty is 6324µv with a coverage factor k = 2 and a 95% level of confidence.
u = 6324µv/2 = 3.162mv

This ‘3.162mv’ value squared is added to column N squared and column M squared and all square rooted to give Uc.

U(The uncertainty) = 2*$\sqrt{(3.162\text{m})^2 + \text{M}^2 + \text{N}^2}$

The results show that the average voltage increases progressively until it gets to 4.906 which is good, as the percentage error in comparison to 5 is 1.88% which is low and the measured voltage value 4.912 gives a 0.12% percentage error.

$$\frac{4.906 - 5}{5} * 100 = -1.88\%$$

$$\frac{4.906 - 4.912}{4.912} * 100 = -0.12\%$$

The 1st, 2nd and 3rd voltages in each weight measurement all range within each other proving good accuracy.

The results prove that the load cell does not need further adjustments as the percentage error, standard deviation and uncertainty are in the tolerance limits and performs within specification.

Conclusion:

Methodology reflection and Future suggestions

Multi-point calibration is the used methodology for this load cell calibration and it is used improve the accuracy of load cell measurements by measuring the output of the cell of known reference weights at multiple points. This helps to account for nonlinearities and other errors in the load cell's response. This allows the relationship between the weights and the output of the load cell to be determined over a range of load values, which provides a more accurate representation of the load cell.

An improvement to this method would be to use more points. This can give a more accurate representation of the load cell's response. The reference weights used should also have with a higher level of precision which would improve the accuracy of the calibration.

The point above can be argued and single point calibration might be a better fit and have less weight uncertainty +/-g than the multi-point calibration as one weight is used instead of the addition of weight uncertainties from other weights. Single point calibration is less time consuming making it more practical in some applications such as environments where load cells are being used for production purposes although, single point calibration does not provide as accurate a representation over a range of input load.

Additionally, it is beneficial to frequently check and validate the accuracy of load cell calibrations by comparing the output of the load cell to known weights or forces, and adjusting the calibration.

Another improvement would be to use more advanced methods for analysing the data from the calibration process. This could include using statistical analysis techniques to identify and correct for any errors or nonlinearities in the load cell's response.

A future development could be the use of machine learning algorithms to generate calibration curves based on the output of the load cell and known weights for efficiency. Additionally, the use of microelectromechanical systems (MEMS) could improve the accuracy of load cell measurements as they measure forces with high precision where the device may be subjected to extreme forces and conditions.

To improve the accuracy of load cell calibration, more sources including advanced methods that account for a wider range of sources of error can be used apart from the use of the strain gauges. For example, the use of temperature compensation techniques can help to improve the accuracy of the calibration.

To improve the accuracy of load cell calibration, carefully design the calibration process and to use high-quality weights and advanced data analysis methods.