Instrumentation Amplifier on load cell sensor

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Aim

* In this experiment, we wish to implement instrumentation amplifier to amplify output from a load cell sensor.

* In part 1, we will build instrumentation amplifier using TL084 IC.

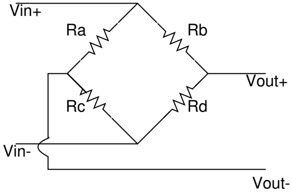
* In part 2, we will be using instrumentation amplifier which is available on a PCB on the front panel of a weighing scale. (This part is optional)

* In part 3, we will implement instrumentation amplifier using INA128 IC.

* This experiment mainly aims at understanding basic three OPAMP instrumentation amplifier and its counterpart in packaged form and comparing the performances of both the configurations. (Both configurations have their own advantages and disadvantages!)

Theory and Design Procedure

A load cell is based on an electrical circuit called Wheatstone bridge. It consists of 4 strain gauges connected on a cantilever beam that undergo change in resistance when deformed (i.e. when the object they are connected to experiences strain.)

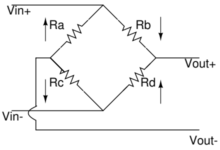


This arrangement allows to measure very small changes in the resistance R, which occurs in the strain gauges placed in the arms of the bridge: R_a, R_b, R_c and R_d.
When the load cell has no load, the four gauges are at rest and have the same ohmic value, the nominal value of the strain gauge R_g:

$$R_a = R_b = R_c = R_d = R_g \tag{1}$$

Theory and Design Procedure

When the load cell experiences deformation due to externally applied force, the resistance of each strain gauge changes by a very small amount ΔR: (when the force is not large enough to make the response of the sensors non-linear.)



R_a=R_g+ΔR ; R_b=R_g-ΔR ; R_c=R_g-ΔR ; R_d=R_g+ΔR
Strain gauges placed on opposite faces of the cantilever present opposite polarity of change in resistance (draw a cantilever beam and convince yourself that the top face undergoes tensile strain i.e. Δlength>0, whereas bottom face undergoes compressive strain i.e. Δlength<0 when you push the cantilever down). Assuming Vin+ =5V, Vin- =-5V, R_g=350 ohms, derive an expression for differential Vout as a function of ΔR. Comment on the nature of dependence of Vout on ΔR (does it vary linearly with ΔR?).

Theory and Design Procedure

An instrumentation amplifier is a type of differential amplifier that has been outfitted with input buffer amplifiers. These input buffers eliminate the need for input impedance matching and thus make the amplifier particularly suitable for use in measurement and test equipment. Additional characteristics include very low DC offset, low drift, low noise, very high open-loop gain, very high common-mode rejection ratio, and very high input impedance. Instrumentation amplifiers are used to achieve high accuracy and stability.
Read the extra reading material on instrumentation amplifier from Sedra Smith's textbook posted on moodle, before coming to lab.

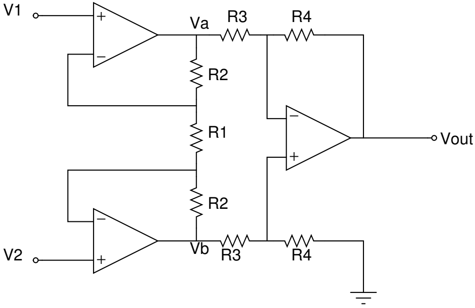


Figure: 1

Theory and Design Procedure

HERE R1,R2,R3,R4 REFER TO VALUES IN FIGURE 1, NOT IN THE WHEATSTONE BRIDGE.

Here, we define the input voltage signals small signal AC differential input V_1 and V_2, as the input of first stage OPAMPs of the instrumentation amplifier. We assume input resistance of OPAMPs to be infinite. Now applying KCL at inverting input of first stage OPAMPs. We get,

$$V_a = V_1(1 + R_2/R_1) + V_2(R_2/R_1) \tag{2}$$

And,

$$V_b = -V_1(R_2/R_1) + V_2(1 + R_2/R_1) \tag{3}$$

Using superposition principle of voltages at second stage OPAMP,

$$V_{out} = R_4/R_3(1 + 2R_2/R_1)(V_2 - V_1) \tag{4}$$

Rearranging this equation, the gain is

$$A_v = \frac{V_{out}}{V_1 - V_2} = \frac{R_4}{R_3}(1 + \frac{2R_2}{R_1}) \tag{5}$$

Pre Lab Work

1. Read up on instrumentation amplifiers posted on Moodle.
2. Read the additional document on weight scale machine uploaded on Moodle.
3. Derive the relation between differential V_{out} and ΔR as mentioned in page 4 and comment on the dependence of V_{out} on ΔR.
4. Calculate the values of R1, R2, R3, R4 of the instrumentation amplifier as mentioned in Point 2 of Page 10.

Important Notes

1. Construct the circuit of part 1 preferably on one side of the breadboard, so that you have space to have both part 1 and part 3 circuits on the breadboard together.
2. Preserve the circuit of Part 1 till end of the experiment. DO NOT DISCONNECT.

Part 1

1 You will use Operational amplifier TL084. Refer to the data sheet of TL084.

2 Refer to figure 1. Use Load Resistance of 10kohms. V+=12V, V-=-12V to power op-amp. Calculate the values of R1, R2, R3 and R4 properly to get a gain of about 300 (Keep in mind that any arbitrary value of resistance is not available in lab, so your choice of values may be constrained). Apply a single ended signal of 20mV p-p 1kHz sine wave as input to tune the circuit to achieve the required amplification. Use decoupling capacitance if necessary.

3 Connect power supply (±5V and ground for bridge) to the weighing machine as shown in the next slide (Fig. 2). Connect raw load cell output to the input of your 3 op-amp instrumentation amplifier. Refer to Fig 4.

4 Measure DMM voltage by varying weights. Calculate sensitivity of your instrumentation amplifier output to applied load in (mV/gm).

5 Adjust R1 value to double the sensitivity. Plot voltage vs weight to verify.

6 Preserve the circuit of Part 1 till end of the experiment.

DO NOT REVERSE THE POLARITY! YOU WILL BE PENALIZED (MONETARY AND/OR GRADE) IF YOU DAMAGE THE BOARD WITH OVERVOLTAGE!!

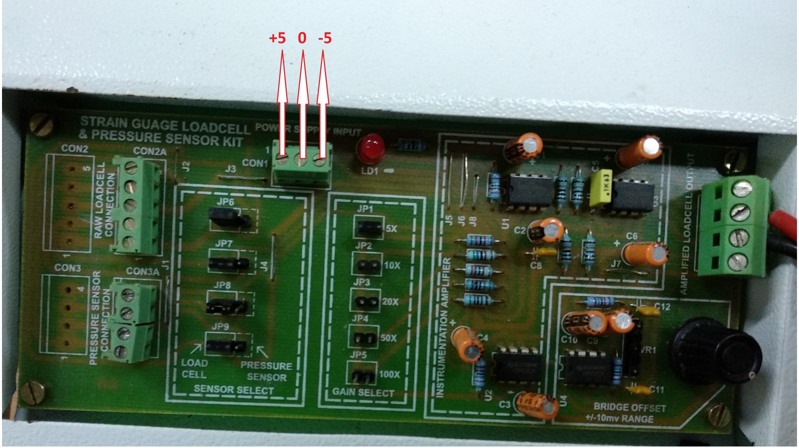


Figure: 2

Part 2 (Optional)

1. Connect the power supply to the weighing machine as in Part 1. Now, connect the output of the weighing machine to DMM to measure voltage.

2. Adjust the potentiometer knob to achieve 0 V output at unloaded condition to correct offset.

3. For 100x gain (refer to Fig. 3), note down DMM voltage by varying weights. Plot voltage v/s weight. What is the sensitivity (in mV/gm) of the sensor?

4. The weighing scale has a load cell giving a differential output to an instrumentation amplifier made up of discrete op-amps (refer to the circuit diagram in the load cell manual). The gain of the instrumentation amplifier can be adjusted to take 5x, 10x, 20x, 50x, 100x by plugging the suitable jumper (JP1-JP5, refer to Fig. 3). Can you identify how gain is being changed? One jumper must be connected at a time - what happens when 2 jumpers are connected?

Part 2: Connections

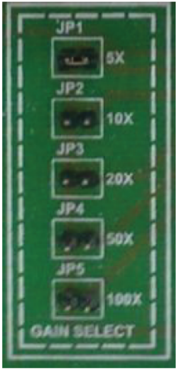


Figure: 3

Part 3

1 Now you will use instrumentation amplifier INA128 for load cell signal amplification. Refer to the data sheet of INA128

2 Using $R_G = 220 ohms, R_L = 10 kohms, C_1 = 0.1 uF, V_+ = 12V$, and $V_- = -12$, wire up the instrumentation amplifier circuit. Refer to Fig. 5. Explain the purpose of capacitor C_1 connected in parallel with the power supply. Note polarity of C_1 and connect accordingly.

3 Connect raw output (unamplified differential output) of load cell to the designed instrumentation amplifier. Refer to Fig 4.

4 Note down the DMM voltage by varying weights. Plot voltage vs weight. Calculate sensitivity in (mV/gm).

5 Adjust R_G value such that you get twice the previous gain. Plot voltage vs weight.

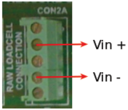


Figure: 4

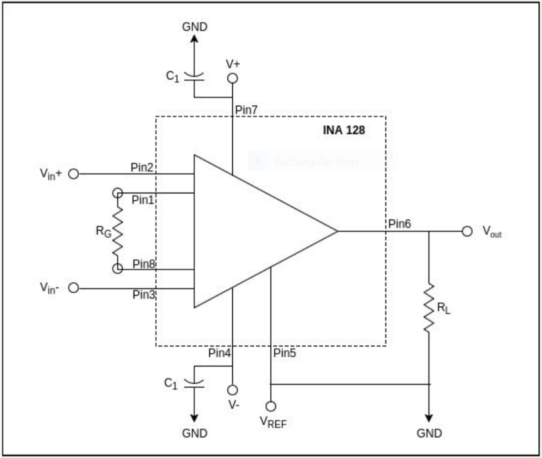


Figure: 5

Additional Questions

1. Note down the differences in output/performance of various instrumentation amplifiers.
2. Mention the reasons of the difference in performance of instrumentation amplifiers.
3. You measured the readings in parts 1, 2 and 3 with a DMM - observe the same on an oscilloscope. What do you observe? Is there a discrepancy? What is the reason for the discrepancy, if any?