APL103 Lab

Experiment 9

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Objective:

A. To study the working of the Bourdon pressure gauge and to calibrate it using a dead-weight pressure gauge calibrator.
B. To calibrate a piezo-resistive transducer using a 'U' tube manometer

Apparatus:

i. Bourdon Gauge ii. Deadweight calibrator iii. Calibration weights iv. Pressure transducer with signal conditioner v. U tube manometer vi. The collapsible cylinder used to generate the required gauge pressure

Background:

A) The Bourdon gauge contains as its key transduction element a hollow elliptical cross-section tube enclosed at one end and bent in the form of a 'question mark'. The other end of the tube is connected to the pressure source. The high pressure in the tube tends to straighten the hollow bent tube. This motion of the tube, dependent on the magnitude of the pressure, is further amplified and converted to rotary motion by a set of gears. Finally, the rotary motion is read on a circular readout on the outside face of the gauge. The schematic sketch is shown in figure (a).

   The dead weight pressure tester is schematically shown in figure (b). It operates on the principle of equalization of pressure in a liquid at the same horizontal level. The motive fluid is oil, which supports known weights at end 'A'. The piston/plunger arrangement acting over a known sectional area at end 'A' generates a standard pressure in the system equal to weight/piston area. This serves as the input or the reference pressure measurement. The pressure gauge to be calibrated is put at end 'B', care being taken (in the manufacture of the apparatus itself) that there is a negligible elevation difference between point of application at 'A' and point of measurement at 'B'. The system is pressurized by means of a piston/plunger arrangement connected to a lead screw. The plunger is moved inwards by turning the lead screw, till the supporting dead weight at 'A' just floats. Then, the pressure shown by the test gauge is noted and checked against the reference pressure.

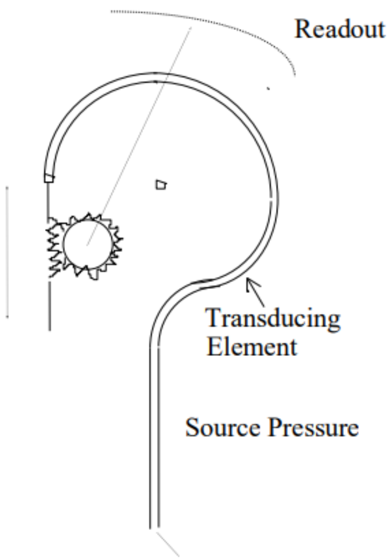


Figure (a)

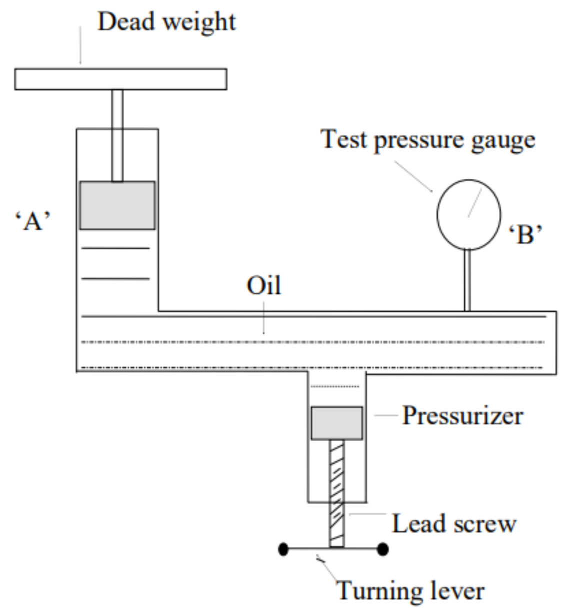


Figure (b)

B) In this part of the experiment, a MEMS-based piezo-resistive pressure transducer is to be calibrated using a U-tube manometer with water as the manometric fluid. The device in question is MPX5700AP made by Freescale Semiconductors. Figure (c) shows a schematic of the experimental setup. Since the sensor measures absolute pressure (one side of the transducer membrane is evacuated) it can be used for both positive and negative gauge pressures.

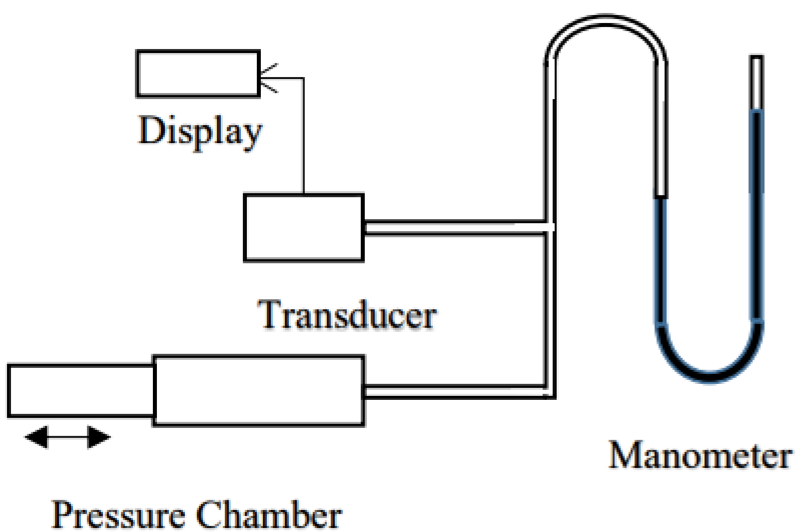


Figure (c)

Procedure:

A) 1. Study the pressure gauge that has been disassembled and draw a detailed sketch of the inner mechanism.
2. Record the least count of the dead-weight system and the pressure gauge to be calibrated.
3. Place the first weight and turn the lead screw till it just floats and record the pressure gauge reading.
4. Repeat step 4 for the full range of weights till the maximum weight is reached.
5. Decrease the weight in steps and again note the pressure gauge reading as in step 4. Take care each time that the chamber is de-pressurized before removing the weight so that oil does not flow out.

B) 1. Record the least count of the manometer and the display unit.
2. Ensure that the two limbs of the manometer are at the same level and note down the reading of the display unit for gauge pressure equal to zero.
3. Increase the pressure from 0 to approximately 50cm of water in 5 steps and note down the reading on the display unit.
4. Bring the pressure down to zero again and repeat step 3 for negative gauge pressures (final value approximately -50cm of water).
5. Bring the system back to atmospheric pressure (zero gauge pressure) at the end of the experiment.

Observations:

A) Bourdon Gauge
Least Count = 0.5 kg/cm2

Loading		Unloading	
Weight (kgf/cm2)	**Reading (kg/cm2)**	**Weight (kgf/cm2)**	**Reading (kg/cm2)**
1	0.5	50	49.5
2	1.5	40	40
3	2.5	30	30
5	4.5	20	20
10	9.5	10	10
20	19.5	5	4.5
30	29.5	3	2.5
40	39.5	2	1.5
50	49.5	1	0.5

B) Manometer

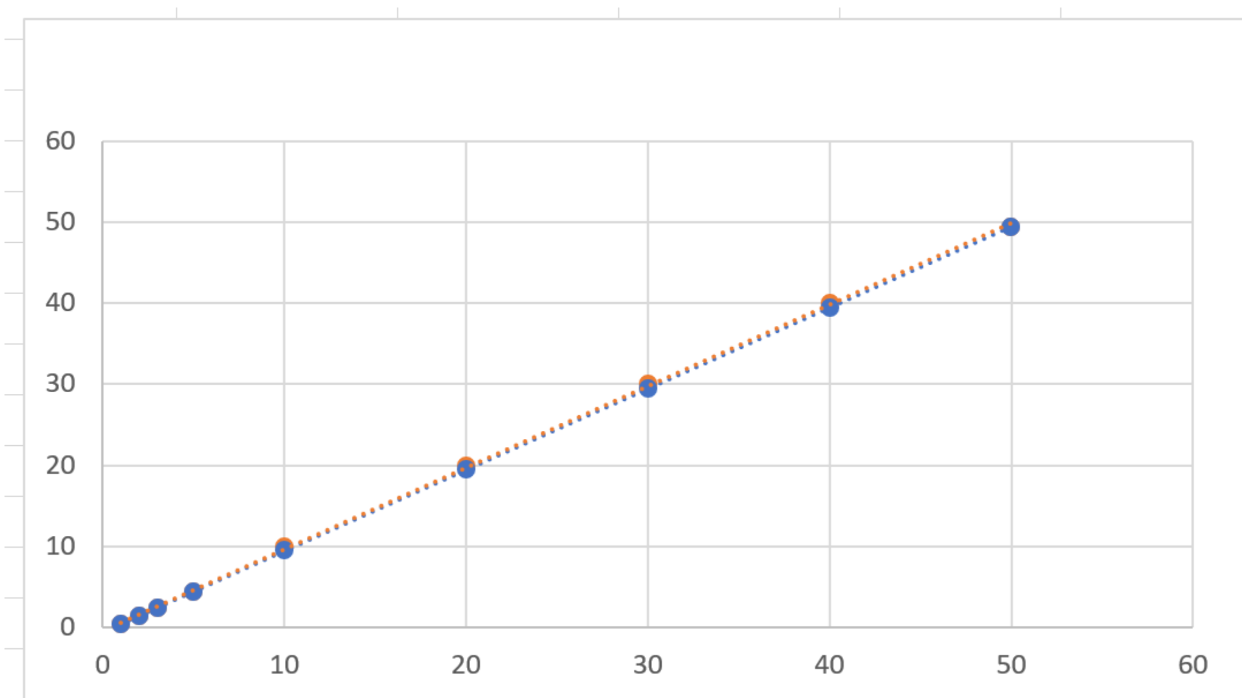
Least count = 0.1 cm

Positive implies (right leg>left leg)	
Length (cm)	**Voltage (V)**
-36	0.49785
-32	0.49648
-28	0.49495
-24	0.49342
-20	0.49175
-16	0.49052
-12	0.489
-8	0.48778
-4	0.48594
0	0.48472
0	0.48457
4	0.48304
8	0.48182
12	0.47999
16	0.47862
20	0.47709
24	0.47556
28	0.47434
32	0.47251
36	0.47113

Analysis:

A)

1. **Plot output v/s input using different symbols for increasing and decreasing weights.**



Legend: Loading in blue, Unloading in Orange

Note - As both data set overlaps, the data points are difficult to distinguish. For weights of 10, 20, 30, and 40 (in kgs), orange dots are slightly visible.

2. **Fit the best straight line using least squares. Use different symbols for the readings for increasing and decreasing pressure.**

Straight line equation: $y = mx + b$

Units: y and b in kg/cm2, x in kgf/cm2, m in kg/kgf. (1kgf = 9.81N)

$$m = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2}$$

$$b = \frac{\sum y - m\sum x}{n}$$

Loading straight line equation: $y = m_1 x + b_1$

Calculating the value of m1, b1, we get

$$m_1 = 1 \,, \, b_1 = -0.5$$

Equation is $y = x - 0.5$

Unloading straight line equation: $y = m_2 x + b_2$

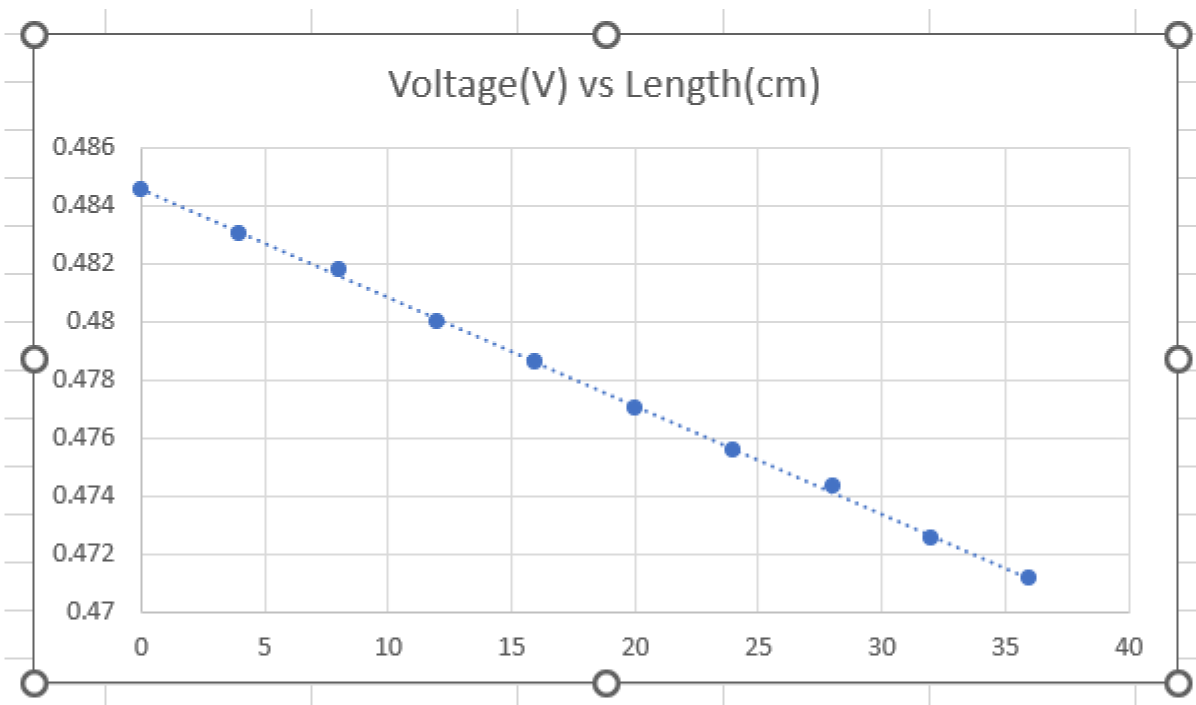
Calculating the value of m2, b2, we get

$$m_2 = 1.005348934 \,, \, b_1 = -0.373464271$$

Equation is $y = 1.005348934x - 0.373464271$

B)

1. **Plot the output of the pressure transducer against the set positive gauge pressure (in Pa) and obtain its calibration equation (straight line fit).**



For the calibration equation, we again need to find the best fit straight line.

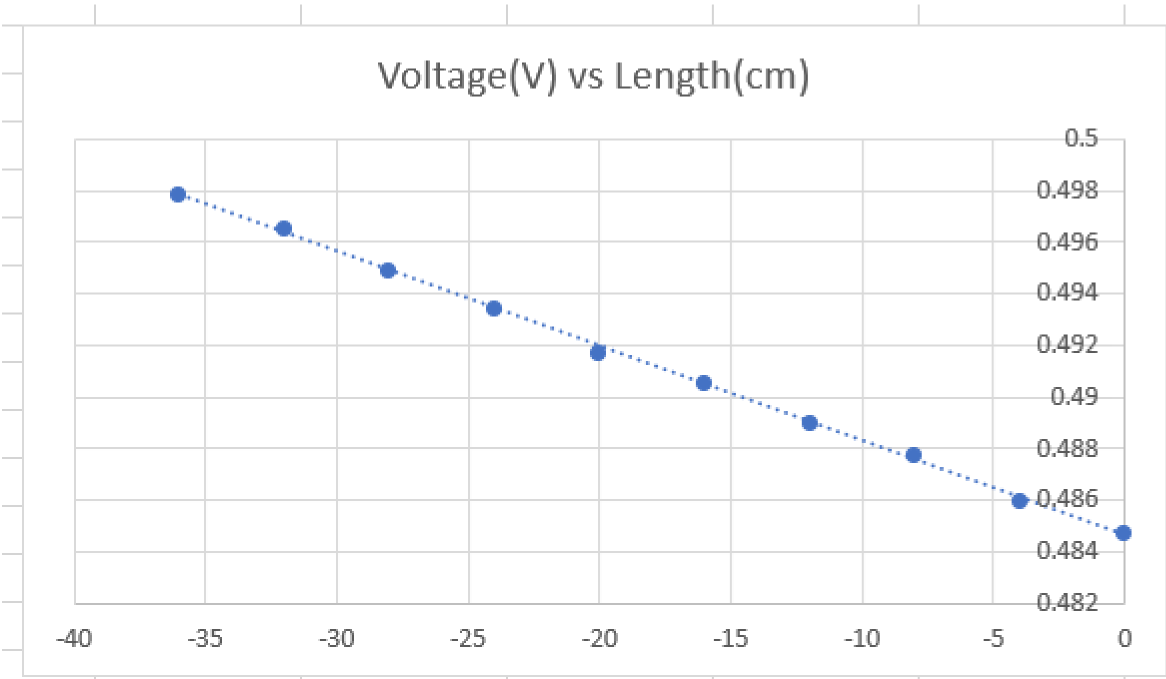
Equation of straight line: $y = mx + b$, y and b in Volts, x in cm, m in (Volts/cm)

$$m = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2}$$

$$b = \frac{\sum y - m\sum x}{n}$$

Using these formulas, $m = -0.0003741$, $b = 0.48460036$

2. Repeat step 1 for negative gauge pressures.



For the calibration equation, we again need to find the best fit straight line.
Equation of straight line: $y = mx + b$, y and b in Volts, x in cm, m in (Volts/cm)

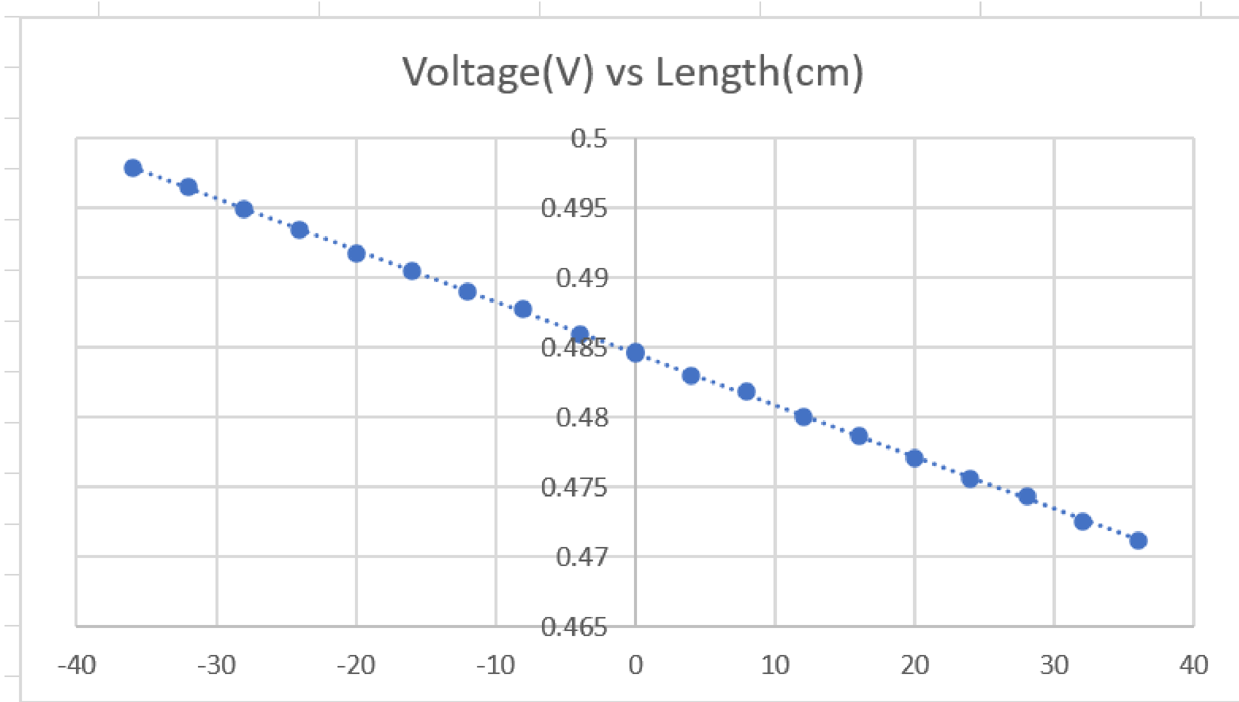
$$m = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2}$$

$$b = \frac{\sum y - m\sum x}{n}$$

Using these formulas, $m = -0.0003671$, $b = 0.48463309$

3. **Compare the two calibration equations.**

The following graph is plotted by combining both the straight lines.



The difference between the two distinct straight lines is quite difficult to spot, which makes us conclude that the graph is quite linear. Also, the values of slopes and intercepts of the two lines are almost equal, which also proves the linearity claim.

Discussion:

1. **Discuss the linearity and the accuracy of the gauges tested.**
   ⇒ Clearly, observing at the graphs, the results of Pressure transducer are more linear compared to Bourdon pressure gauge.
   Also, the Pressure transducer is able to detect small changes in pressure, whereas in bourdon gauge, the readings are nearly equal to the loaded weights, which clearly indicates that Pressure Transducer should be preferred whenever accuracy is important.

2. **Can the procedure used in part A be used to detect hysteretic behavior in the gauge?**
   ⇒ Hysteresis can be thought of as a measure of how effectively a pressure gauge repeats the upscale reading on the down-scale cycle if all conditions remain the same. There is a slight stretch in the down-scale cycle, enabling it to detect hysteretic behavior, although to an inappreciable extent.