APL103 Lab

Experiment 2

By - **1) Swapnil Kashyap (2021AM10782)**
2) Aditya Agrawal (2021AM10198)

OBJECTIVES:

To measure the radius of gyration of a bar pendulum.

THEORETICAL BACKGROUND:

Consider a bar pendulum. Let the pivot point be O, the centre of gravity be at C, and the distance from O to C be L. At the time of interest the bar makes an angle θ with the vertical. The angular momentum equation about is:

$I\ddot{\theta} = -Mg \sin(\theta)$

where, I is the moment of inertia of the bar about O, M the mass of the bar, and g is the acceleration due to gravity.

For small angles, $\sin\theta \approx \theta$ and hence $I\ddot{\theta} + MgL\theta = 0$

The solution to the above equation is simple harmonic motion with time period, T, given by

$T = 2\pi (I/ MgL)^{1/2}$

By the definition of the radius of gyration, k, is given by

$I = Mk^2$

$\Rightarrow k = T/2\pi (gL)^{1/2}$

Thus the radius of gyration may be estimated from the time period of small oscillations.

APPARATUS:

Compound pendulum, stop watch, measuring scale

PROCEDURE:

1. Determine the centre of gravity of the bar,C, by balancing it on a sharp edge.

2. Measure the distance, L, between the pivot O and the center of gravity, C, 10 times.

3. Measure the time required for 10 oscillations, 20 times —keep $\theta \leq 50$.

OBSERVATIONS and ANALYSIS:

1. Least count of scale = 1mm

2. Least count of stopwatch = 0.01sec

3. L*= 0.275m

4. Width of bar = 1.15cm

5. Thickness of bar = 0.45cm

6. Diameter of holes = 0.75cm

7. Spacing of holes = 5.05cm

8. No. of holes = 6

Data Set 1:

S.No.	Length of bar(x_i) (in cm)	Deviation (d =x-x')(in cm)	d^2(in cm^2)
1	11.3	0.01	0.0001
2	11.2	-0.09	0.0081
3	11.4	0.11	0.0121
4	11.3	0.01	0.0001
5	11.3	0.01	0.0001
6	11.3	0.01	0.0001
7	11.2	-0.09	0.0081
8	11.4	0.11	0.0121
9	11.3	0.01	0.0001
10	11.2	-0.09	0.0081
SUM	112.9		0.049

1.

Mean of length of bar = 11.29 cm

Variance(σ^2) = 0.0049 cm^2, where σ is the standard deviation

σ = 0.07 cm

Adjusted standard deviation, $S_n = \sigma*(\sqrt{(n/(n-1))}) = 0.0738$

Internal error estimate, UI = $Sn/\sqrt{n}$ = 0.023 cm

External error estimate, UE = 1 mm = 0.1 cm

Total uncertainty, UTL = $\sqrt{(UI^2+UE^2)}$ = 0.103 cm

L = 11.29 ± 0.103 cm

S.No.	Time for 10 Oscillations(10T)	Time Period(T)(in sec)	Deviation(d=T-T')	d^2
1	8.41	0.841	-0.0182	0.00033124
2	8.61	0.861	0.0018	0.00000324
3	8.59	0.859	-0.0002	0.00000004
4	8.46	0.846	-0.0132	0.00017424
5	8.52	0.852	-0.0072	0.00005184
6	8.66	0.866	0.0068	0.00004624
7	8.74	0.874	0.0148	0.00021904
8	8.53	0.853	-0.0062	0.00003844
9	8.79	0.879	0.0198	0.00039204
10	8.65	0.865	0.0058	0.00003364
11	8.34	0.834	-0.0252	0.00063504
12	8.64	0.864	0.0048	0.00002304
13	8.62	0.862	0.0028	0.00000784
14	8.63	0.863	0.0038	0.00001444
15	8.48	0.848	-0.0112	0.00012544
16	8.85	0.885	0.0258	0.00066564
17	8.87	0.887	0.0278	0.00077284
18	8.65	0.865	0.0058	0.00003364
19	8.2	0.82	-0.0392	0.00153664
20	8.6	0.86	0.0008	0.00000064
SUM	171.84	17.184		0.00510520

2.

Mean of T = 0.8592 sec

Variance(σ^2) = 255.26×10^{-6} sec^2, where σ is standard deviation

$\sigma = 15.977 \times 10^{-3}$ sec

Adjusted standard deviation, $S_n = \sigma * (\sqrt{(n/(n-1))}) = 0.0164$

Internal error estimate, $UI = Sn/\sqrt{n} = 0.00366$

External error estimate, UE =0.01 sec

Total uncertainty, $UTT = \sqrt{(UI^2 + UE^2)} = 0.01065$

T = 0.8592 ± 0.01065 sec

3.

Best estimate for K (radius of gyration):

$K = (T/2\pi) * \sqrt{gL}$

$K = f(T, L)$

T = 0.8592 sec

L = 11.29 cm

$g = 9.81\ m/sec^2$

K = 0.1439 m = 14.39 cm

4. Determination of K directly:

a) ignoring the effect of holes:

$K^2 = L_e^2/3$ (L_e = effective length of bar = 24.75 cm)

K = 14.289 cm

Data Set 2:

S.No.	Length of bar(x_i) (in cm)	Deviation(d =x-x')	d^2
1	6.8	-0.015	0.000225
2	6.85	0.035	0.001225
3	6.8	-0.015	0.000225
4	6.8	-0.015	0.000225
5	6.8	-0.015	0.000225
6	6.85	0.035	0.001225
7	6.8	-0.015	0.000225
8	6.8	-0.015	0.000225
9	6.85	0.035	0.001225
10	6.8	-0.015	0.000225
SUM	68.15		0.00525

Mean of length of bar = 6.815 cm

Variance(σ^2) = 0.000525 cm^2, where σ is the standard deviation

σ = 0.0229 cm

Adjusted standard deviation, $S_n = \sigma*(\sqrt{(n/(n-1))}) = 0.0241$

Internal error estimate, $UI = S_n/\sqrt{n}$ = 0.0076 cm

External error estimate, UE = 1 mm = 0.1 cm

Total uncertainty, UTL = $\sqrt{(UI^2+UE^2)}$ = 0.0125 cm

L = 6.815 ± 0.0125 cm

S.No.	Time for 10 Oscillations(10T)	Time Period(T)(in sec)	Deviation(d=T-T')	d^2
1	8.5	0.85	0.01175	0.00013806
2	8.15	0.815	-0.02325	0.00054056
3	8.1	0.81	-0.02825	0.00079806
4	8.5	0.85	0.01175	0.00013806
5	8.22	0.822	-0.01625	0.00026406
6	8.8	0.88	0.04175	0.00174306
7	8.03	0.803	-0.03525	0.00124256
8	8.37	0.837	-0.00125	0.00000156
9	8.65	0.865	0.02675	0.00071556
10	8.66	0.866	0.02775	0.00077006
11	8.46	0.846	0.00775	0.00006006
12	8.15	0.815	-0.02325	0.00054056
13	8.33	0.833	-0.00525	0.00002756
14	8.34	0.834	-0.00425	0.00001806
15	8.59	0.859	0.02075	0.00043056
16	8.12	0.812	-0.02625	0.00068906
17	8.46	0.846	0.00775	0.00006006
18	8.62	0.862	0.02375	0.00056406
19	8.54	0.854	0.01575	0.00024806
20	8.06	0.806	-0.03225	0.00104006
SUM	167.65	16.765		0.01002975

2.

Mean of T = 0.83825 sec

Variance(σ^2) = 501.4875*10^{-6} sec^2, where σ is standard deviation

σ = 22.39*10^{-3} sec

Adjusted standard deviation, S_n = $\sigma*(\sqrt{(n/(n-1))})$ = 0.0334

Internal error estimate, UI = Sn/$\sqrt{n}$ = 0.00746

External error estimate, UE =0.01 sec

Total uncertainty, UTT = $\sqrt{(UI^2 + UE^2)}$ = 0.0125

T = 0.83825 ± 0.0125 sec

3.

Best estimate for K (radius of gyration):

$K = (T/2\pi) * \sqrt{gL}$

$K = f(T, L)$

$T = 0.83825$ sec

$L = 6.815$ cm

$g = 9.81$ m/sec^2

$K = 0.1090$ m $= 10.90$ cm

4. Determination of K directly:

a) ignoring the effect of holes:

$K^2 = L_e^2/3$ (L_e = effective length of bar = 19.25 cm)

$K = 11.11$ cm

Data Set 3:

S.No.	Length of bar(x_i) (in cm)	Deviation(d =x-x')	d^2
1	2.4	0.015	0.000225
2	2.45	0.065	0.004225
3	2.4	0.015	0.000225
4	2.35	-0.035	0.001225
5	2.35	-0.035	0.001225
6	2.4	0.015	0.000225
7	2.4	0.015	0.000225
8	2.35	-0.035	0.001225
9	2.4	0.015	0.000225
10	2.35	-0.035	0.001225
SUM	23.85		0.00525

Mean of length of bar = 2.385 cm

Variance(σ^2) = 0.000525 cm^2, where σ is the standard deviation

$\sigma = 0.0229$ cm

Adjusted standard deviation, $S_n = \sigma*(\sqrt{(n/(n-1))}) = 0.0241$

Internal error estimate, UI = $S_n/\sqrt{n}$ = 0.0076 cm

External error estimate, UE = 1 mm = 0.1 cm

Total uncertainty, UTL = $\sqrt{(UI^2+UE^2)}$ = 0.0125 cm

L = 2.385 ± 0.0125 cm

S.No.	Time for 10 Oscillations(10T)	Time Period(T)(in sec)	Deviation(d=T-T')	d^2
1	12.1	1.21	-0.0087	0.00007569
2	12.21	1.221	0.0023	0.00000529
3	12.07	1.207	-0.0117	0.00013689
4	12.94	1.294	0.0753	0.00567009
5	12.31	1.231	0.0123	0.00015129
6	12.17	1.217	-0.0017	0.00000289
7	12.12	1.212	-0.0067	0.00004489
8	12.22	1.222	0.0033	0.00001089
9	12.15	1.215	-0.0037	0.00001369
10	12.02	1.202	-0.0167	0.00027889
11	12.18	1.218	-0.0007	0.00000049
12	12.13	1.213	-0.0057	0.00003249
13	12.16	1.216	-0.0027	0.00000729
14	12.09	1.209	-0.0097	0.00009409
15	12.12	1.212	-0.0067	0.00004489
16	12.21	1.221	0.0023	0.00000529
17	12.24	1.224	0.0053	0.00002809
18	12.02	1.202	-0.0167	0.00027889
19	12.13	1.213	-0.0057	0.00003249
20	12.15	1.215	-0.0037	0.00001369
SUM	243.74	24.374		0.00692820

2.

Mean of T = 1.2187 sec

Variance(σ^2) = 346.41*10^{-6} sec^2, where σ is standard deviation

σ = 18.61*10^{-3} sec

Adjusted standard deviation, $S_n = \sigma*(\sqrt{(n/(n-1))})$ = 0.019

Internal error estimate, UI = Sn/$\sqrt{n}$ = 0.00427

External error estimate, UE =0.01 sec

Total uncertainty, UTT = $\sqrt{(UI^2 + UE^2)}$ = 0.0109

$T = 1.2187 \pm 0.0109$ sec

3.

Best estimate for K (radius of gyration):

$K = (T/2\pi) * \sqrt{gL}$

$K = f(T, L)$

$T = 1.2187$ sec

$L = 2.385$ cm

$g = 9.81$ m/sec^2

$K = 0.0938$ m = 9.38 cm

4. Determination of K directly:

a) ignoring the effect of holes:

$K^2 = L_e^2/3$ (L_e = effective length of bar = 14.65 cm)

$K = 9.15$ cm

DISCUSSION:

Question 1:

We calculate time taken for ten oscillations to lower the result's internal(standard) error by a factor of root ten.

Question 2:

By using Taylor's expansion:

$\theta^3/6 < 0.05$

θ (in rad) = 0.669432

θ (in degree) = 38.35568

Question 3:

The experimental value of k is less than the theoretically obtained. Yes, it is within the error bound of the experiment.

Question 4:

To reduce the overall error in k, we would increase the no. of readings

APL103(Experimental Methods)

LAB REPORT

Exp no:- 3

Objective:

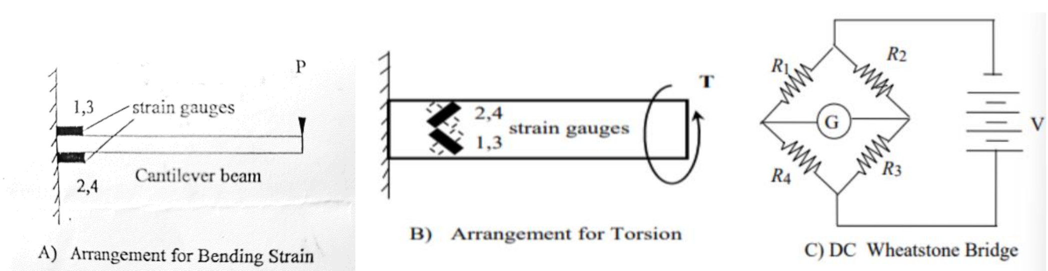
- To calibrate a strain gauge-type load cell.
- To study various methods of fitting a straight line through a set of data points.

Apparatus:

- A bent cantilever beam on which resistance-type strain gauge has been mounted near the clamped end.
- A straight cantilever plate with strain gauges mounted near the support.
- Strain meter.
- Slotted weights and a load hanger are also provided.

Theory:

Strain gauge load cells measure a given load (of force) with the help of resistance-type strain gauges. When a cantilever beam (shown below) is loaded at its free end, it deflects, and the strain produced at the fixed end is maximum. This strain can be sensed by strain gauges mounted near the fixed end. Strain gauges are resistance-type transducers in which the applied strain produces a change in resistance (ΔR) of the gauge. R can be measured by the strain meter which is generally an AC or DC Wheatstone bridge (figure C). With proper care in the installation and operation of strain gauges, these gauges can be made very sensitive and accurate, and insensitive to environmental changes like temperature. A similar method can be used to measure strains due to torsion as shown in part B of the figure.



A) Arrangement for Bending Strain
B) Arrangement for Torsion
C) DC Wheatstone Bridge

In both arrangements (A and B) gauges 1 and 3 are in tension while 2 and 4 are in compression. If all four gauges are connected as shown in Figure C, we have the full-bridge configuration. This is what you will be using in this experiment. Sometimes only gauges 1 and 2 are used, while R3 and R4 are fixed and have equal resistances --- this is the half-bridge configuration.

Procedure:

- Measure the lengths of the two limbs of the bent cantilever arm.
- Measure the distance from the hanger to the middle of the strain gauges for the straight cantilever.

Torsion:

- Now place the hanger at the free end of the bent cantilever.
- With no load on the hanger adjust the torsion strain meter to read zero.
- Gradually load the beam in steps of 0.50 Kg weights. Weights should be placed without any jerk or vibrations. After every increment of load wait for the reading on the strain meter to stabilize and then take the reading. The total load should not exceed 5 Kg.
- Now reduce the load in steps of 0.50 Kgs and take the readings using the same precautions as stated above.
- Take the readings for the unknown weight.

Observations:

Length of moment arm(L) = 18.75 cm

Loading:

Load(kg)	Voltage(V)
0	0.01679
1	0.01786
2	0.01878
3	0.0197
4	0.02076
4.5	0.02122

Unloading:

Load(kg)	Voltage(V)
4.5	0.02122

4	0.02061
3	0.01954
2	0.01863
1	0.01756
0	0.01664

Analysis:

To convert load into torque:

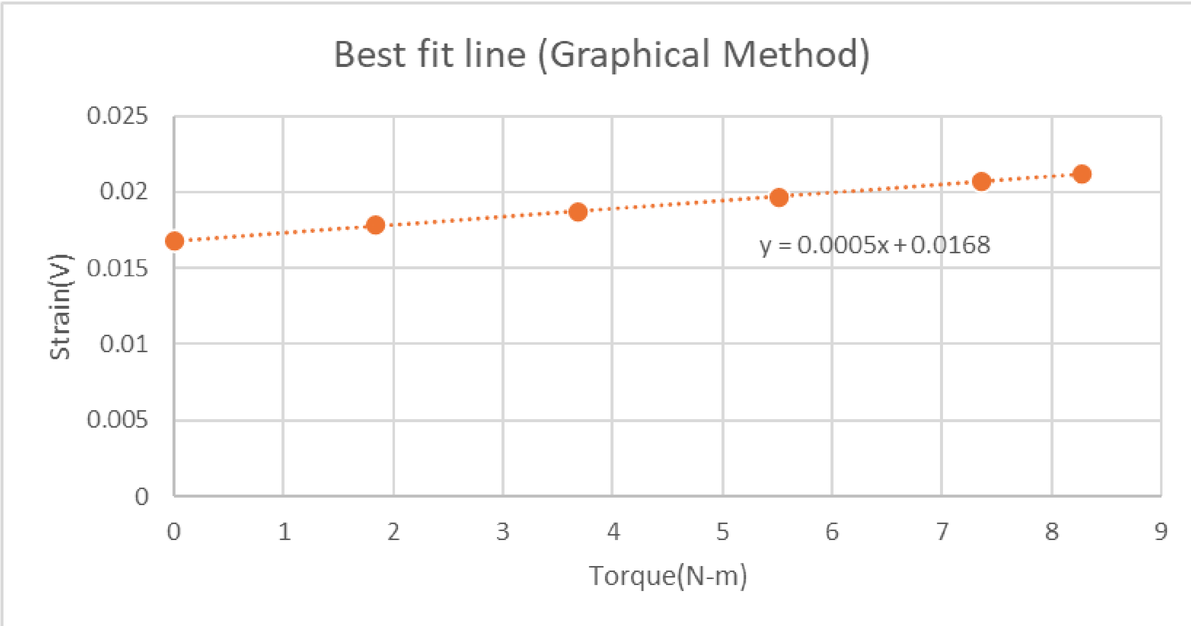
Arm length=18.75 cm

Torque = Load X Length of Arm X 9.8

Plotting the curve of Strain (Volts) vs torque:

Loading:

Torque(N-m)	**Strain(V)**
0	0.01679
1.8375	0.01786
3.675	0.01878
5.5125	0.0197
7.35	0.02076
8.26875	0.02122



Equation of best fit line using graphical method => Y= 0.0005*X+0.0168

Slope = 0.0005

Intercept = 0.0168

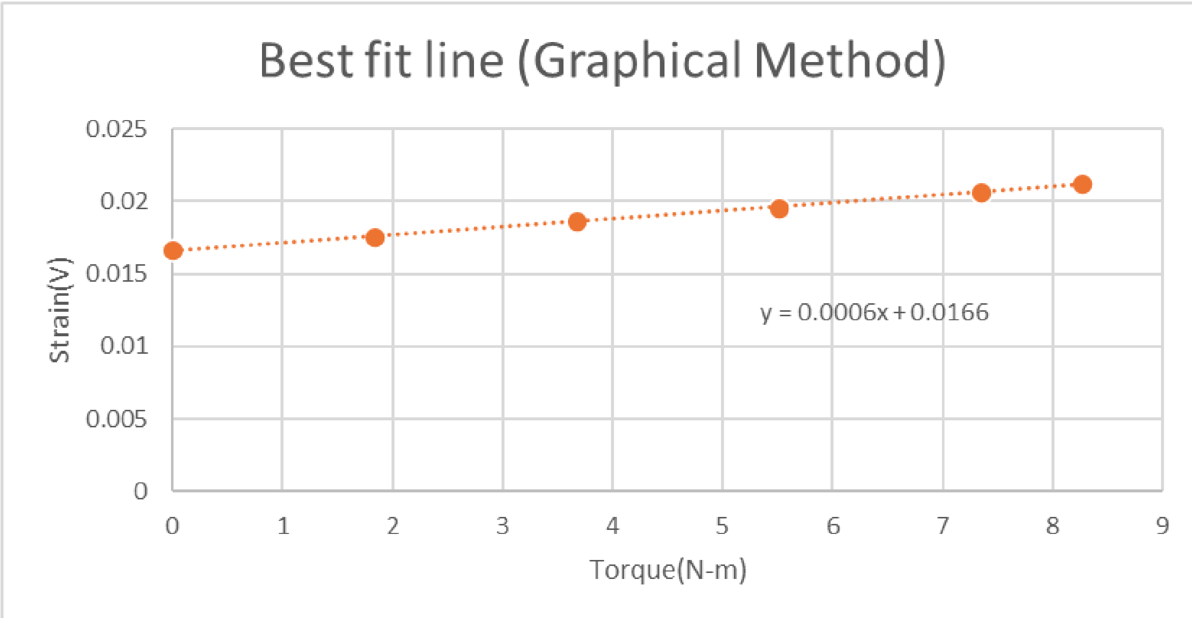
Equation of best fit line using least squares method => Y = 0.00053*X + 0.0168

Slope = 0.00053

Intercept = 0.0168

Unloading:

Torque(N-m)	Strain(V)
8.26875	0.02122
7.35	0.02061
5.5125	0.01954
3.675	0.01863
1.8375	0.01756
0	0.01664



Equation of best fit line using graphical method => Y = 0.0006*X + 0.0166

Slope = 0.0006

Intercept = 0.0166

Using Methods of least square: Y = 0.00055*X + 0.0166

Slope = 0.00055

Intercept = 0.0166

For Unknown Weight, Strain = 0.01741V

For Loading case: M = 663.9g

For Unloading case: M = 801g

Therefore, Mean = 732.45g

DISCUSSION:

2. Though the slopes in both the cases are similar by visual method, there is a significant difference in the intercept.
This is because of change in zero error of gauge after loading and unloading the weights due to load.

3. Yes, there was a change in the initial and final readings for no mass, this is because the weights may have put strain on the gauge, thus changing it's zero error.