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ELECTROMAGNETISM LABORATORY

EXPERIMENT-2

Title: THEORY OF BALLISTIC GALVANOMETER

Aim:

To determine the current sensitivity, ballistic constant or charge sensitivity of a Ballistic Galvanometer.

Apparatus and Accessories:

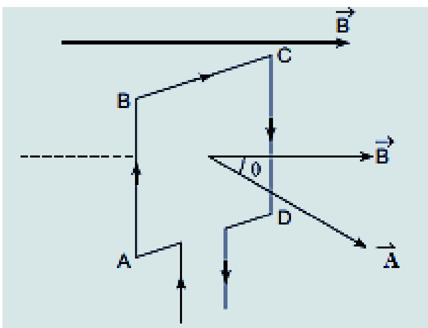
1. Ballistic galvanometer (suspended set up with light and mirror)
2. Meter scale
3. Resistance box
4. Voltage source
5. Commutator
6. Connecting wires

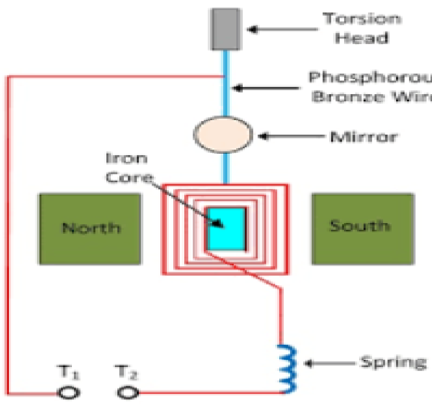
Theory:

A ballistic galvanometer consists of a rectangular coil of area A and number of turns N suspended in a uniform magnetic field B.

Ballistic Galvanometer

Let it carry a current I for a short interval of time, dt. Then the momentary torque on the coil is given by $\tau = NiABsin\Theta$





Ballistic Galvanometer Design

As the plane of the coil is always parallel to B or A⊥B, we can write it as $\tau = NIAB$.
Now, $\tau = NiAB = C\theta$ (Restoring couple of suspension wire).
Angular impulse (G) given to the coil = change in angular momentum of the coil.

$G = \int \tau dt = NAB\int_0^t idt = I\omega$, where I is the Moment of inertia of the coil about its axis of suspension and ω is the angular velocity of the coil.

$NABq = I\omega \; or \; \omega = \frac{NABq}{I}$ .... (1)

K.E of the coil = P.E of the suspension wire (As the coil rotates, the suspension wire get twisted and hence K.E of the coil is converted into P.E of the wire)

i.e., $\frac{1}{2}I\omega^2 = \frac{1}{2}C\theta^2$ where C is the couple per unit twist of the suspension wire and q0 is the first throw of the light spot on the scale.

$$\omega^2 = \frac{C\theta^2}{I} = \frac{N^2A^2B^2q^2}{I^2}$$

$$q^2 = \frac{IC\theta^2}{N^2A^2B^2} = \frac{C^2\theta^2}{N^2A^2B^2} \times \frac{I}{C} \quad \text{..............} \; (2)$$

The period of oscillation of the coil is given by

$$T = 2\pi\sqrt{\frac{I}{C}}T^2 \Rightarrow T^2 = 4\pi^2\frac{I}{C} \Rightarrow \frac{I}{C} = \frac{T^2}{4\pi^2} \text{............} \; (3)$$

Substituting (3) in (2), we get:

$$q^2 = \frac{C^2}{N^2A^2B^2} \times \frac{T^2}{4\pi^2}\theta^2 \Rightarrow q = \frac{C}{NAB}\frac{T}{2\pi}\theta \text{............} \; (4)$$

<u>Current Sensitivity (η):</u>
From equation $\tau = NIAB\theta = C\theta$
From the definition of current sensitivity,

$$\frac{di}{d\theta} = \frac{C}{NAB}$$

<u>Charge Sensitivity (k):</u>
It is defined as the deflection produced in the coil per unit change. If a change q passing through Ballistic Galvanometer produces a deflection q0, then charge sensitivity,

$$\frac{dq}{d\theta} = \frac{C}{NAB}\frac{T}{2\pi}$$

CURRENT SENSITIVITY OR FIGURE OF MERIT:

To determine the current sensitivity of a cell of constant e.m.f. E and negligible internal resistance is connected in series with two resistance boxes P and Q. The ballistic galvanometer G in series with a resistance box R is connected across P through a reversing key C (commutator) as shown in the figure below.

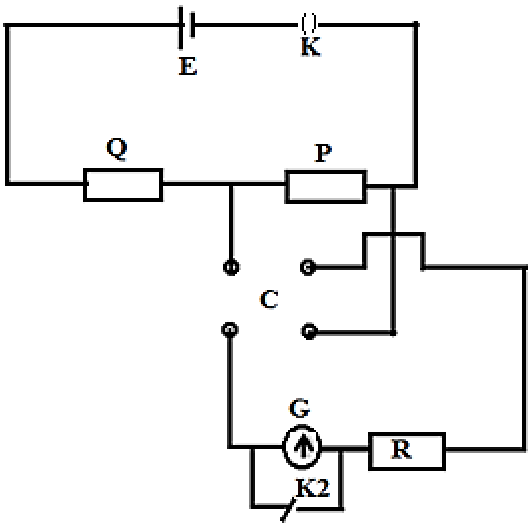


Figure-01

E.M.F. across P = EP/(P+Q)

If G is the resistance of the galvanometer and resistance P is negligible as compared to (R+G), then the current I in the galvanometer circuit is given by

$$i = \frac{\frac{EP}{P+Q}}{(R+G)} = \frac{EP}{(R+G)(P+Q)}$$

If θ is the deflection produced, then

$$\text{Current sensitivity } \eta = \frac{di}{d\theta} = \frac{EP}{(P+Q)(R+G)}\frac{1}{\theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

The resistance G can be eliminated by taking two observations for different values of R. Thus from equation (1), we have

$$R_1 + G = \frac{EP}{(P+Q)\eta} \times \frac{1}{\theta_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

$$R_2 + G = \frac{EP}{(P+Q)\eta} \times \frac{1}{\theta_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

From equations (2) & (3)

$$R_2 - R_1 = \frac{EP}{(P+Q)\eta} \times \left(\frac{1}{\theta_2} - \frac{1}{\theta_1}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

$$\therefore \eta = \frac{EP}{(P+Q)(R_2-R_1)} \times \left(\frac{1}{\theta_2} - \frac{1}{\theta_1}\right) \quad \ldots\ldots\ldots \text{(5)}$$

$\therefore$ Ballistic constant or charge sensitivity $k = \frac{dq}{d\theta} = \frac{\eta T}{2\pi}$ ……… (6)

On plotting $1/\theta$ (rad)$^{-1}$ vs R(Ω), we get a straight line as shown in figure-02, and its slope m is used to find current sensitivity η, using the formula, $\eta = \frac{EP}{(P+Q)} \times m$ and charge sensitivity can be found using the formula, $k = \frac{\eta T}{2\pi}$.

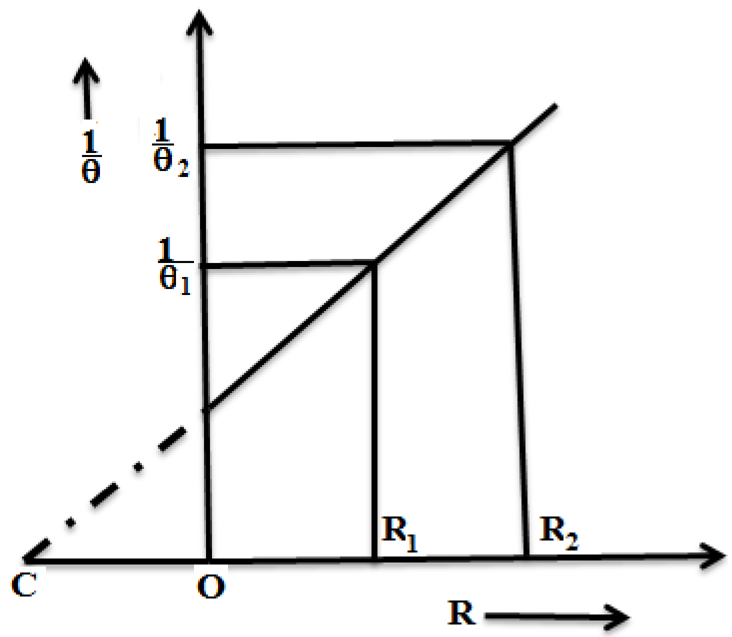


Figure-02

Observations:

Table-1-

E.M.F of the cell E = 3.19 Volts

D = 75 cm, Least count of meter scale = 0.1 cm

Sl. No.	Resistance			Deflection		Mean deflection(d)	Mean (θ) = d/2D (rad)	$1/\theta$ $(rad)^{-1}$
	P	Q	R (Ω)	Direct	Reversed			
01	2 Ω	2500 Ω	3000	8.1	8.0	8.05	0.0536	18.65
02			4000	6.5	6.5	6.5	0.0433	23.09
03			5000	5.2	5.2	5.2	0.0345	28.98
04			6000	4.3	4.5	4.4	0.0293	34.12
05			7000	3.7	3.8	3.75	0.0250	40.00
06			8000	3.3	3.3	3.3	0.0220	45.45
07			9000	2.8	2.9	2.85	0.0190	52.63
08			10000	2.6	2.6	2.6	0.0170	58.82

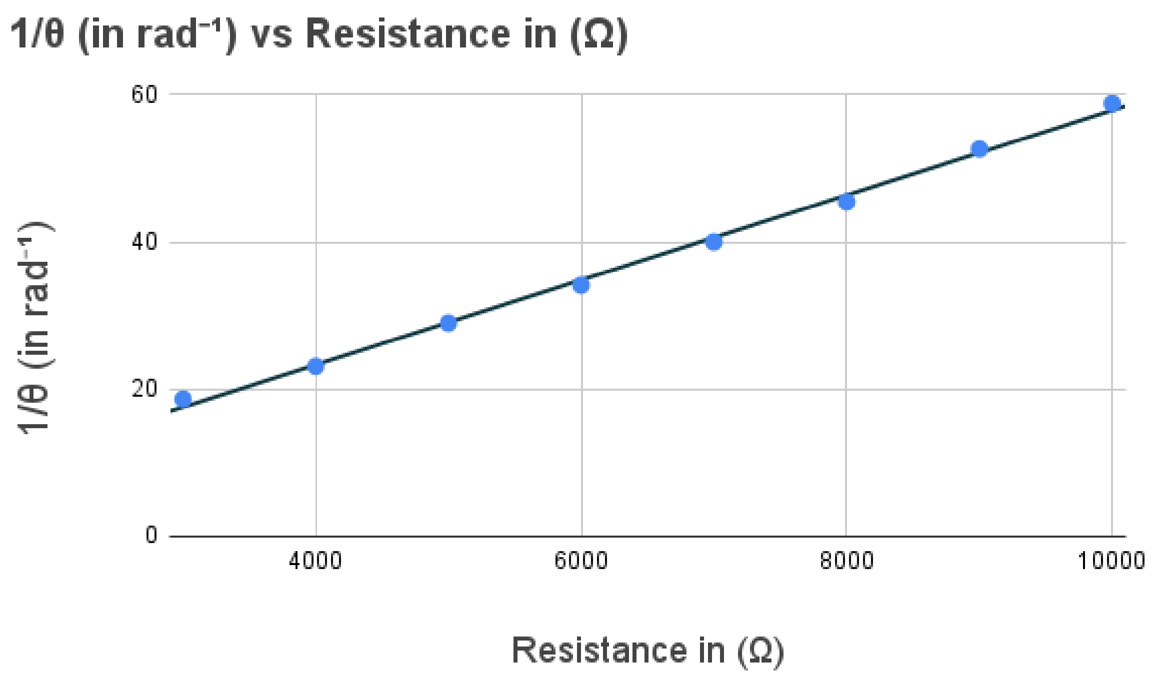
Table-2-

TIME PERIOD OF THE GALVANOMETER

Sl. No.	No. of oscillations	Time (S)	Time period (S)	Mean time period T (S)
01	03	28.71	9.57	9.31
02	04	37.47	9.36	
03	04	36.06	9.01	

Graphs:

<u>Graph-1 of Observation Table-1-</u>



Calculations:

Value of slope from the graph, $m = \left(\frac{1}{\theta_2} - \frac{1}{\theta_1}\right)/\left(R_2 - R_1\right)$

$\therefore$, m= 0.0057964047619 Ω^{-1} rad^{-1} is obtained using the plotting tools of excel sheet.

$\therefore$, $m \approx$ 0.00576 Ω^{-1} rad^{-1}

$\therefore$ Figure of merit or current sensitivity $\eta = \frac{EP}{(P+Q)} \times m$

where E=3.19 Volts, P=2Ω, Q=2500Ω and m=0.005764047619 Ω^{-1} rad^{-1}

$\therefore$, η= 0.00001469809105 **A rad^{-1}**

$\therefore$, $\eta \approx 14.698$ μ **A rad^{-1}**

Hence, ballistic constant or charge sensitivity $k = \frac{dq}{d\theta} = \frac{\eta T}{2\pi}$

where T=9.31 seconds, η= 0.00001469809105 A rad^{-1}

$\therefore$, k =0.00002178968594 **A rad^{-1} s**

$\therefore$, $k \approx 21.789$ μ **A rad^{-1} s**

Error:

$$\ln(\eta) = \ln \frac{EP}{(P+Q)(R_2 - R_1)} + \ln\left(\frac{1}{\theta_2} - \frac{1}{\theta_1}\right)$$

$$\frac{\Delta\eta}{\eta} = 0 - \frac{\left(\frac{\Delta\theta}{\theta_2^2} + \frac{\Delta\theta}{\theta_1^2}\right)}{\frac{1}{\theta_2} - \frac{1}{\theta_1}} = \frac{\Delta\theta}{\theta_2} + \frac{\Delta\theta}{\theta_1}$$

Again, $\theta = \frac{length\ of\ deflection\ (d)}{distance\ between\ mirror\ to\ scale\ (D)}$

$$\therefore \frac{\Delta\theta}{\theta} = \frac{2\times\Delta d}{d} + \frac{\Delta D}{D}$$

Here Δd is the least count of lamp-scale (0.1 cm) and ΔD is the least count of meter (0.1cm) scale.

Let $1/\theta_1$=23.09 rad^{-1} and its corresponding d=6.5cm , $1/\theta_2$=52.63 rad^{-1} and its corresponding d=2.85cm, D= 75cm.

$$\frac{\Delta\theta}{\theta_2} = \frac{2\times\Delta d}{d} + \frac{\Delta D}{D} = \frac{2\times 0.1}{2.85} + \frac{0.1}{75} = 0.071508771 \quad \rightarrow (\ i\ )$$

Similarly,

$$\frac{\Delta\theta}{\theta_1} = \frac{2\times\Delta d}{d} + \frac{\Delta D}{D} = \frac{2\times 0.1}{6.5} + \frac{0.1}{75} = 0.03202564 \quad \rightarrow (\text{ i i })$$

Substituting the values of equations (i) and (ii) in the below equation, we get -

$$\frac{\Delta\eta}{\eta} = 0 - \frac{\left(\frac{\Delta\theta}{\theta_2^2} + \frac{\Delta\theta}{\theta_1^2}\right)}{\frac{1}{\theta_2} - \frac{1}{\theta_1}} = \frac{\Delta\theta}{\theta_2} + \frac{\Delta\theta}{\theta_1}$$

$$\frac{\Delta\eta}{\eta} = \frac{\Delta\theta}{\theta_2} + \frac{\Delta\theta}{\theta_1} = 0.071508771 + 0.03202564 = 0.103611336$$

$$\therefore \frac{\Delta\eta}{\eta} = 0.103611336 \approx 0.1036$$

$\Delta\eta = 1.521014412 \approx 1.521\mu$ **A rad^{-1}**

$$\frac{\Delta\eta}{\eta} \text{x } 100 = 10.3611336\,\% \approx 10.36\%$$

And here $\Delta T = 0.01$ seconds least count of stop watch, and hence,

$$\frac{\Delta k}{K} = \frac{\Delta\eta}{\eta} + \frac{\Delta T}{T} = 0.103611336 + \frac{0.01}{9.31} = 0.104685449$$

$$\frac{\Delta k}{K} = 0.104685449 \approx 0.1047$$

$\Delta k = 2.280991248 \approx 2.281$ μ **A rad^{-1} s**

$$\frac{\Delta k}{K} \text{x } 100 = 10.4685449\,\% \approx 10.47\%$$

The fractional error of current sensitivity is 0.1036 and its percentage error is 10.36%.
The fractional error of ballistic constant is 0.1047 and its percentage error is 10.47%.

Result:

1. The current sensitivity of the given ballistic galvanometer is (14.698 ± 1.521) μA rad^{-1}
2. The charge sensitivity of the given ballistic galvanometer is (21.789 ± 2.281) μ A rad^{-1} s
3. The fractional error of current sensitivity is 0.1036 and its percentage error is 10.36%.
4. The fractional error of ballistic constant is 0.1047 and its percentage error is 10.47%.

Precautions:

1. The galvanometer should be levelled so that the movement of the spot of light is free
2. The scale should be set up at a distance of about one meter from the mirror of the galvanometer.
3. The value of R should be very large as compared to the value of P.
4. A tap key should be placed across the galvanometer terminals and should be pressed to bring the spot of light to a stationary position.
5. A cell of constant e.m.f and very low internal resistance should be used.
6. While finding the time period of the galvanometer coil, the galvanometer circuit must be open.

Discussion:

1. The ballistic galvanometer is an instrument, which is used to measure or indicate current in a closed circuit. The galvanometer also is known as PMMC instrument, works on the principle of permanent magnet moving coil.
2. Current sensitivity: The figure of merit or current sensitivity of a moving coil galvanometer is the current required to produce a deflection of 1 mm on a scale kept at a distance of 1 m from the mirror. It is expressed in μA/mm.
3. The wire used for the suspension of the coil is made up of phosphor bronze because phosphor bronze has low torsional constant. It allows the coil to suspend easily. Also phosphor bronze is nonmagnetic. So it does not comes

under the influence of magnetic poles. And phosphor bronze does not oxidize easily. This allows the suspension wire not to get rusted due to atmospheric conditions.

4. Charge sensitivity: The charge sensitivity (the ballistic reduction factor) of a moving coil galvanometer is the charge (transient current) required to produce a deflection (throw or kick) of 1 mm on a scale kept at a distance of 1 m from the mirror.
5. Uses of Ballistic galvanometer:
    a. To compare capacities of capacitors.
    b. To compare e m f of cells.
    c. To find self and mutual inductance of coils.
    d. To find the magnetic flux or to find the intensity of a magnetic field.
    e. To find the angle of dip at a place using earth inductor.
    f. To find a high resistance, by method of leakage through a capacitor.