PH1202

Physics Laboratory II

Experiment Number - 02

Construction of one-ohm coil using Carey Foster Bridge

Submitted to: Dr. Prof. Dhananjay Nandi (DPS), Dr. Prof. Rumi De (DPS), Dr. Prof. Rangeet Bhattacharya (DPS)
By: Priyanshu Mahato (*pm21ms002@iiserkol.ac.in*)
Roll No.: pm21ms002
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Construction of one-ohm coil using `Carey Foster Bridge`.

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3 Circuit Diagram

A Carey Foster bridge is an electrical circuit that can measure very small resistance. It works on the similar principle as Wheatstone's bridge. A Wheatstone's bridge consists of four resistances P, Q, R and S that are connected as shown in the Figure 1.

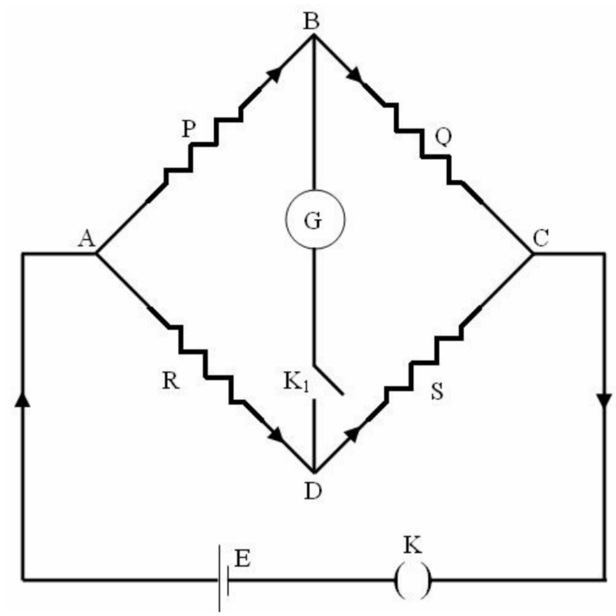

Figure 1: A Wheatstone Bridge

In this circuit, G is a galvanometer, E is a lead accumulator, and K1 and K are the galvanometer and battery key, respectively. If the value of resistances are adjusted so that no current flows through the galvanometer, then if any three of the resistances are known, the forth unknown resistance can be determined by using the relationship $\dfrac{P}{Q} = \dfrac{R}{S}$.

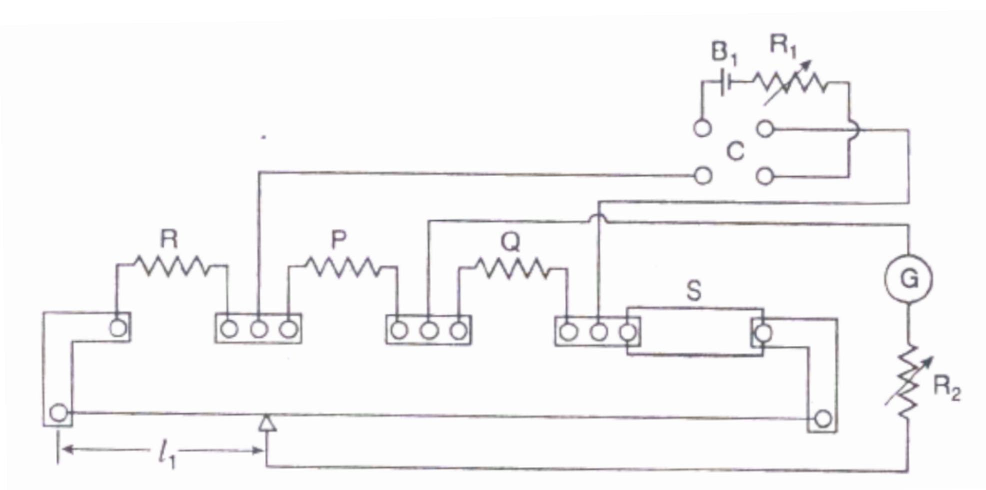

Figure 2: A Carey-Foster Bridge

A meter bridge also works is similar principle. In the meter bridge, two of the resistors, R and S are replaced by a one meter length of resistance wire, with uniform cross-sectional are fixed on a meter scale. Point D is an electrical contact that can be moved along the wire, thus varying the magnitudes of resistances R and S. The Carey Foster bridge is a modified form of the meter bridge in which the effective length of the wire is considerably increased by connecting a resistance in series with each end of the wire. This increases the accuracy of the bridge. *Figure 2* shows the circuit diagram of a Carey Foster bridge.

In this circuit, P and Q are two nearly equal resistances (each of 1 or 2 Ω), R is a known resistance, S is a thick metal strip having zero resistance, G is a galvanometer, B_1 is a storage battery, C is a commutator, R_1 is a rheostat in the battery circuit and R_2 is a rheostat in series with the galvanometer.

4 Procedure

1. Make the circuit as in Figure 2. Note that S is a metal strip. Connect a resistance box in place of R. Observe the null point. Insert a small resistance in the circuit from the box. Note the null point readings for both direct and reverse currents. Increase gradually the resistance R (say, in steps of 0.1Ω) and each time record the null points (l_1) for both direct and reverse currents till the end of the bridge wire is approached.

2. Interchange the metal strip S and the resistance box R. Repeat the process as in step 1 and record the null points (l_2).

3. Find the value of ρ of the bridge wire from each set of readings using equation $\rho = \dfrac{R}{l_2 - l_1}$ and obtain the mean ρ.

4. Take the sample wire and bend its two ends over 1cm length for insertions in the binding screws of the bridge. Measure the length L of the wire between the two bends and record this length.

5. Put the sample wire in the extreme left gap and a resistance box r in the extreme right gap of the bridge. Insert a resistance (say, 1.6Ω) from the resistance box r and record the null points (l'_1) for direct and reverse currents. Increase gradually the value of the resistance r (say, in steps of 0.1Ω or 0.2Ω) from the box and each time record the null points for direct and reverse currents.

6. Interchange the positions of the sample wire and the resistance box r and repeat step 5. Find the null points (l'_2).

7. Knowing the value of r and the positions of the null points in steps 5 and 6, calculate the value of the resistance R_x of the sample wire by using the equation $R_x = r + \rho(l'_2 - l'_1)$.

8. Calculate the length L' of the wire required for 1Ω from R_x and L by using the equation $L' = \dfrac{L}{R_x}$.

9. Cut off a length which is slightly less than L' from the sample wire and solder its two ends to two metal strips.

10. Connect metal strips to the two outer gaps of the bridge so that $R = 0\Omega$ and $S = 0\Omega$. Obtain the null points (l_0) for both direct and reverse currents.

11. Connect the wire in place of metal strip at the left and the standard ohm in place of the right metal strip of the bridge. Obtain the null points for direct and reverse currents and find the mean value (l_1”).

12. Rub a little the wire by a fine grained sand paper and obtain the null point again. In this case, the difference (l_1”$-l_0$) will be reduced from the previous value. The process of rubbing is repeated several times until the value of (l_2”$-l_0$) becomes approximately equal to zero.

13. Interchange the position of the wire and the standard ohm and record the null point reading (l_2”). Calculate the correct value of the resistance of the wire by using equation $P_1 = S_1 + \rho(l_2" - l_1")$ with last value of l_1” obtained in step 12.

14. Fold the prepared one ohm wire on itself and wind round a bobbin non-conductively.

5 Tables

No. of sets	Resistance in the extreme		Position of null point for			$(l_2 - l_1)$ cm	$\rho = \frac{R}{(l_2 - l_1)}$ (Ωcm^{-1})	Mean ρ (Ωcm^{-1})
	Left gap (Ω)	Right gap (Ω)	Direct Current (cm)	Reverse Current (cm)	Mean (cm)			
1	0.2	0	48.7	48.5	48.6	4.6	0.0435	
	0	0.2	53.3	53.1	53.2			
2	0.3	0	47.6	47.6	47.6	7.1	0.0423	
	0	0.3	54.7	54.7	54.7			
3	0.4	0	46.4	46.2	46.3	9.5	0.0421	
	0	0.4	55.7	55.9	55.8			
4	0.5	0	45	45	45	11.9	0.0420	**0.0425**
	0	0.5	56.9	56.9	56.9			
5	0.6	0	44.0	44.2	44.1	14.0	0.0429	
	0	0.6	58.0	58.2	58.1			
6	0.7	0	42.7	42.7	42.7	16.6	0.0422	
	0	0.7	59.3	59.3	59.3			

Table 1: Determination of ρ of the bridge wire (Least Count of Meter Rule = $1mm$)

Initial Balance Point, $l_0 = 51cm$
Now, we can calculate the value of Resistance Gradient $\rho = 0.0425\ \Omega cm^{-1}$
So, length of wire required to construct a coil of 1 ohm resistance $= \frac{1}{\rho} = \frac{1}{0.0425} = 23.5cm$

Sl. No.	Resistance (Ω)	Average l_1 (cm)	Average l_2 (cm)	$l_2 - l_1$ (cm)	Unknown Resistance ($r = R - \rho(l_2 - l_1)$)
1	1.0	48.0	52.8	4.8	0.80
2	1.2	46.0	55.8	9.8	0.78
3	1.4	44.5	59.5	15.0	0.76

Table 2: Value of unknown resistance of a given wire

$$\text{Average Value of the Unknown Resistance} = \frac{0.80 + 0.78 + 0.76}{3} = 0.78\ \Omega$$

6 Calculations and Results

1. Resistance gradient i.e. resistance per unit length (ρ) of the supplied wire is 0.0425 Ωcm^{-1}
2. Mean unknown resistance is calculated to be 0.78 Ω
3. Length of wire required to make 1 ohm resistance is 23.5 cm.

7 Error Analysis

$\delta R = 0.001\Omega$
$\delta l = 1mm = 0.1cm \Rightarrow \delta l_1 = \delta l_2 = 0.1cm$

7.1 Expected Error in the Calculation of ρ:

$$\begin{aligned}
\delta\rho &= \left|\frac{1}{l_2 - l_1}\right|\delta R + \left|\frac{R}{(l_2 - l_1)^2}\right|\delta l_2 + \left|\frac{R}{(l_2 - l_1)^2}\right|\delta l_1 \\
&= \left|\frac{1}{4.6}\right|0.001 + \left|\frac{0.2}{(4.6)^2}\right|0.1 + \left|\frac{0.2}{(4.6)^2}\right|0.1 \\
&= 0.00211\ \Omega cm^{-1} \\
\Rightarrow \frac{\delta\rho}{\rho} &= \frac{0.00211}{0.0425} \approx 5.0\%
\end{aligned}$$

7.2 Expected error in calculation of the unknown resistance (r):

$$\begin{aligned}
\delta r &= \delta R + |l_2 - l_1|\delta\rho + |\rho|\delta l_2 + |\rho|\delta l_1 \\
&= 0.001 + 16.6 \times 0.00211 + 0.0425 \times 0.1 + 0.0425 \times 0.1 \\
&= 0.045\Omega \\
\Rightarrow \frac{\delta r}{r} &= \frac{0.045}{0.78} \approx 5.8\%
\end{aligned}$$

Note: $l_2 - l_1$ has been taken 16.6 cm as it gives the largest possible error in calculation of r.

7.3 Expected error in calculation of length of wire required to construct 1 ohm resistance coil:

$$\begin{aligned}
\delta L &= \left|\frac{1}{\rho^2}\right| \delta\rho \\
&= \left|\frac{1}{0.0425^2}\right| \times 0.00211 \\
&= 1.17cm \\
\Rightarrow \frac{\delta L}{L} &= \frac{1.17}{23.5} \approx 5.0\%
\end{aligned}$$

8 Discussion

8.1 Sources of Error

1. Due to Joule's heating effect the resistance of the wires increases, thereby deviating the readings a bit from the actual value and hence adding to error in the experiment.
2. Errors arising and accumulated while identifying the null points and measuring l_1 and l_2.
3. Errors arising due to limited accuracy of the instruments used.
4. The two resistances P and Q in the upper arms of the Carey Foster Bridge aren't exactly equal ($l_0 = 51$ cm), thus leading to further (small) error.

9 Conclusion

The experimental values of resistance per unit length (ρ) of the supplied wire, resistance of the unknown wire and length of wire required to make 1 ohm resistance are 0.0425 Ωcm^{-1}, 0.78 Ω and 23.5 cm with respective percentage errors : 5.0 %, 5.8 % and 5.0 % .