Expt-5
Helmholtz Coils

Aim

a) To measure the magnetic field produced by the Helmholtz coil.

b) To determine the torque experienced by a current carrying loop, suspended between the Helmholtz coils, as a function of

   (i) the strength of the magnetic moment (by varying current 'i_L' through the loop),

   (ii) the angle (α) between the magnetic field and the axis of the loop,

   (iii) the number of turns (n) in the current loop.

Apparatus

- Helmholtz coils, digital Gaussmeter, Hall probe.
- Torsion dynamometer, power supply with inbuilt digital ammeter, connecting wires, supporting stand and two small coils having n=1 and 3.

Theory

Helmholtz coil consist of a pair of identical coils (each having N number of turns and radius R) placed coaxially and separated by a distance R. Such a pair produces a fairly uniform magnetic field $\mathbf{B_0}$ in the region between the coils, provided the sense of the current 'I' through the coils are such that the two magnetic fields add.

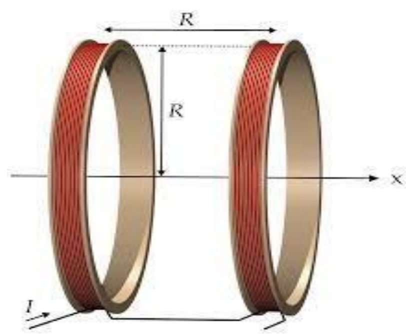

Fig.1. Picture of the Helmholtz coils

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The theoretical formula expressing $\mathbf{B_0}$ in terms of I, N and R is:

$$|B_0| = \frac{8}{5\sqrt{5}} \mu_0 N \frac{I}{R} \tag{1}$$

In the laboratory setup, R=0.2m, N=154, and 'I' maybe varied up to 3A. Note $\mu_0 = 4\pi \times 10^{-7}$ Henry/m.

When a current (i_L) carrying conducting loop of radius 'r' with n turns, is placed in the uniform magnetic field $\mathbf{B_0}$ between the Helmholtz coils, it experiences a non- zero torque $\boldsymbol{T}$, provided the axis of the loop makes a non-zero angle 'α' with $\boldsymbol{B_0}$. The magnetic moment of the loop is $\boldsymbol{m}$, where $|\mathbf{m}| = \pi r^2 i_L n$.
The mathematical formulas are as follows:

$$\boldsymbol{T} = \boldsymbol{m} \times \boldsymbol{B_0} \tag{2}$$

and

$$|T| = \pi r^2 i_L n |\boldsymbol{B_0}| \sin(\alpha) \tag{3}$$

where r=6 cm.

Experimentally the torque experienced by the coil, transfers to a torque on the lever arm, which can be measured directly from the force experienced by a dynamometer. Note that,

$$|\boldsymbol{T}| = |\boldsymbol{F}| L \tag{4}$$

Where $|\boldsymbol{F}|$ is the force measured by the force indication knob of the dynamometer, and L is the half the length of the lever arm (L=12cm). The angle between $\boldsymbol{F}$ and $\boldsymbol{L}$ is 90°.
Equations (1), (3) and (4) provide important formulas to be used while performing the experiment.

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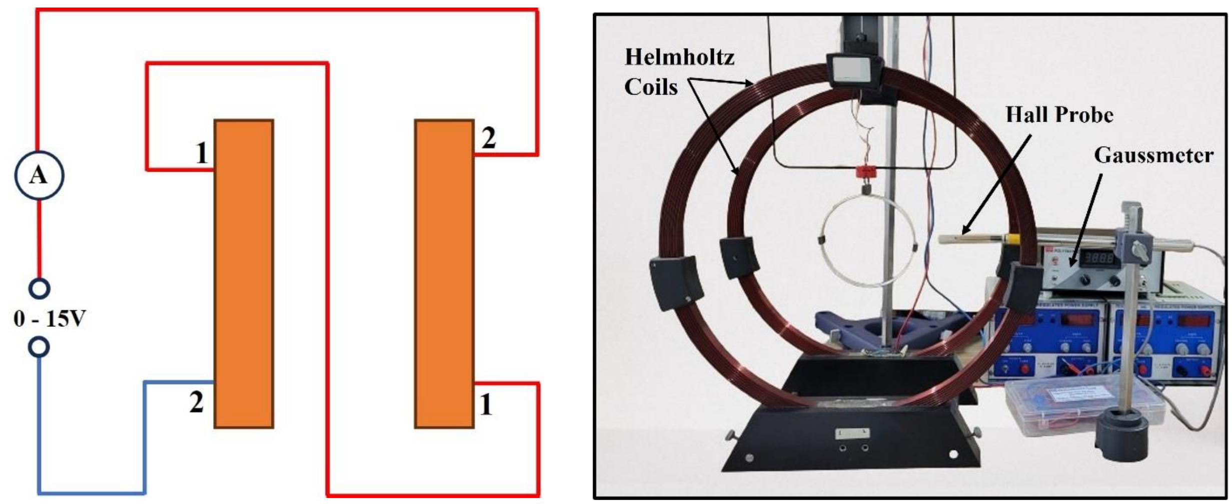
Experimental steps

1) *[Measurement of the magnetic field produced by the Helmholtz coils](#)***:**
Make the circuit as in the figure below.



(a) **(b)**

Fig.2(a) Schematic diagram of the circuit **(b)** The actual laboratory setup showing the Helmholtz coils, power supply, Hall probe, Gaussmeter and the connections.

Connect the Hall probe to the Gaussmeter and do the initial calibration of the Gaussmeter – in the CAL position display should read 100.0, and then switching to READ position, adjust the reading to zero value by tuning the ZERO control.

Switch on the power supply and set the Helmholtz coil current (I) by using coarse knob and fine knob of the power supply. Note that '*I*' should not exceed 3A at any time. During the experiment use two values of I=2A and 3A.

Place the Hall probe between the Helmholtz coils. The Gaussmeter directly gives the magnetic field (B_0) value. (a) At any position, by rotating the Hall probe along its axis, you will find the B_0 value to be maximum when the probe plane is parallel to the plane of the coils. That position of the probe should be kept fixed by the clamp and not changed further during the experiment. (b) Also check how B_0 varies in space, and is fairly constant over a large region. Note down this measured constant value. Repeat (b) for two values of '*I*' as mentioned above.

Table 1: Make a table and compare these experimental values of B_0 with the calculated values from the theoretical formula in Eq.1.

2) *Measurement of the torque experienced by the current carrying loop*:

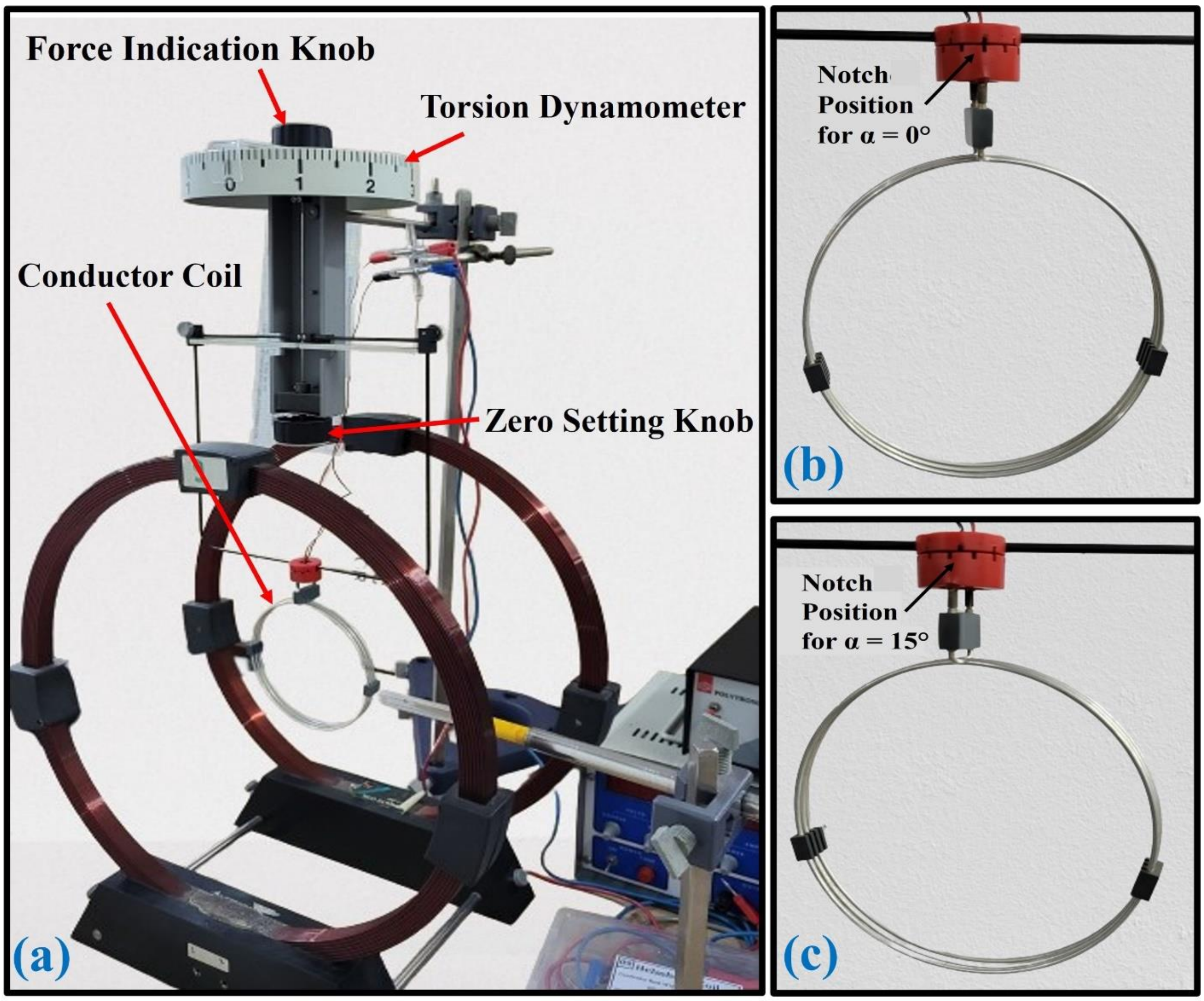


Fig.3(a) Set-up for determining the torque experienced by the current carrying loop. And notch positions for **(b)** $\alpha=0^0$ and **(c)** $\alpha=15^0$.

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Connect the leads of the conducting coil to the power supply terminals (see Fig3(a). Set current 'i_L' = 0A. In this condition, balance the lever arm by bringing it between the black indication lines, by rotating the bottom knob (zero setting knob) of the torsion dynamometer. Also check that the top knob (force indication knob) of the torsion dynamometer is in zero (reading) position.

By rotating the red wheels (as shown in Fig.3(b) and Fig.3(c)), align the notch to set a particular angle 'α' between the axis of the coil and field $\mathbf{B_0}$. Turn on the loop current and set 'i_L' to a non-zero value.

You will see that the lever arm will rotate and move from the balanced position. Bring the lever arm to the initial zero indication position by rotating the force indication knob (top knob). The final reading on the force indication knob is the measured value of force $|\boldsymbol{F}|$ experienced by the system and multiplying it by half the length (L) of the lever arm (see Eq.4), you may obtain the measured value of torque $|\boldsymbol{T}|$. This may be compared to the theoretical value of torque using Eq.3.

Table 2: Keep a constant value of Helmholtz coil current I=3A, and angle α=30°. Use the coil with n=3 turns. Vary 'i_L' to have values 2A, 3A, 4A, 5A. Show the measured force $|\boldsymbol{F}|$, measured torque $|\boldsymbol{T}|$, and calculated torque $|\boldsymbol{T}|$.

Table 3: Keep a constant value of Helmholtz coil current I=3A, and i_L = 4A. Use the coil with n=3 turns. Vary 'α' to have values 15°, 30°, 45°, 60°. Show the measured force $|\boldsymbol{F}|$, measured torque $|\boldsymbol{T}|$, and calculated torque $|\boldsymbol{T}|$.

Table 4: Keep a constant value of Helmholtz coil current I=3A, angle α=30°, and i_L= 4A. Now use two coils with n=1 and 2 turns, and for each case, show the measured force $|\boldsymbol{F}|$, measured torque $|\boldsymbol{T}|$, and calculated torque $|\boldsymbol{T}|$.

Graph plotting, calculation of experimental B_0, and error estimation

In Graph 1, plot experimentally measured torque $|\boldsymbol{T}|$ versus i_L using the data of Table 2. Draw a best fit line to the data and calculate the slope. From the slope and using Eq.3, obtain the experimental B_0.

In Graph 2, plot experimentally measured torque $|\boldsymbol{T}|$ versus sin(α) using the data of Table 3. Draw a best fit line to the data and calculate the slope. From the slope and using Eq.3, obtain the experimental B_0.

Calculate the average value of these two measured values of B_0 (obtained from Graphs 1 and 2).

Calculate the percentage difference of the measured value of B_0 (from Graph 1) with respect to the calculated theoretical value according to eqn (1) for I = 3A, i.e.

$$\left|\frac{\delta B_0}{B_0}\right| = \left|\frac{B_0(measured) - B_0(theory)}{B_0(theory)}\right| \qquad (5)$$

Using Eq.5, also calculate the percentage difference of the measured value of B_0 (from Graph 2) with respect to the calculated theoretical value according to eqn (1) for I = 3A.

The error in B_0 due to instrumental precision can also be calculated from the errors in force (F) measurements (by dynamometer reading) and angle measurements (by notch setting). For this purpose, calculate $\delta F/F$ (take the smallest F in Table 2) and $\frac{cos\alpha}{sin\alpha}\delta\alpha$ (take $\delta\alpha = \pi/180$). Then calculate,

$$\frac{\delta B_0}{B_0} = \frac{\delta F}{F} + \frac{cos\alpha}{sin\alpha}\delta\alpha \qquad (6)$$

Results

Report the average value of B_0 obtained from the torque measurements (from Graphs 1 and 2) together with the error δB_0 obtained from equation (6).

Precautions

(1) While connecting and changing the circuit, the power supply must be switched off. If at any time, the red light on the power supply glows (indicating overload), immediately switch off the power supply and check any possibility of short circuit.

(2) Make sure that no other magnetic material is placed in the vicinity of the coils. While measuring the magnetic field.

(3) Align the lever arms very carefully it is very delicate and should be handled with extreme care.

(4) Rotate the Force indication knob very carefully, while measuring the deflection on torsion dynamometer.