Variation of Magnetic Field along the Axis of a Circular Coil

Experiment No. 9

Object : To Study the variation of magnetic field with distance along the axis of a current carrying coil and then to estimate the radius of the coil.

Apparatus : *Stewart and Gee type tangent galvanometer, storage battery, commutator, ammeter, rheostat, one way plug key, connection wires and a piece of sand paper.*

Description of the apparatus and Circuit : Stewart and Gee type tangent galvanometer consists of a large number of turns of insulated copper wire wound over the groove of a circular wooden or brass frame (non-magnetic) fixed on a horizontal base with its plane in a vertical direction as shown in fig. 9.1. The

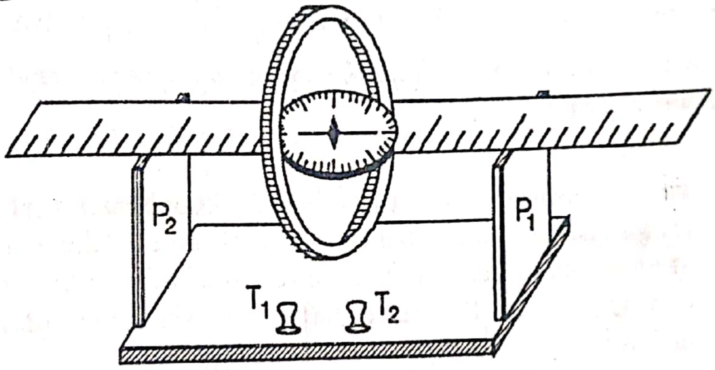

Fig. 9.1

ends of the coil are connected to the two binding terminals T_1 and T_2 provided at the base of the instrument. A deflection magnetometer compass box is placed on a bench fixed on two vertical pillars P_1 and P_2 in

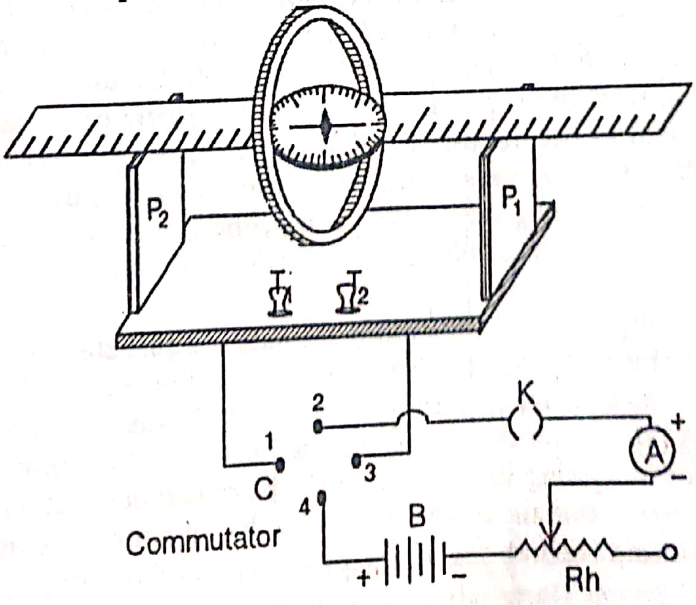

Fig. 9.2

such a way that magnetometer box can slide along the horizontal direction with centre of the magnetic needle always lies on the axis of the coil. Two meter scales opposite to each other are firmly attached with the bench of the magnetometer for measuring the distances of the needle from the centre of the coil on either side.

The scheme of connections is clearly depicted in the diagram shown in fig. 9.2. The binding terminals T_1 and T_2 of the tangent galvanometer are connected to the two diagonally opposite fixed terminals (1, 3) of commutator C. The remaining two movable terminals (2, 4) of commutator are connected to the storage battery B with a rheostat Rh, an ammeter A and key K in series as shown in figure.

Theory and Formula : *The magnetic field F at any point distant x from the centre of the coil along its axis is given by*

$$F = \frac{2\pi n i r^2}{10\,(x^2 + r^2)^{3/2}}$$

where i is the current flowing through the circular coil of radius r and n the number of turns in the coil.

If the magnetometer is placed with the bench in the East-West direction or coil parallel to the magnetic meridian, then the field F will be at right angle to the horizontal component of the earth's magnetic field H. In this situation the tangent law hold good and the deflection θ of the magnetic needle from the magnetic meridian is given by

$$F = H \tan\theta$$

$$\therefore \quad \frac{2\pi n i r^2}{10\,(x^2 + r^2)^{3/2}} = H \tan\theta \quad \text{or} \quad \frac{2\pi n i r^2}{10\,(x^2 + r^2)^{3/2}} \propto \tan\theta$$

Hence, the variation of magnetic field along the axis of a current carrying circular coil involves the plotting of a graph between x and tan θ.

Procedure

1. First of all the magnetometer compass box is placed on the bench such that its magnetic needle lies at the centre of the coil. Rotate the instrument in the horizontal plane till the plane of the coil lies roughly in the magnetic meridian or bench in the East-West direction. Now without disturbing the setting of the apparatus rotate the compass box till pointer read 0° – 0° on the circular scale. This adjustment of the instrument remain unchanged throughout the experiment.
2. Clean the ends of the connecting wires with sand paper and make electric connections as explained in fig. 9.2.
3. Insert the plug in the key K so that the current flows in the coil. Adjust the value of current with the help of rheostat Rh such that the deflection in the galvanometer lies between 70° – 75°. Note this value at both ends of the pointer. Reverse the direction of current in the coil with the help of the commutator and again note the readings of both the pointers. **If the mean deflections in the two cases are very nearly equal, then the plane of the coil is exactly in the magnetic meridian. If it is not so, then slightly turn the instrument in the horizontal direction towards greater deflection side till the mean deflections with direct and reverse current become nearly equal.**
4. Now slide the magnetometer box along the axis to get maximum deflection. In this situation (that is, at $x = 0$) the centre of the needle coincides with the centre of the coil. Note this position of magnetometer box on the meter scale.
5. Now shift the position of compass needle box along the axis in equal step of 2 cm on one side of the coil along the bench. Note this distance and also the reading of both ends of the pointer for direct as well as reversed current. This process of shifting of compass in small step of 2 cm and taking the observation of ends of the pointer for direct and reversed current, is continued till the deflection is reduced to 30°. Note all these reading in table. It should be remember that during each observation the current in the circuit always remain constant (check it by an ammeter connected in the circuit).
6. Now repeat the process of taking observation on other side of the coil keeping current always constant. **(The measurement of deflection along with distance can also be measured from one end of the**

bench in the following manner :

Shift compass box towards the either end of the bench till the deflection reduces to about 30°. At this position, note down the distance of the compass needle from one end of the bench and also record the deflections at the two ends of the pointer before and after reversing the current through the coil. Find the mean deflection θ.

Now shift the compass box towards the coil by 2 cm and note down its distance from the same end. Also note down the deflections at the two ends of the pointer before and after reversing the current through the coil and find the mean deflection θ.

Go on moving the compass box in regular steps of 2 cm, each time recording its distance from the same end and determining the mean deflection θ till the compass box after crossing the coil reaches the other end of the bench)

7. Plot a graph between the distance x of the compass needle box from the centre of the coil or from the one end of the bench and tangent of deflection of magnetic needle, that is, tan θ. The resulting curve shall be symmetrical and its maximum value shall correspond to the position of the needle at the centre of the coil itself (Fig. 9.3).
8. Find out the points of inflexion (The points at which the curve changes its sign, that is, from concave to convex) A and B on the curve by drawing common tangent at the place where the curve is practically a straight line for a short length and measure the distance between them to get the radius of the coil.

Observations

Current in the coil, I = ... Amp.

(a) **Table for distance x from the centre of the coil and tangent of deflection of the magnetic needle that is, tan θ**

S.No.	Distance of the needle from the centre of the bench* (x) cm	Deflection on left side of the coil in degree: Direct Current, One end of the pointer θ_1	Direct Current, Other end of the pointer θ_2	Reversed Current, One end of the pointer θ_3	Reversed Current, Other end of the pointer θ_4	Mean θ $\left[=\frac{\theta_1+\theta_2+\theta_3+\theta_4}{4}\right]$ in deg.	Tan θ	Deflection on right side of the coil in degree: Direct Current, One end θ_1'	Direct Current, Other end θ_2'	Reversed Current, One end θ_3'	Reversed Current, Other end θ_4'	Mean θ' $\left[=\frac{\theta_1'+\theta_2'+\theta_3'+\theta_4'}{4}\right]$ in deg.	Tan θ'
1.	...	...	...	...	...	...	...	...	...	...	...	...	...
2.	...	...	...	...	...	...	...	...	...	...	...	...	...
3.	...	...	...	...	...	...	...	...	...	...	...	...	...
4.	...	...	...	...	...	...	...	...	...	...	...	...	...
5.	...	...	...	...	...	...	...	...	...	...	...	...	...
6.	...	...	...	...	...	...	...	...	...	...	...	...	...
7.	...	...	...	...	...	...	...	...	...	...	...	...	...
8.	...	...	...	...	...	...	...	...	...	...	...	...	...
9.	...	...	...	...	...	...	...	...	...	...	...	...	...
10.	...	...	...	...	...	...	...	...	...	...	...	...	...
11.	...	...	...	...	...	...	...	...	...	...	...	...	...
12.	...	...	...	...	...	...	...	...	...	...	...	...	...

* (If the distance is measured from the one end of the bench, then change the second column as "Distance of the compass needle from one end of the bench")

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(b) *The circumference of the coil measured by a thread and meter scale = ... cm*

Graph : *Plot a graph taking the distances x of the needle from the centre of the coil towards one end of the bench on X-axis by choosing a suitable scale and corresponding value of tan θ on Y-axis. The resulting curve shown in fig. 9.3 has two symmetric branches. Find out the points of inflexion A and B on the curve by drawing tangents on the curve. The tangent just above and just below the points of inflexion lie on opposite side of the curve. This situation will not occur for any other point on the curve.*

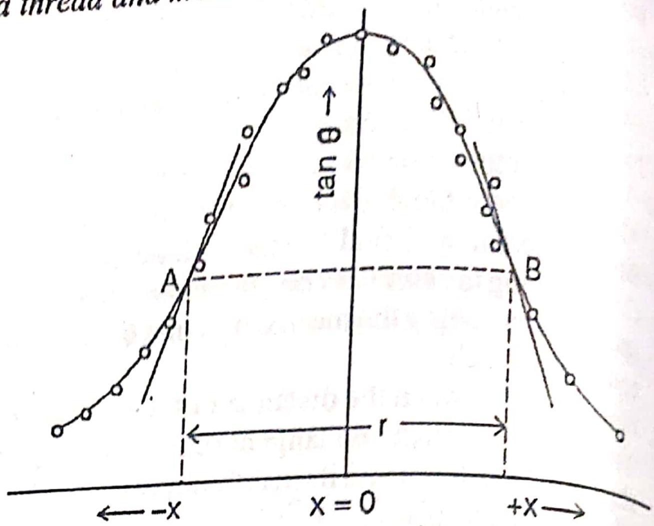

Fig. 9.3

Calculations

1. *The radius of the coil (AB) as measured from X-tan θ graph = ... cm*

2. *The radius of the coil from the measurement of circumference* $= \dfrac{circumference}{2\pi} = \ldots\ cm.$

3. *The percentage error in the experimental result is calculated by the following formula*

$$\text{Percentage error} = \frac{\text{Standard value} \sim \text{Calculated value}}{\text{Standard value}} \times 100 = \ldots\ \%$$

Result :

1. *The attached graph shows the variation of the magnetic field along the axis of a circular coil carrying current.*

2. *The radius of the coil as measured from X–tan θ graph = ... cm.*

Standard Result : *The actual radius or the radius of the coil as measured by circumferential length = ... cm*

Percetage Error : *Percentage error in radius measurement = ... %.*

Precautions and Sources of Error

1. *The plane of the coil should be carefully set in the magnetic meridian and the centre of the compass box should always lie on the axis of the coil.*
2. *There should no magnetic substance or current carrying conductors in the neighbourhood of the instrument, otherwise actual reading will be considerably affected.*
3. *The current flowing in the circuit should be constant and of such a value as to produce a deflection of about 70° when the magnetometer is at the centre of the coil.*
4. *For every observation the positions of both the pointers of the compass needle should be noted for direct as well as for reverse current.*
5. *While taking deflections, there should be no parallax between the pointer and its image.*
6. *There should be no friction between needle and its pivot.*
7. *X-tan θ curve should be smooth and the positions of the points of inflexion should be carefully find out.*

Viva-Voce

Q. 1. **What are you doing ?**

Ans : Sir, I am studying the variation of magnetic field with distance along the axis of a circular coil carrying current.

Q. 2. **What do you mean by the magnetic effect of current ?**

Ans : When a current flows in a conductor, a magnetic field is produced around it, this is called magnetic effect of current.

Q. 3. **What is the strength of magnetic field at any point on the axis of the coil ?**

Ans : The magnetic field F at any point distant x from the centre of a circular coil of radius r is given by the formula $$F = \frac{2\pi n i r^2}{10\,(r^2 + x^2)^{3/2}}$$
where n is the number of turns and i the current flowing in the coil.

Q. 4. **What is the strength of magnetic field at the centre of the coil ?**

Ans : The strength of the magnetic field at the centre of the coil is given by $F = \frac{2\pi n i r^2}{10\,(r^2 + 0)^{3/2}} = \frac{2\pi n i}{10\,r}$

Q. 5. **What is the nature of the material of the circular coil ?**

Ans : The coil is made up of an insulated copper wire wound on a circular frame of non-magnetic material.

Q. 6. **What is the direction of field at a point on the axis of the coil ?**

Ans : The direction of the field is along the axis of the coil.

Q. 7. **What is the direction of magnetic field at the centre of the coil ?**

Ans : The direction of magnetic field at the centre of the coil is normal to the plane of the coil. If the current in the face of the coil facing the observer flows in the clockwise direction then that face attains south polarity and direction of the field will be directed away from the observer. Conversely, if the current flows in the anticlockwise direction in the face facing the observer, then the field will be directed towards the observer.

Q. 8. **What is the practical utility of finding the variation of magnetic field along the axis of a circular coil ?**

Ans : The study of variation of magnetic field reveals the existence of two points of inflexion at which the rate of change of magnetic field with distance (dF/dx) is constant. This property has been used in the construction of Helmholtz galvanometer.

Q. 9. **What is Helmholtz galvanometer ?**

Ans : Helmholtz galvanometer is the modified form of a tangent galvanometer in which two identical vertical flat circular coils placed coaxially at a distance equal to the radius of the either coil (Fig. 9.4). Near the point on the common axis mid-way between them the magnetic field is very nearly

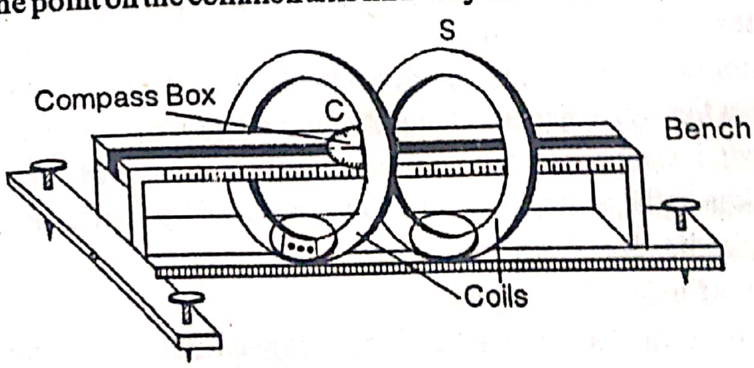

Fig. 9.4

constant over an appreciable region. Therefore, the magnetic needle of the magnetic compass box placed mid-way between the two coils rotates in uniform fields Due to this reason, a Helmholtz galvanometer is more sensitive than tangent galvanometer.

Q. 10. What are the advantages of a Helmholtz galvanometer over an ordinary tangent galvanometer?

Ans : Helmholtz galvanometer is superior than tangent galvanometer due to following reasons :

1. In the ordinary tangent galvanometer the field is uniform only at the centre of the coil, while in Helmholtz galvanometer the resultant field in the entire region between the two coils is almost uniform.
2. For the coil of same radius and for the same number of turns, the reduction factor of Helmoholtz galvanometer is less than that of the tangent galvanometer. Hence, the sensitivity of Helmholtz galvanometer is more than that of the tangent galvanometer.
3. For the same current, Helmholtz galvanometer produces greater resultant field and hence greater deflection.

Therefore Helmholtz galvanometer is superior, more sensitive and accurate than tangent galvanometer.

Q. 11. What is reduction factor ?

Ans : It is a factor ($K = 2rH/\mu_0 N$, where r is the radius of the coil, H horizontal component of earth's magnetic field, N the number of turns in the coil, μ_0 the permeability of free space) which when multiplied by the tangent of the angle of deflection (θ) gives the current through the coil.

Q. 12. Why Helmholtz galvanometer is more accurate than tangent galvanometer ?

Ans : Because due to wide region of uniform magnetic field, tangent law is more strictly followed in Helmholtz galvanometer than in tangent galvanometer.

Q. 13. What is tangent law ?

Ans : In two mutually perpendicular uniform magnetic fields F and H, a magnetic needle, in equilibrium, makes an angle θ with the horizontal component of earth's magnetic field H, such that $F = H \tan \theta$. This is called tangent law.

Q. 14. Why is it necessary to set the plane of the coil in magnetic meridian ?

Ans : To make the magnetic field F produced by circular coil at right angles to the horizontal component of earth's magnetic field (or for fulfilling the condition of tangent law) the setting of the plane of the coil in magnetic meridian is necessary.

Q. 15. What is magnetic meridian ?

Ans : A vertical plane passing through the axis of a magnetic needle suspended freely through its centre of gravity and rest under earth's field is called the magnetic meridian.

Q. 16. Why a small magnetic needle is used ?

Ans : A small magnetic needle ensures that the two magnetic fields are uniform in the region surrounding the centre of the coil in which it is deflecting. The horizontal component of earth's magnetic field H is uniform over a large region but the field produced by the circular coil along its axis on passing current through it depends upon the distance of the point from the centre and is thus non-uniform. However, it can be considered fairly uniform over a small region. Therefore, if a small magnetic needle is taken at the centre, magnetic field produced by the coil F can be taken uniform. For a long magnetic needle, F can not be uniform.

Q. 17. What is the necessity of using a long pointer ?

Ans : In order to measure a small angular deflection of the needle in the two uniform magnetic fields accurately, the circular scale has to be made large and a long pointer has to be provided. The pointer should be made of a light and non-magnetic material like aluminium.

Q. 18. Why is the mirror provided at the base of the box ?

Ans : Mirror at the base of the compass box is provided for measuring correct deflection of the magnetic needle by removing parallax between the pointer and its image.

Q. 19. How will you eliminate the error in the measurement of deflection, if the coil is not exactly in the magnetic meridian ?

Ans : If the coil is not exactly in the magnetic meridian the error is eliminated by recording the deflection of needle when current is passed in one direction and then in reverse direction. The mean of these four readings of deflection will be free from this error.

Q. 20. Is there any harm in fixing the pointer parallel to the magnetic needle ?

Ans : In fixing the pointer parallel to the magnetic needle there is a difficulty in the adjustment of the coil in the magnetic meridian. While adjusting the coil, the pointer shall fall below the coil, when the eye is held vertically above it. Except this difficulty there is no technical harm in fixing the pointer parallel to the magnetic needle.

Q. 21. Can we use Leclanche cell for drawing the current in your experiment ?

Ans : We can not use Leclanche cell because it does not give constant current.

Q. 22. What is the use of commutator in your experiment ?

Ans : Commutator is used to reverse the direction of current in an electric circuit.

Q. 23. Why the Stewart Gee type galvanometer is called tangent galvanometer ?

Ans : It is called tangent galvanometer because the working of this galvanometer is based upon tangent law.

Q. 24. What do the numbers 2, 50 and 500 at the base of the apparatus indicate ?

Ans : The numbers 2, 50 and 500 indicate the number of turns of the coil. The two turn coil has minimum resistance and is used to measure heavy currents. The fifty turn coil has intermediate resistance and is used to measure intermediate currents. The 500 turn coil has the maximum resistance and is used to measure weak currents.

Q. 25. What is point of inflexion ?

Ans : The point of inflexion is the point on the x-$\tan\theta$ curve where the continuous curve changes its direction of curvature or the points at which the curve changes its sign (concave to convex) are called points of inflexion.

Q. 26. What is the distance between two points of inflexion ?

Ans : The distance between the two point of inflexion is equal to the radius of the circular coil.

Q. 27. What is the magnitude of the magnetic field at the centre of the coil in case of tangent galvanometer ?

Ans : At the centre of the coil, the magnetic field is, $F = \dfrac{2\pi n I}{10 r}$

where n is the number of turns in the coil and r the radius of coil.

Q. 28. What is the magnitude of resultant magnetic field near the point on the axis mid way between the coils of a Helmholtz galvanometer ?

Ans : The resultant field F due to both the coils near the point on the axis mid way between them is very nearly constant over an appreciable region and is obtained by putting $x = r/2$ in the formula as,

$$F = 2 \times \frac{2\pi n i r^2}{\left(r^2 + \dfrac{r^2}{4}\right)^{3/2}} = \frac{32\,\pi n i}{5\sqrt{5}\, r}$$