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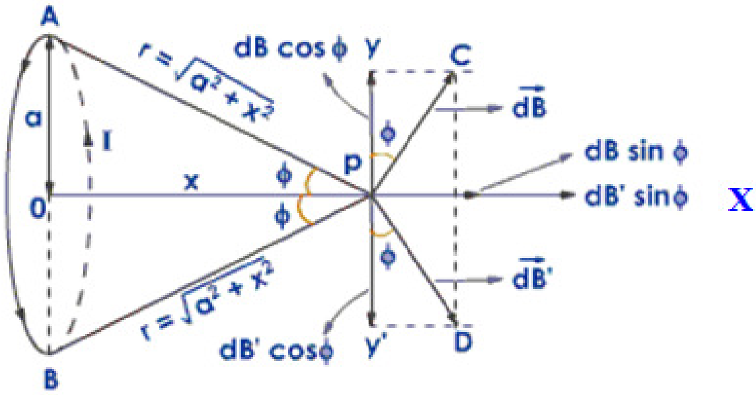
MAGNETIC FIELD ON THE AXIS OF A CIRCULAR COIL

(వృత్తాకార తీగ చుట్ట వల్ల అయస్కాంత ప్రేరణ)

Consider a circular coil of radius 'a' carrying a current 'i' as shown in the following figure. Let 'P' is a point on the axis of the circular coil at a distance 'x' from the centre. The aim of this topic is to derive an expression for magnetic induction 'B' at point 'P'. For this purpose, consider a small element of length 'dl' at point A on the coil. Let 'r' be the distance of the element from the point 'P' and 'θ' be the angle between the direction of current and the line joining the line element and point 'P'. The magnetic induction 'dB' at point P due to the line element 'dl' is given by

$dB = \frac{\mu_0}{4\pi} \times \frac{idl \times \hat{r}}{r^3} = \frac{\mu_0}{4\pi} \times \frac{idlsin90^{\circ}}{r^2} = \frac{\mu_0}{4\pi} \times \frac{idl}{r^2}$ (here, the angle between 'dl' and r is 90°



The vector 'dB' at point 'P' due to the line element 'dl' will be perpendicular to 'r' which can be resolved into two components, one along the axis of the coil and other perpendicular to the axis as dBsinϕ and dBcosϕ respectively.

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If we take another line element 'dl' at 'B' diametrically opposite to point 'A', it also produces magnetic induction at point 'P'. The direction of 'dB' in this case will be opposite to the previous one. This too can be resolved into two components, dBsinϕ and dBcosϕ. Therefore, the components along the axis will be add up while the components perpendicular to the axis will cancel. Similar to this, we divide the circular coil number of elements, vertical components will cancel and the horizontal components will add up.

$\therefore The\ total\ magnetic\ flux\ along\ the\ axis = B = \int dBsin\phi$

$\Longrightarrow B = \frac{\mu_0 i}{4\pi r^2}\int dlsin\phi = \frac{\mu_0 i}{4\pi r^2}\int dl \times \frac{a}{r} = \frac{\mu_0 ia}{4\pi r^3}\int dl$ (From the figure, $sin\phi = \frac{a}{r}$)

But, $\int dl = circumference\ of\ the\ coil = 2\pi a$

From the figure, $r = [a^2 + x^2]^{\frac{1}{2}}$

$B = \frac{\mu_0 ia}{4\pi[a^2+x^2]^{\frac{3}{2}}} \times 2\pi a = \frac{\mu_0 ia^2}{2[a^2+x^2]^{\frac{3}{2}}}$ -----(1)

If there are N turns is the coil, then

$B = \frac{\mu_0 ia^2 N}{2[a^2+x^2]^{\frac{3}{2}}} \frac{weber}{meter^2}\ or\ Tesla$ -----(2)

Here, the direction of 'B' will be along the axis of the coil.

Case I:

At the centre of the coil, x=0. At this point magnetic induction 'B' is given by

$$B = \frac{\mu_0 ia^2 N}{2a^3} = \frac{\mu_0 ni}{2a}$$

Case II:

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At a very far point, i.e., x>>a, $(a^2 + x^2)^{\frac{3}{2}} \approx x^3$, in this case, the value of 'B' is $B = \frac{\mu_0 i a^2 N}{2x^3}$

Model questions (మాదిరి ప్రశ్నలు):

1. Derive an expression for the magnetic field at any point on the axis of a circular coil
2. Find the magnetic field intensity at a point on the axis of a circular coil carrying current. Explain the variation of intensity of magnetic field with a neat diagram.
3. Using Biot Savart law, calculate 'B' at a point on the axis of a circular coil radius 'r' carrying a steady current 'i'.
4. Calculate the intensity of magnetic field at point on the axis of a circular coil.

References:

1. Unified Physics, Volume III, Jai Prakash Nath Publications, Meerut

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