A Circular Coil Of Radius 5.0 Cm Is Wound With Five Turns And Carries A Current Of 5.0 A. If The Coil

Understanding the Magnetic Properties of a Circular Coil

A Circular Coil Of Radius 5.0 Cm Is Wound With Five Turns And Carries A Current Of 5.0 A. If The Coil is a fundamental configuration in electromagnetism, often encountered in various electrical and electronic applications. This setup exemplifies how current-carrying conductors generate magnetic fields, which is essential knowledge for students, engineers, and enthusiasts interested in electromagnetism, motor design, inductors, and electromagnetic induction.

In this comprehensive article, we explore the magnetic characteristics of such a coil, how to compute its magnetic field, magnetic flux, inductance, and the practical implications of these parameters. Whether you're preparing for exams, designing electromagnetic devices, or simply curious about how currents produce magnetic effects, this guide aims to provide detailed insights into the physics of circular coils.

Fundamentals of Magnetic Fields in Circular Coils

To understand the behavior of the given coil, it's necessary to grasp the basics of magnetic fields generated by current-carrying conductors.

Magnetic Field Due to a Circular Loop

A single circular loop of wire carrying current produces a magnetic field along its axis. The strength of this field at any point along the axis depends on the current, the radius of the loop, and the distance from the center.

The magnetic field at the center of a single circular loop is given by:

$$ B = \frac{\mu_0 I}{2 R} $$

where:

- μ_0 is the permeability of free space ($4\pi \times 10^{-7} \, \mathrm{T \cdot m/A}$)
- I is the current in amperes
- R is the radius of the loop in meters

This formula provides the magnetic field at the center of one turn.

Effect of Multiple Turns

When multiple turns are wound in the same coil, the magnetic field at the center is amplified proportionally to the number of turns:

$$ B_{total} = N \times B_{single} $$

where:

- N is the number of turns

Thus, for N turns, the magnetic field at the coil's center becomes:

$$ B = \frac{\mu_0 N I}{2 R} $$

Application to the Given Coil

Given the parameters:

- Radius $R = 5.0 \, \mathrm{cm} = 0.05 \, \mathrm{m}$
- Number of turns $N = 5$
- Current $I = 5.0 \, \mathrm{A}$

The magnetic field at the center can be calculated directly using the formula.

Calculating the Magnetic Field of the Coil

Step-by-step Calculation

Let's perform the calculation:

$$ B = \frac{\mu_0 N I}{2 R} $$

Plugging in the values:

$$
B = \frac{(4\pi \times 10^{-7}) \times 5 \times 5.0}{2 \times 0.05}
$$

Calculating numerator:

$$
(4\pi \times 10^{-7}) \times 5 \times 5.0 = 4\pi \times 10^{-7} \times 25 = 100\pi \times 10^{-7}
$$

Calculating denominator:

$$
2 \times 0.05 = 0.10
$$

Therefore,

$$
B = \frac{100\pi \times 10^{-7}}{0.10} = \frac{100\pi \times 10^{-7}}{1 \times 10^{-1}} = 100\pi \times 10^{-7} \times 10 = 1000 \pi \times 10^{-7}
$$

Simplify:

$$
B = 1000 \pi \times 10^{-7} = \pi \times 10^{-4} \, \mathrm{T}
$$

Approximate:

$$
B \approx 3.1416 \times 10^{-4} \, \mathrm{T} = 0.314 \, \mathrm{mT}
$$

Thus, the magnetic field at the center of the coil is approximately 0.314 millitesla.

Implications of the Magnetic Field

This magnetic field strength influences various phenomena, such as:

- Inducing voltages in nearby conductors (electromagnetic induction)
- Creating magnetic forces on ferromagnetic materials
- Affecting the behavior of nearby magnetic or electronic devices

Magnetic Flux and Its Significance

Understanding Magnetic Flux

Magnetic flux (Φ) quantifies the total magnetic field passing through a given area and is expressed as:

$$ \Phi = B \times A \times \cos \theta $$

where:

- B is the magnetic flux density (Tesla)
- A is the area perpendicular to the magnetic field (square meters)
- θ is the angle between the magnetic field and the normal to the surface

For a coil, the flux through each turn is essential for understanding how electromagnetic induction occurs, especially when the coil or magnetic field varies over time.

Calculating Magnetic Flux for the Coil

Assuming the magnetic field is uniform across the coil's area and perpendicular ($\theta=0$), the flux becomes:

$$\Phi = B \times A$$

The area A of the circular coil:

$$A = \pi R^2 = \pi \times (0.05)^2 \approx 7.854 \times 10^{-3} \, \mathrm{m^2}$$

Thus,

$$\Phi = 0.314 \times 10^{-3} \, \mathrm{T} \times 7.854 \times 10^{-3} \, \mathrm{m^2} \approx 2.47 \times 10^{-6} \, \mathrm{Wb}$$

This flux indicates the total magnetic field passing through one turn of the coil.

Inductance of the Circular Coil

Understanding Inductance

Inductance (L) measures a coil's ability to oppose changes in current, arising from the magnetic flux linkage. It depends on the coil's geometry and the magnetic permeability of the core material.

Calculating the Inductance of a Multi-Turn Circular Coil

For a single circular coil, the approximate inductance can be estimated using the formula:

$$L = \frac{\mu_0 N^2 A}{2 R}$$

where:

- N is the number of turns
- A is the area
- R is the radius

Applying the known values:

$$L = \frac{(4\pi \times 10^{-7}) \times 25 \times 7.854 \times 10^{-3}}{2 \times 0.05}$$

Calculations:

Numerator:

$$
4\pi \times 10^{-7} \times 25 \times 7.854 \times 10^{-3} \approx 4\pi \times 25 \times 7.854 \times 10^{-10}
$$

Simplify:

$$
(4 \times 25) \pi \times 7.854 \times 10^{-10} = 100 \pi \times 7.854 \times 10^{-10}
$$

Calculate:

$$
100 \times 3.1416 \times 7.854 \times 10^{-10} \approx 100 \times 3.1416 \times 7.854 \times 10^{-10}
$$

$$
= 100 \times 24.679 \times 10^{-10} = 2467.9 \times 10^{-10} = 2.468 \times 10^{-7}
$$

Denominator:

$$
2 \times 0.05 = 0.10
$$

Finally,

$$
L = \frac{2.468 \times 10^{-7}}{0.10} = 2.468 \times 10^{-6} \, \mathrm{H}
$$

The inductance of the coil is approximately 2.47 microhenries.

Practical Applications of Circular Coils

Understanding the magnetic properties of circular coils is vital across numerous technological fields.

Electromagnetic Induction Devices

- Transformers rely on coils with specific inductance to transfer energy efficiently.
- Inductors in circuits store magnetic energy, filtering signals or managing current flow.

Electric Motors and Generators

- Coils are fundamental in converting electrical energy into mechanical energy and vice versa.
- The magnetic field generated by coils interacts with magnetic materials to create torque or induce currents.

Magnetic Resonance Imaging (MRI)

- Precision coils generate uniform magnetic fields essential for high-resolution imaging.

Factors Affecting Magnetic Field and Inductance

Several parameters influence the magnetic field strength and inductance of a coil, including:

-

Frequently Asked Questions

What is the magnetic field at the center of a circular coil with five turns and a radius of 5.0 cm carrying a 5.0 A current?

The magnetic field at the center is given by $B = (\mu_0 N I) / (2 R)$. Substituting values: $B = (4\pi \times 10^{-7}$ T·m/A 5 5.0 A) / (2 0.05 m) $\approx 3.14 \times 10^{-4}$ T.

How does increasing the number of turns in the coil affect the magnetic field at the center?

Increasing the number of turns (N) increases the magnetic field proportionally since $B \propto N$, resulting in a stronger magnetic field at the center.

What is the magnetic flux through the coil if the magnetic field at the center is 3.14×10^{-4} T and the coil has an area of 78.5 cm^2?

Flux $\Phi = B \times A = 3.14 \times 10^{-4}$ T $\times 78.5 \times 10^{-4}$ m^2 $\approx 2.46 \times 10^{-5}$ Weber.

If the current in the coil is suddenly reduced to zero, what is the induced emf according to Faraday's

law?

The induced emf is equal to the rate of change of flux. If the current drops instantly, emf = $\Delta\Phi$ / Δt. For an instantaneous change, emf is maximum and depends on how quickly the current changes.

What is the effect of increasing the number of turns on the coil's inductance?

Increasing the number of turns increases the coil's inductance because inductance $L \propto N^2$, resulting in greater opposition to changes in current.

How does the radius of the coil influence the magnetic field at its center?

The magnetic field at the center is inversely proportional to the radius ($B \propto 1/R$), so increasing the radius decreases the magnetic field strength.

What is the approximate magnetic field at the center of the coil if the radius is doubled to 10 cm?

Since $B \propto 1/R$, doubling the radius to 10 cm from 5 cm halves the magnetic field: approximately 1.57×10^{-4} T.

How would the magnetic field change if the current in the coil is increased from 5.0 A to 10.0 A?

The magnetic field would double, since $B \propto I$, resulting in approximately 6.28×10^{-4} T.

What is the significance of the number of turns in determining the coil's magnetic properties?

The number of turns amplifies the magnetic field and flux, making multi-turn coils essential for creating strong magnetic fields in applications like electromagnets and transformers.

In what practical devices are coils like this used, and why?

Such coils are used in electromagnets, inductors, transformers, and inductive sensors because they efficiently generate magnetic fields and store magnetic energy.

Additional Resources

Magnetic Field of a Circular Coil: An In-Depth Analysis

Understanding the magnetic field generated by current-carrying coils is fundamental in electromagnetism, with applications spanning from electric motors to MRI machines. In this comprehensive review, we analyze a specific case: a circular coil of radius 5.0 cm, wound with five turns, carrying a current of 5.0 A. We will explore the principles governing magnetic fields in coils, perform detailed calculations, examine the effects of coil parameters, and consider practical applications and implications.

Introduction to Magnetic Fields in Circular Coils

A circular coil, often called a solenoid in a simplified form, produces a magnetic field when an electric current flows through its turns. The magnetic field's strength and configuration depend on multiple factors, including the coil's geometry, number of turns, current magnitude, and the position where the magnetic field is measured.

Key concepts:
- Biot-Savart Law: Fundamental principle describing how currents produce magnetic fields.
- Ampère's Law: Useful in analyzing magnetic fields in symmetric geometries.
- Magnetic Dipole Moment: The measure of a coil's magnetic effect, proportional to current, turns, and area.

Understanding these, we delve into the specific problem:

> A circular coil of radius 5.0 cm, wound with 5 turns, carries a current of 5.0 A.

Parameters and Initial Setup

Let's first define the known parameters precisely:

Parameter	Value	Notes
Radius of the coil (r)	5.0 cm = 0.05 m	Radius of each turn
Number of turns (N)	5	Total turns in the coil
Current (I)	5.0 A	Current flowing through each turn

Understanding these parameters allows us to analyze the magnetic field at various points, especially along the axis and at the center of the coil.

Magnetic Field at the Center of the Coil

One of the most common calculations involves determining the magnetic field at the coil's geometric center, which provides insight into the coil's magnetic strength and potential use as an electromagnet or magnetic dipole.

Derivation Using Biot-Savart Law

The magnetic field at the center of a single circular loop of radius r carrying current I is given by:

$$
B_{single} = \frac{\mu_0 I}{2r}
$$

where:
- $\mu_0 = 4\pi \times 10^{-7} \, \text{T}\cdot\text{m/A}$ (permeability of free space).

For a coil with N turns, the magnetic field at the center is:

$$
B_{center} = N \times B_{single} = \frac{\mu_0 N I}{2r}
$$

Calculating for our parameters:

$$
B_{center} = \frac{4\pi \times 10^{-7} \times 5 \times 5.0}{2 \times 0.05}
$$

Simplify step-by-step:

1. Multiply numerator:

$$
4\pi \times 10^{-7} \times 5 \times 5.0 = 4\pi \times 10^{-7} \times 25 = 100\pi \times 10^{-7}
$$

2. Divide by denominator:

$$
2 \times 0.05 = 0.1
$$

3. Compute:

$$
B_{center} = \frac{100\pi \times 10^{-7}}{0.1} = 1000 \pi \times 10^{-7}
$$

4. Final calculation:

$$
B_{center} \approx 1000 \times 3.1416 \times 10^{-7} = 3.1416 \times 10^{-4} \, \text{T}
$$

Result:

$$
\boxed{
B_{center} \approx 3.14 \times 10^{-4} \text{ Tesla}
}
$$

\]

This is approximately 0.314 millitesla, representing the magnetic field at the coil's center.

Magnetic Field Along the Axis of the Coil

While the center field is straightforward, understanding how the magnetic field varies along the coil's axis is crucial for applications like magnetic resonance imaging or inductive coupling.

Derivation of the Axial Field

The magnetic field at a point x along the axis of a circular coil (from its center) is given by:

$$
B(x) = \frac{\mu_0 N I r^2}{2 (r^2 + x^2)^{3/2}}
$$

- When $x = 0$, this reduces to the center field calculated above.

Field at the Coil's Center (x=0)

Rearranged, as previously calculated, the axial field at the center:

$$
B_{center} = \frac{\mu_0 N I}{2 r}
$$

Field at a Point Along the Axis

Suppose we want to know the magnetic field at a distance x from the center along the axis:

$$
B(x) = \frac{\mu_0 N I r^2}{2 (r^2 + x^2)^{3/2}}
$$

Example:

- At a point 1 cm (0.01 m) from the center:

$$
x = 0.01\, \text{m}
$$

Calculate:

$$
B(0.01) = \frac{4\pi \times 10^{-7} \times 5 \times 5.0 \times 10^{-2}^2}{2 \times (0.05^2 + 0.01^2)^{3/2}}
$$

- $r^2 = (0.05)^2 = 2.5 \times 10^{-3}$
- $x^2 = (0.01)^2 = 1 \times 10^{-4}$

Sum:

$$
r^2 + x^2 = 2.5 \times 10^{-3} + 1 \times 10^{-4} = 2.6 \times 10^{-3}
$$

Calculate denominator:

$$
(2.6 \times 10^{-3})^{3/2} = (2.6 \times 10^{-3}) \times \sqrt{2.6 \times 10^{-3}} \approx 2.6 \times 10^{-3} \times 0.051 \approx 1.33 \times 10^{-4}
$$

Numerator:

$$
4\pi \times 10^{-7} \times 5 \times 5.0 \times 10^{-2}^2 = 4\pi \times 10^{-7} \times 5 \times 5.0 \times 10^{-2}^2
$$

Note that $5.0 \times 10^{-2} = 0.05$, so:

$$
\text{Numerator} = 4\pi \times 10^{-7} \times 5 \times 0.05^2 = 4\pi \times 10^{-7} \times 5 \times 0.0025
$$

Calculate:

$$
4\pi \times 10^{-7} \times 5 \times 0.0025 = 4\pi \times 10^{-7} \times 0.0125 \approx 4 \times 3.1416 \times 10^{-7} \times 0.0125
$$

$$
= 12.566 \times 10^{-7} \times 0.0125 \approx 1.57 \times 10^{-8}
$$

Finally:

$$
B(0.01) \approx \frac{1.57 \times 10^{-8}}{2 \times 1.33 \times 10^{-4}} = \frac{1.57 \times 10^{-8}}{2.66 \times 10^{-4}} \approx 5.9 \times 10^{-5} \, \text{T}
$$

This is about 0.059 millitesla, illustrating how the magnetic field diminishes with distance from the center.

Effects of Increasing Turns and Current

The magnetic field's strength scales directly with the number of turns N and the current I:

- Increasing N: Since $B \propto N$, doubling the number of turns doubles the magnetic field.
- Increasing I: Similarly, $B \propto I$, so higher current yields a stronger magnetic field.

Practical implications:
- To amplify the magnetic field, one can increase turns or current, but with considerations:
- Higher current may lead to greater resistive heating.
- More turns increase coil resistance and size.

Impact of Coil Radius on Magnetic Field

The radius r

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