

A Closely Wound, Circular Coil With Radius 2.70 Cm Has 800 Turns. Part A What Must The Current In The Coil

A Closely Wound, Circular Coil With Radius 2.70 Cm Has 800 Turns. Part A: What Must The Current In The Coil?

In the realm of electromagnetism and electrical engineering, understanding the relationship between current, magnetic field, and coil parameters is fundamental. A common scenario involves analyzing a tightly wound circular coil—often called a solenoid or a coil—and determining the current required to produce a specific magnetic field or fulfill a particular purpose. In this article, we delve into the specifics of a closely wound circular coil with a radius of 2.70 cm and 800 turns, aiming to calculate the current needed in the coil under certain conditions. This exploration not only highlights the core principles of electromagnetism but also offers practical insights into designing electromagnetic devices such as electromagnets, transformers, and inductors.

Understanding the Basics of Circular Coils and Magnetic Fields

The Magnetic Field of a Circular Coil

A circular coil, when current flows through it, generates a magnetic field similar to that of a bar magnet. The magnetic field at the center of the coil can be approximated using the Biot-Savart Law, which relates the magnetic field to the current and geometry of the current-carrying conductor.

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

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

where:

- B is the magnetic flux density at the center,
- μ_0 is the permeability of free space ($4\pi \times 10^{-7} \text{ T} \cdot \text{m/A}$),
- I is the current in the coil,
- R is the radius of the coil.

When multiple turns are involved, the magnetic field scales linearly with the number of turns:

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

where:

- N is the total number of turns in the coil.

This formula assumes the coil is tightly wound, with the turns closely packed, and that the magnetic field is measured at the coil's center along its axis.

Relevance of Coil Parameters

The key parameters influencing the magnetic field in the coil are:

- Number of turns (N): The greater the number of turns, the stronger the magnetic field for a given current.
- Radius (R): A larger radius results in a weaker magnetic field since the field strength is inversely proportional to the radius.
- Current (I): The current directly influences the magnetic field's magnitude; higher current produces a stronger magnetic field.

Given these relationships, the primary goal in Part A is to determine the current I required to produce a specified magnetic field or fulfill a particular magnetic requirement, based on the given parameters.

Given Data and Assumptions

Let's restate the key data:

- Radius of the coil, $R = 2.70 \text{ cm} = 0.0270 \text{ m}$,
- Number of turns, $N = 800$,
- The specific magnetic field or flux density needed is not explicitly provided in the problem statement, but typically, the task involves calculating the current for a given magnetic field strength or for a particular application.

Assuming the problem asks: "What current is necessary to produce a magnetic field of a certain magnitude at the center of the coil?", we proceed with this general approach.

Clarifying the Goal

For the purpose of this analysis, let's consider a common scenario:

- The magnetic flux density B at the center of the coil is specified or needs to be calculated.
- The goal: Find the current I required to generate this B .

Suppose the target magnetic flux density B_{target} is provided or can be deduced.

Note: If the exact magnetic flux density value is not provided, the calculation can be expressed in terms of B_{target} , allowing you to substitute the desired value later.

Calculating the Current in the Coil

Using the Magnetic Field Formula

The fundamental formula relating the magnetic field at the center of a tightly wound circular coil is:

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

Rearranged to solve for I :

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

where:

- I is the current in amperes,
- R is the radius of the coil,
- N is the total number of turns,
- B is the magnetic flux density at the center,
- $\mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m/A}$.

Step-by-Step Calculation

Suppose the target magnetic flux density at the coil's center is $B_{\text{target}} = 1 \text{ mT}$ (which is a common value in many electromagnetic applications). Plugging into the formula:

$$I = \frac{2 \times 0.0270 \text{ m} \times 1 \times 10^{-3} \text{ T}}{4\pi \times 10^{-7} \text{ T} \cdot \text{m/A} \times 800}$$

Calculating numerator:

$$2 \times 0.0270 \times 1 \times 10^{-3} = 5.4 \times 10^{-5}$$

Calculating denominator:

$$\begin{aligned} 4\pi \times 10^{-7} \times 800 &\approx 4 \times 3.1416 \times 10^{-7} \times 800 \\ &\approx 12.5664 \times 10^{-7} \times 800 \\ &\approx 12.5664 \times 8 \times 10^{-5} \\ &\approx 100.5312 \times 10^{-5} \\ &\approx 1.0053 \times 10^{-3} \end{aligned}$$

Finally, calculating I :

$$I = \frac{5.4 \times 10^{-5}}{1.0053 \times 10^{-3}} \approx 0.0537 \text{ A}$$

or approximately 53.7 mA.

Generalized Formula and Flexibility

The formula allows for flexible substitution of the desired magnetic flux density (B) . For different applications requiring a stronger or weaker magnetic field, simply replace (B) with the target value.

Practical Considerations

- Resistive heating: Higher currents increase the coil's temperature. Adequate wire gauge and cooling are essential.
- Core material: If the coil is wound around a magnetic core, the magnetic field strength can be significantly enhanced, reducing the required current.
- Precision: Real-world factors like coil spacing, wire resistance, and external magnetic influences can affect the actual current needed.

Additional Factors Involving Coil Design

Impact of Coil Geometry and Material

While the calculation above assumes an ideal coil in free space, practical scenarios consider:

- Core materials: Ferromagnetic cores (iron or ferrite) amplify magnetic fields, allowing for lower currents.
- Wire resistance: Resistance causes energy loss; selecting thicker wire reduces resistance but increases size and cost.
- Cooling methods: Adequate cooling prevents overheating during operation at higher currents.

Design Optimization

Designing an efficient coil involves balancing:

- Desired magnetic flux density,
- Current limitations,
- Power consumption,
- Physical size constraints,
- Cost.

By understanding the relationships between these parameters, engineers can optimize coil design for specific applications such as electromagnet cranes, inductors in circuits, or magnetic resonance imaging (MRI) devices.

Summary: Key Takeaways

- The magnetic field at the center of a closely wound circular coil is directly proportional to the number of turns and the current.
- The fundamental relationship is given by $B = \frac{\mu_0 N I}{2 R}$.
- To find the current I , rearranged as $I = \frac{2 R B}{\mu_0 N}$.
- The calculation depends on the target magnetic flux density; once specified, the current can be precisely determined.
- Practical considerations include coil resistance, core material, and heat dissipation.

Conclusion

Calculating the current required in a closely wound circular coil with given parameters is straightforward once the target magnetic flux density or field strength is known. Using the fundamental electromagnetism relationship, engineers and physicists can design coils tailored to their specific needs, whether for scientific experiments, industrial applications, or electronic devices. The key is to understand the interplay between coil geometry, number of turns, current, and magnetic field, ensuring safe, efficient, and effective operation.

By mastering these principles, you can confidently approach coil design challenges and optimize electromagnetic systems for a variety of technological innovations.

Frequently Asked Questions

What is the formula to calculate the magnetic field at the center of a closely wound circular coil?

The magnetic field at the center of a circular coil is given by $B = (\mu_0 N I) / (2 R)$, where μ_0 is the permeability of free space, N is the number of turns, I is the current, and R is the radius of the coil.

Given a coil with 800 turns and a radius of 2.70 cm, how do you determine the current needed to produce a specific magnetic field?

Rearranged from the magnetic field formula: $I = (2 R B) / (\mu_0 N)$. You need the desired magnetic field B to compute the current I .

What is the significance of the coil being 'closely wound' in calculating magnetic field strength?

A closely wound coil ensures that the turns are tightly packed, making the magnetic field calculations

more accurate by assuming the turns are effectively at the same point, mimicking a solenoid.

How do the number of turns (N) in a coil affect the magnetic field at its center?

The magnetic field is directly proportional to the number of turns; increasing N increases the magnetic field strength for a given current.

If the coil's radius is 2.70 cm and there are 800 turns, what is the magnetic field at the center when a current of 1 A passes through?

Using $B = (\mu_0 N I) / (2 R)$, with $\mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$, $N=800$, $I=1 \text{ A}$, $R=0.027 \text{ m}$, $B \approx (4\pi \times 10^{-7} 800 1) / (2 0.027) \approx 1.86 \times 10^{-2} \text{ T}$.

What is the importance of converting the coil radius from centimeters to meters in calculations?

Converting centimeters to meters ensures consistency with SI units, which is essential for accurate calculation of magnetic fields and currents in physics formulas.

How would increasing the number of turns affect the current required to produce a specific magnetic field?

Increasing the number of turns reduces the required current to produce the same magnetic field, since the field strength depends on the product $N I$.

What safety considerations should be taken into account when running current through a closely wound coil?

Ensure the coil is properly insulated, avoid overheating by limiting current, and use appropriate safety devices to prevent electrical shocks or damage due to excessive current.

Additional Resources

A Closely Wound, Circular Coil With Radius 2.70 cm Has 800 Turns: Part A — What Must The Current In The Coil?

Introduction

In the realm of electromagnetism, understanding how current and coil parameters influence magnetic fields is fundamental. The question of determining the current in a closely wound circular coil with specific dimensions and turns is a classic problem that bridges theory with practical applications. This detailed exploration aims to dissect the problem comprehensively, covering the physics principles

involved, relevant formulas, step-by-step calculations, and implications of the results.

Understanding the Problem Statement

The core data provided are:

- Radius of the coil (r): 2.70 cm
- Number of turns (N): 800
- Nature of the coil: Closely wound circular coil
- Part A query: "What must the current in the coil be?"

While the problem does not explicitly specify the magnetic field strength or the specific purpose of the coil, such questions typically relate to generating a certain magnetic field or understanding the coil's magnetic properties under given conditions.

Fundamental Concepts and Principles

To solve this problem, several key physics concepts come into play:

1. Magnetic Field of a Circular Coil

A circular coil behaves as a magnetic dipole when current flows through it. The magnetic field along its central axis is given by:

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

where:

- B is the magnetic field at a point along the axis,
- μ_0 is the permeability of free space ($4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$),
- N is the number of turns,
- I is the current,
- r is the radius of the coil,
- x is the distance from the coil along its axis.

For the magnetic field at the center of the coil ($x = 0$), this simplifies to:

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

This is often the starting point for calculations involving coils.

2. Magnetic Field at the Center of the Coil

Given the parameters, if the problem specifies a certain magnetic field strength or requires the current needed to produce a specific magnetic field, the above formula becomes instrumental.

3. Coil Geometry and Turn Density

- The coil is "closely wound," implying tight packing without significant gaps.
- The number of turns (N) and radius (r) directly influence the magnetic field strength.

Assumptions and Additional Data

Since the question asks, "What must the current in the coil be?" without specifying the target magnetic field, we'll consider typical scenarios:

- Scenario 1: The coil is designed to produce a magnetic field of a specific magnitude (say, 1 mT at the center).
- Scenario 2: The question is a generic inquiry to understand the relationship between current, turns, and magnetic field.

Given the absence of explicit target field strength, we'll focus on the general formula and how to compute the current for a specified magnetic field.

Step-by-Step Calculation Approach

Step 1: Convert Units Appropriately

- Radius $(r = 2.70\text{ cm} = 0.027\text{ m})$
- Number of turns $(N = 800)$

Step 2: Establish the Magnetic Field Requirement

Suppose, for illustrative purposes, you want the magnetic field at the center of the coil to be 1 millitesla ($1\text{ mT} = 10^{-3}\text{ T}$).

Step 3: Use the Magnetic Field Formula at the Center

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

Rearranged to solve for (I) :

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

Substituting known values:

$$I = \frac{2 \times 0.027 \text{ m} \times 10^{-3} \text{ T}}{4\pi \times 10^{-7} \text{ T}\cdot\text{m/A} \times 800}$$

Detailed Calculation

Calculating numerator:

$$2 \times 0.027 \text{ m} \times 10^{-3} \text{ T} = 5.4 \times 10^{-5} \text{ T}\cdot\text{m}$$

Calculating denominator:

$$4\pi \times 10^{-7} \text{ T}\cdot\text{m/A} \times 800 \approx 4 \times 3.1416 \times 10^{-7} \times 800$$

$$\approx 12.5664 \times 10^{-7} \times 800 = 12.5664 \times 8 \times 10^{-5} = 100.5312 \times 10^{-5} = 1.005312 \times 10^{-3}$$

Finally, compute (I) :

$$I = \frac{5.4 \times 10^{-5}}{1.005312 \times 10^{-3}} \approx 0.0537 \text{ A}$$

Result:

$$\boxed{I \approx 0.054 \text{ A} \quad \text{or} \quad 54 \text{ mA}}$$

This indicates that to generate a magnetic field of 1 mT at the center of this coil, approximately 54 milliamps of current are required.

General Relationship and Implications

The above calculation highlights several key points:

- **Linear Relationship:** The magnetic field at the center is directly proportional to both the number of turns (N) and the current (I) . Doubling (N) or (I) doubles the magnetic field.

- Design Flexibility: For a target magnetic field, increasing the number of turns or the current can achieve the goal, but practical considerations like wire heating and coil size limit these parameters.
- Specificity of Applications: Different applications require different magnetic field strengths, affecting the necessary current.

Practical Considerations

1. Heat Dissipation and Resistance

- Wire Resistance: As current increases, resistive heating becomes significant.
- Material Choice: Copper is standard due to its low resistivity.
- Wire Gauge: Thicker wire reduces resistance but increases coil size.

2. Mechanical and Thermal Constraints

- Physical Durability: The coil must withstand thermal expansion and mechanical stress.
- Insulation: Proper insulation prevents short circuits, especially at higher currents.

3. Power Supply Limitations

- The power supply must be capable of delivering the required current safely.
- Power dissipation: $(P = I^2 R)$, where (R) is the total resistance.

Advanced Topics and Variations

1. Magnetic Field at Arbitrary Points

- For points off-center or along the axis, the magnetic field calculation becomes more complex.
- Numerical methods or finite element analysis can be employed for precise modeling.

2. Effect of Coil Thickness and Winding Tightness

- The assumption of a single radius works well for thin coils.
- For thick coils with multiple layers, the field calculation must account for the coil's geometry.

3. Inductive Effects and Self-Resonance

- High currents induce significant inductance.
- Time-varying currents lead to electromagnetic oscillations and potential resonance issues.

Real-World Applications and Significance

Understanding the current requirements for specific coil parameters is critical in various fields:

- Electromagnets: Used in MRI machines, particle accelerators, and industrial lifting magnets.

- Transformers and Inductors: Design depends on current and coil parameters.
- Wireless Power Transfer: Coil design influences efficiency and power levels.
- Educational Demonstrations: Illustrating magnetic fields and electromagnetic induction.

Summary and Final Insights

- The key to determining the current in a closely wound circular coil lies in the fundamental magnetic field formula at the coil's center.
- For a coil with a radius of 2.70 cm and 800 turns, generating a magnetic field of 1 mT requires approximately 54 milliamps.
- Adjustments to coil parameters (number of turns, radius, wire gauge) directly influence the current needed for a given magnetic field.
- Practical implementation demands attention to heat dissipation, material properties, and power supply capabilities.

Closing Remarks

The exploration of the current required in a circular coil encapsulates core principles of electromagnetism and electrical engineering. Whether for academic purposes, practical device design, or research applications, understanding this relationship enables precise control over magnetic field generation. As technology advances, such foundational knowledge remains vital, guiding innovations across multiple domains.

Note: If the problem provides a specific magnetic field value or additional parameters in Part B, the calculations can be tailored accordingly.

A Closely Wound Circular Coil With Radius 2.70 Cm Has 800 Turns Part A What Must The Current In The Coil

A Closely Wound Circular Coil With Radius 2.70 Cm Has 800 Turns Part A What Must The Current In The Coil

Related Articles

- [A Circular Coil Of Wire Has 300 Turns And An Average Radius Of 2.00 Cm. The Coil Is Placed At A 60 Angle](#)
- [A Nurse Assesses A Client's Pupils For The Reaction To Light And Observes That The Pupils Are Of Unequal](#)
- [Aaron Drew The Figure Below For A School Art Project. What Is The Total Area Of The Figure. Use The Drop](#)

[Back to Home](#)