

Q/C A 40.0-mA Current Is Carried By A Uniformly Wound Air-core Solenoid With 450 Turns, A 15.0-mm Diameter,

Q/C A 40.0-mA Current Is Carried By A Uniformly Wound Air-core Solenoid With 450 Turns, A 15.0-mm Diameter, and understanding the fundamental electromagnetic principles involved can provide valuable insights into the behavior of such coils in various applications. This article explores the key parameters, calculations, and practical considerations associated with this specific solenoid, offering an in-depth overview suitable for students, engineers, and enthusiasts interested in electromagnetism and coil design.

Introduction to Air-core Solenoids

A solenoid is a long wire wound in the form of a helix that produces a magnetic field when an electric current passes through it. When the solenoid is air-core, it lacks a magnetic core material, which means its magnetic properties depend solely on the current and geometry of the coil. These devices are widely used in applications such as inductors, electromagnets, radio antennas, and sensors.

Understanding the behavior of air-core solenoids requires analyzing parameters like the number of turns, current, diameter, and length of the coil. In our case, the key data points are:

- Current (I): 40.0 mA (milliamperes)
- Number of turns (N): 450
- Diameter (D): 15.0 mm (millimeters)

This information allows us to calculate important characteristics such as magnetic field strength, inductance, magnetic flux, and related electromagnetic properties.

Fundamental Parameters and Definitions

Before delving into calculations, let's clarify some fundamental concepts:

Current (I)

The current passing through the coil, in this case, is 40.0 mA, which is 0.040 A. This current produces a magnetic field within and around the solenoid.

Number of Turns (N)

The total number of wire turns in the coil is 450. More turns generally lead to a stronger magnetic field and higher inductance.

Diameter (D)

The diameter of the coil is 15.0 mm, or 0.015 meters. This dimension influences the magnetic field distribution and the coil's inductance.

Cross-sectional Area (A)

The area of the coil's cross-section is important for calculating magnetic flux:

$$A = \pi \left(\frac{D}{2}\right)^2$$

Calculating the Cross-sectional Area of the Coil

Given the diameter $D = 15.0 \text{ mm} = 0.015 \text{ meters}$,

$$A = \pi \left(\frac{0.015}{2}\right)^2 = \pi \times (0.0075)^2 \approx 3.1416 \times 5.625 \times 10^{-5} \text{ m}^2 \approx 1.767 \times 10^{-4} \text{ m}^2$$

This area represents the cross-sectional surface through which the magnetic flux passes.

Estimating the Magnetic Field Inside the Solenoid

One of the primary characteristics of a solenoid is its magnetic field (B). For an ideal solenoid with a uniform magnetic field, the field inside can be approximated by:

$$B = \mu_0 \times \frac{N}{L} \times I$$

Where:

- μ_0 is the permeability of free space ($4\pi \times 10^{-7} \text{ H/m}$)
- L is the length of the solenoid in meters
- N is the number of turns

- I is the current in amperes

However, the length of the coil is not provided directly. Assuming the coil is tightly wound with minimal spacing, the length L can be estimated:

$$L \approx \text{Number of turns} \times \text{winding pitch}$$

For simplicity, if the wire is wound tightly without gaps, the total length of wire can be approximated, and the length of the coil can be calculated using the wire length per turn. But since the length isn't specified, a common approach is to assume a typical coil length proportional to the number of turns and diameter.

Estimating coil length:

If each turn is approximately the circumference of the coil, then:

$$\text{Circumference} = \pi D = 3.1416 \times 0.015 \text{ m} \approx 0.0471 \text{ m}$$

Total length of wire:

$$L_{\text{wire}} = N \times \text{circumference} = 450 \times 0.0471 \text{ m} \approx 21.2 \text{ m}$$

Assuming the coil is tightly wound, the length of the coil (L) can be roughly approximated by the number of turns times the wire thickness or the coil's physical length. Alternatively, if the coil is wound with a pitch equal to the wire diameter, the length can be estimated:

$$L \approx \frac{\text{Total wire length}}{N} \approx \frac{21.2 \text{ m}}{450} \approx 0.047 \text{ m}$$

which matches the circumference, indicating a coil length roughly equal to the diameter, i.e., about 15 mm.

Given the approximate nature, we proceed with an estimated length of 15 mm (0.015 meters).

Now, calculating the magnetic field:

$$B = \mu_0 \times \frac{N}{L} \times I$$

\]

\[

$$B = 4\pi \times 10^{-7} \times \frac{450}{0.015} \times 0.040$$

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\[

$$B \approx 4\pi \times 10^{-7} \times 30,000 \times 0.040$$

\]

\[

$$B \approx (1.2566 \times 10^{-6}) \times 30,000 \times 0.040$$

\]

\[

$$B \approx 1.2566 \times 10^{-6} \times 1,200$$

\]

\[

$$B \approx 1.5079 \times 10^{-3} \text{ T}$$

\]

or approximately 1.51 mT (millitesla).

This magnetic flux density is typical for small laboratory coils and demonstrates the coil's capability to generate a measurable magnetic field with modest current.

Calculating the Inductance of the Solenoid

Inductance (L) measures the coil's ability to oppose changes in current. For a long, air-core solenoid:

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

\]

Using the previously estimated parameters:

\[

$$L = 4\pi \times 10^{-7} \times 450^2 \times \frac{1.767 \times 10^{-4}}{0.015}$$

\]

Calculating step-by-step:

\[

$$N^2 = 450^2 = 202,500$$

\]

$$L = 4\pi \times 10^{-7} \times 202,500 \times \frac{1.767 \times 10^{-4}}{0.015}$$

$$L \approx 1.2566 \times 10^{-6} \times 202,500 \times 11.78 \quad (\text{since } \frac{1.767 \times 10^{-4}}{0.015} \approx 0.01178)$$

$$L \approx 1.2566 \times 10^{-6} \times 2,386,245$$

$$L \approx 2.996 \text{ H}$$

This result suggests an inductance of approximately 3 Henrys, which is quite high for such a small coil—indicating that the approximation may need refinement for real-world applications. Typically, small coils have inductances in the micro- to millihenry range. The discrepancy arises from the rough estimations and assumptions. For practical purposes, the inductance is likely in the order of a few millihenries, depending on coil dimensions and winding.

Magnetic Flux and Magnetic Force

Magnetic flux (Φ) through the coil is given by:

$$\Phi = B \times A$$

Using the earlier calculated ($B \approx 1.51 \text{ mT}$):

$$\Phi = 1.5079 \times 10^{-3} \times 1.767 \times 10^{-4} \approx 2.666 \times 10^{-7} \text{ Wb}$$

This flux indicates the total magnetic flux passing through the coil's cross-section at the specified current.

The magnetic force exerted by the coil, especially in electromagnetic applications, depends on the magnetic field gradient and the coil's environment but generally requires more detailed context.

Practical Applications and Considerations

Understanding the parameters of this coil highlights its potential uses:

- **Electromagnetic Inductors:** The coil's induct

Frequently Asked Questions

What is the magnetic field strength inside a uniformly wound air-core solenoid carrying a 40.0-mA current with 450 turns and a diameter of 15.0 mm?

The magnetic field strength B inside the solenoid can be calculated using $B = \mu_0 (N/L) I$. Assuming a length L (not provided), the field is proportional to the current and the number of turns per unit length. With the given data, the specific B value depends on the solenoid length, but the formula remains fundamental.

How does increasing the number of turns in the solenoid affect the magnetic field for a fixed current?

Increasing the number of turns (N) enhances the magnetic field proportionally, since $B \propto N$, assuming the length remains constant. More turns concentrate the magnetic flux, resulting in a stronger field.

What is the significance of the air-core in the design of this solenoid?

An air-core eliminates magnetic material influences, ensuring a linear relationship between current and magnetic field. This makes the solenoid ideal for precise magnetic field applications, free from hysteresis or saturation effects associated with ferromagnetic cores.

How can the magnetic field be estimated using the given diameter and current?

The magnetic field inside a solenoid is primarily determined by the current and the number of turns per unit length, not directly by the diameter. However, the diameter helps determine the coil's dimensions and the solenoid's length, which influences the field calculation if the length is known.

What are the safety considerations when operating a solenoid with a 40.0-mA current?

While 40.0 mA is a relatively low current, safety precautions include ensuring proper insulation, avoiding short circuits, and preventing accidental contact with energized components to prevent electric shock or damage to the device.

How does the diameter of 15.0 mm impact the inductance and magnetic field uniformity of the solenoid?

A diameter of 15.0 mm defines the coil's cross-sectional area, affecting the magnetic flux density and inductance. A larger diameter may reduce the magnetic field strength near the center, but generally, the uniformity depends more on the coil's length and winding density than on the diameter alone.

Additional Resources

Q/C A 40.0-mA Current Is Carried By A Uniformly Wound Air-core Solenoid With 450 Turns, A 15.0-mm Diameter

In the realm of electromagnetism and electrical engineering, understanding the magnetic properties of solenoids is fundamental for designing inductors, transformers, and various electromagnetic devices. Today, we delve into a specific scenario: a uniformly wound air-core solenoid carrying a current of 40.0 milliamperes (mA), with 450 turns and a diameter of 15.0 millimeters. This example not only highlights key principles of magnetic fields in solenoids but also serves as a practical reference for engineers and students alike.

Fundamentals of Solenoid Magnetic Fields

Before exploring the specific parameters of this solenoid, it's essential to understand the underlying physics governing its magnetic field.

What Is a Solenoid?

A solenoid is a long coil of wire wound in a helix, often used to generate controlled magnetic fields when an electric current passes through it. When current flows through the wire, it produces a magnetic field inside and around the coil, following Ampère's circuital law.

Air-core vs. Iron-core Solenoids

This particular solenoid features an air core, meaning it does not contain ferromagnetic materials like iron. As such, its magnetic field strength depends solely on the current, number of turns, and geometry, making it ideal for precise electromagnetic applications where minimal hysteresis or saturation effects are desired.

Calculating the Magnetic Field of the Solenoid

The magnetic field inside an ideal solenoid can be approximated using a fundamental formula derived from Ampère's law:

$$B = \mu_0 \times \frac{N}{L} \times I$$

where:

- B is the magnetic flux density (Tesla, T),
- μ_0 is the permeability of free space ($4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$),
- N is the total number of turns (here, 450),
- L is the length of the solenoid (meters),
- I is the current passing through the wire (Amperes).

Given the parameters, our goal is to determine the magnetic field at the center of this solenoid.

Determining the Length of the Solenoid

The length (L) can be estimated from the number of turns and the winding pitch, but lacking explicit pitch data, a common approximation assumes tightly wound coils with a uniform winding. The total length can be inferred from the diameter and the number of turns if the wire is wound closely without gaps.

Given:

- Diameter $(d = 15.0\text{ mm} = 0.015\text{ m})$,
- Number of turns $(N = 450)$.

Assuming each turn is wound tightly around a cylinder, the length (L) can be approximated as:

$$L \approx \text{number of turns} \times \text{winding pitch}$$

If we assume the wire is wound with minimal spacing, the pitch roughly equals the diameter of the wire. For simplicity and illustrative purposes, let's assume the coil's length is approximately 45 mm (a typical value for such a coil), but to be more precise, we can relate the length to the number of turns and the coil's geometrical parameters.

Alternatively, if the coil is wound so that the total number of turns is spread uniformly along a length (L) , then:

$$L = N \times p$$

where (p) is the pitch per turn. Without explicit data, we approximate the coil length as:

$$L \approx 0.045\text{ m}$$

This is consistent with typical small solenoid dimensions.

Calculating the Magnetic Field (B)

Given:

- $(N = 450)$,
- $(I = 40.0\text{ mA} = 0.040\text{ A})$,
- $(L \approx 0.045\text{ m})$,
- $(\mu_0 = 4\pi \times 10^{-7}\text{ T}\cdot\text{m/A})$.

Applying the formula:

$$B = \mu_0 \frac{NI}{L}$$

$$B = \mu_0 \times \frac{N}{L} \times I$$

$$B = (4\pi \times 10^{-7}) \times \frac{450}{0.045} \times 0.040$$

Calculating step-by-step:

1. $\left(\frac{N}{L} = \frac{450}{0.045} = 10,000 \right)$, turns/m ,
2. $\left(\mu_0 \times \frac{N}{L} = 4\pi \times 10^{-7} \times 10,000 = 4\pi \times 10^{-3} \right)$,
3. $\left(4\pi \times 10^{-3} \approx 0.01257 \right)$,
4. Multiply by current:

$$B = 0.01257 \times 0.040 = 5.028 \times 10^{-4} \text{ T}$$

or approximately:

$$B \approx 0.503 \text{ mT}$$

This means the magnetic flux density at the center of this coil is roughly 0.5 millitesla under these assumptions.

Implications and Applications of the Magnetic Field

Understanding the magnitude of this magnetic field has practical implications across various fields.

Electromagnetic Devices and Sensors

The calculated magnetic field strength is relevant for designing sensors like magnetic field detectors, inductors, and electromagnetic actuators. For instance, in magnetic resonance imaging (MRI) or sensitive magnetometers, knowing the precise magnetic field is crucial for calibration.

Educational Demonstrations

Small coils like this are often used in educational settings to demonstrate electromagnetic induction, Faraday's law, and the relationship between current, turns, and magnetic field strength.

Design Considerations in Engineering

Engineers designing inductors or coils for wireless charging, RF applications, or magnetic shielding must consider factors such as:

- The number of turns,
- Coil dimensions,
- Current levels,
- Core material properties (air vs. ferromagnetic).

These parameters influence the field strength, inductance, and overall efficiency of the device.

Further Factors Influencing the Magnetic Field

While the above calculation provides a baseline estimate, several other factors can influence the actual magnetic field in a real-world setup.

Wire Thickness and Winding Pitch

The diameter of the wire affects how tightly it can be wound and the overall length of the coil. Thicker wire results in fewer turns per unit length, reducing the total number of turns for a given length.

Core Material and Permeability

Although this coil features an air core, inserting a ferromagnetic core like iron can significantly amplify the magnetic field. The relative permeability (μ_r) of the core material enhances B proportionally.

Current Limitations and Heat Dissipation

Even at low currents like 40 mA, resistive heating can occur. Proper insulation and cooling mechanisms are essential for maintaining coil integrity during operation.

Field Uniformity and Edge Effects

The magnetic field strength is most uniform at the coil's center. Near the edges, the field lines diverge, and the actual magnetic flux density may vary.

Conclusion: From Theory to Practice

This exploration of a 40.0-mA current in a 450-turn, 15.0-mm diameter air-core solenoid illustrates fundamental electromagnetic principles with practical relevance. By accounting for geometric parameters and current, engineers can predict the magnetic flux density with reasonable accuracy, enabling optimized device design and application.

While the calculations involve approximations, they serve as a vital starting point for understanding how small coils generate magnetic fields and how these fields can be manipulated for various technological applications. As electromagnetic technology continues to evolve, such foundational insights remain pivotal in advancing innovations across electronics, communications, and medical instrumentation.

In essence, this example underscores the profound connection between simple physical laws and their real-world manifestations—an enduring testament to the elegance of electromagnetism in engineering.

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