What Is The Maximum Torque On A 150-turn Square Loop Of Wire 18.0 Cm On A Side That Carries A 55.1 A

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Understanding electromagnetic torque is essential in the fields of physics and electrical engineering, especially when designing devices like electric motors, transformers, and magnetic sensors. In this article, we will explore how to determine the maximum torque exerted on a specific configuration: a 150-turn square loop of wire, each side measuring 18.0 centimeters, carrying a current of 55.1 amperes. This case provides a practical example of applying fundamental magnetic principles to real-world scenarios.

Fundamentals of Magnetic Torque on a Current Loop

Magnetic Dipole Moment

The magnetic dipole moment ($\vec{\mu}$) is a vector quantity that characterizes the magnetic strength and orientation of a current-carrying loop. It is given by:

$$
\vec{\mu} = N \times I \times \vec{A}
$$

where:

- N = number of turns in the loop
- I = current in the wire (amperes)
- $\vec{A}$ = area vector of the loop (m²), perpendicular to the plane of the loop

For a square loop, the magnitude of the magnetic dipole moment is:

$$
\mu = N \times I \times A
$$

since the area vector's magnitude is just the area, and its direction depends on the right-hand rule.

Torque on a Magnetic Dipole in a Magnetic Field

When placed in an external magnetic field (B), a current loop experiences a torque (τ) that tends to align its magnetic dipole moment with the magnetic field:

$$
\tau = \mu B \sin \theta
$$

where:
- θ = angle between $\vec{\mu}$ and $\vec{B}$

The maximum torque occurs when $\sin \theta = 1$, i.e., when the magnetic moment is perpendicular to the magnetic field:

$$
\tau_{max} = \mu B
$$

In many practical situations, the magnetic field is either known or can be controlled, and understanding the maximum torque involves calculating μ and knowing the magnetic field B.

Calculating the Magnetic Dipole Moment for the Square Loop

Step 1: Determine the Area of the Square Loop

Given that each side of the square is 18.0 cm, convert this to meters:

$$
\text{Side length} = 18.0\, \text{cm} = 0.180\, \text{m}
$$

The area A of the square is:

$$
A = (\text{side})^2 = (0.180\, \text{m})^2 = 0.0324\, \text{m}^2
$$

Step 2: Calculate the Magnetic Dipole Moment (μ)

Using the formula:

$$
\mu = N \times I \times A
$$

where:

- $N = 150$ turns

- $I = 55.1\, \text{A}$
- $A = 0.0324\, \text{m}^2$

we get:

$$
\mu = 150 \times 55.1\, \text{A} \times 0.0324\, \text{m}^2
$$

Calculating step-by-step:

$$
150 \times 55.1 = 8,265
$$

Then:

$$
\mu = 8,265 \times 0.0324 \approx 267.94\, \text{A} \cdot \text{m}^2
$$

Thus, the magnetic dipole moment magnitude is approximately 268 $A \cdot m^2$.

Determining the Maximum Torque

Requirement of Magnetic Field (B)

To compute the maximum torque, the magnetic field B at the loop's location must be known. The maximum torque is:

$$
\tau_{max} = \mu B
$$

Without a specified magnetic field, the best we can do is express the maximum torque in terms of B.

Suppose the loop is in a known magnetic field B, then:

$$
\boxed{
\text{Maximum Torque} = 268\, \text{A·m}^2 \times B
}
$$

where B is in teslas (T).

Example: Calculating Torque in a Typical Magnetic Field

If, for example, the magnetic field is 0.1 T (a common value for laboratory magnets), then:

$$
\tau_{max} = 268 \times 0.1 = 26.8\, \text{N·m}
$$

This indicates the maximum torque the loop can experience in such a magnetic field.

Additional Considerations

Orientation and Mechanical Constraints

The maximum torque is achieved when the magnetic dipole moment is perpendicular to the magnetic field. In practical applications, the orientation of the loop relative to the magnetic field can be controlled or varies, impacting the torque experienced at any instant.

Impacts of Magnetic Field Variability

In real-world scenarios, magnetic fields may not be uniform or constant. Variations can affect the torque magnitude, especially in dynamic systems such as electric motors or magnetic resonance devices.

Material and Structural Factors

The physical integrity of the wire and the loop's construction can influence how effectively torque translates into mechanical work. High current densities and magnetic forces can induce stress, so material selection and engineering designs are crucial.

Applications of Calculated Torque

Electric Motors and Actuators

Understanding the maximum torque on a current-carrying loop helps in designing efficient electric motors, where torque determines the mechanical output power.

Magnetic Sensors and Measurement Devices

Precise torque calculations enable the development of sensitive magnetic field sensors, which depend on the torque experienced by a coil or loop within a magnetic environment.

Educational Demonstrations and Experiments

Demonstrating the principles of magnetic torque using loops of wire and magnetic fields provides valuable insights into electromagnetic theory for students and researchers.

Conclusion

Calculating the maximum torque exerted on a current-carrying loop involves understanding the magnetic dipole moment and the external magnetic field. In the case of a 150-turn square loop of wire, each side measuring 18.0 cm and carrying a current of 55.1 A, the magnetic dipole moment is approximately 268 A·m². The maximum torque is then directly proportional to the magnetic field \(B\):

\[
\boxed{
\text{Maximum Torque} = 268\, \text{A·m}^2 \times B
}
\]

This fundamental relationship is instrumental in designing and analyzing electromagnetic systems, from simple experiments to complex industrial machinery. Whether working with static magnetic fields or dynamic environments, understanding these principles enables engineers and scientists to optimize device performance and ensure safety and efficiency.

Keywords: maximum torque, magnetic dipole moment, current loop, electromagnetic torque, square loop, magnetic field, electric motor, physics, electrical engineering

Frequently Asked Questions

What is the formula to calculate the maximum torque on a current-carrying square loop in a magnetic field?

The maximum torque □_max is given by □_max = n I A B, where n is the number of turns, I is the current, A is the area of the loop, and B is the magnetic field strength, multiplied by sin(90°) since the torque is maximized when the plane of the loop is perpendicular to the field.

How do you determine the area of the square loop in this problem?

The area A of the square loop is calculated by squaring the length of one side: A = (0.18 m)^2 = 0.0324 m^2.

What additional information is needed to compute the maximum torque on the loop?

You need to know the magnetic field strength B where the loop is placed, as the torque depends directly on B along with the current, number of turns, and area.

How does the number of turns affect the maximum torque in this scenario?

The maximum torque is directly proportional to the number of turns n; more turns increase the torque proportionally, so a 150-turn loop produces 150 times the torque compared to a single-turn loop under the same conditions.

If the magnetic field strength is known, how do you calculate the maximum torque for this 150-turn loop?

Use the formula □_max = n I A B, substituting n=150, I=55.1 A, A=0.0324 m^2, and the given B value to find the maximum torque.

Why is the maximum torque achieved when the plane of the loop is perpendicular to the magnetic field?

Maximum torque occurs when the angle between the magnetic moment and the magnetic field is 90°, because torque □ = μ × B, where μ is the magnetic dipole moment; sin(□) is maximized at 90°, resulting in maximum torque.

Additional Resources

What Is The Maximum Torque On A 150-turn Square Loop Of Wire 18.0 Cm On A Side That Carries A 55.1 A

Imagine a simple square loop of wire, but not just any loop—this one is composed of 150 turns, each side measuring 18.0 centimeters, carrying a significant current of 55.1 amperes. Such configurations are fundamental in electromagnetism, underpinning devices like electric motors, transformers, and various sensing instruments. Understanding the maximum torque that can be exerted on this loop when placed within a magnetic field is vital for engineers and physicists designing efficient electromagnetic systems. But what exactly governs this torque, and how can we calculate its maximum value? Let’s delve deep into the physics behind this scenario to uncover the answer.

Fundamental Principles: Magnetic Torque on Current Loops

The concept of torque in magnetic systems arises from the interaction between a current-carrying conductor and an external magnetic field. When a current loop is placed within a magnetic field, it experiences a torque that tends to align the plane of the loop perpendicular to the magnetic field lines. The magnitude of this torque depends on several factors, including the current, the shape and size of the loop, the number of turns, and the strength and orientation of the magnetic field.

The fundamental equation for the magnetic torque (τ) on a current loop is:

$$
\tau = \mu \times B \times \sin \theta
$$

where:

- μ is the magnetic moment of the loop,
- B is the magnetic flux density (magnetic field strength),
- θ is the angle between the magnetic moment and the magnetic field.

The magnetic moment μ for a current loop is given by:

$$
\mu = N I A
$$

where:

- N is the number of turns,
- I is the current,
- A is the area of one loop.

The maximum torque occurs when $\sin \theta = 1$, i.e., when the plane of the loop is perpendicular to the magnetic field, making the magnetic moment aligned such that the torque is maximized.

Calculating the Magnetic Moment

Given the parameters:

- Number of turns: $N = 150$
- Current: $I = 55.1\, \text{A}$
- Side length of the square loop: $L = 18.0\, \text{cm} = 0.18\, \text{m}$

The area A of one square loop is:

$$
A = L^2 = (0.18\, \text{m})^2 = 0.0324\, \text{m}^2
$$

The magnetic moment μ thus becomes:

$$
\mu = N \times I \times A = 150 \times 55.1\, \text{A} \times 0.0324\, \text{m}^2
$$

Calculating:

$$
\mu = 150 \times 55.1 \times 0.0324
$$

First, multiply the constants:

- $150 \times 55.1 = 8,265$
- $8,265 \times 0.0324 \approx 268.0$

So, the magnetic moment:

\[
\boxed{
\mu \approx 268.0\, \text{A}\cdot\text{m}^2
}
\]

This magnetic moment is a measure of the strength and orientation of the loop’s magnetic dipole.

The Role of the External Magnetic Field

To determine the maximum torque, we need to consider the magnetic field \(B\) in which the loop is placed. The problem statement, as provided, does not specify \(B\). In many practical cases, the magnetic field strength is known from the context—say, the field produced by a nearby magnet or current-carrying conductor.

Suppose, for the purpose of this calculation, that the magnetic field \(B\) is provided or is a known constant. For illustration, let's assume a typical magnetic field strength such as \(B = 0.50\, \text{T}\) (Tesla), a common field strength in laboratory electromagnet setups.

Computing the Maximum Torque

Since the maximum torque occurs when the sinusoidal factor \(\sin \theta = 1\), the formula simplifies to:

\[
\boxed{
\tau_{\max} = \mu \times B

}

\]

Plugging in our values:

\[

\tau_{\max} = 268.0\, \text{A}\cdot\text{m}^2 \times 0.50\, \text{T}

\]

\[

\tau_{\max} = 134.0\, \text{N}\cdot\text{m}

\]

Interpreting the Result

This value indicates that, under the assumed magnetic field strength, the loop experiences a maximum torque of approximately 134 Newton-meters when oriented optimally. This torque is substantial, reflecting the strong interaction between the high current, multiple turns, and magnetic field.

Factors Influencing the Actual Torque

While the calculation provides a clear theoretical maximum, real-world conditions can influence the actual torque experienced:

- Magnetic Field Variability: The actual magnetic field may vary in strength and direction, affecting the torque.
- Material and Structural Constraints: Mechanical limitations of the wire and supporting structure can influence how much torque can be practically exerted or tolerated.
- Current Limitations: Safety and thermal considerations restrict the maximum current, which in turn

caps the magnetic moment.
- Environmental Factors: External magnetic influences, temperature, and vibrations can alter the system's behavior.

Practical Applications and Significance

Understanding and calculating the maximum torque on such a loop is essential in designing electromagnetic devices. For instance:

- Electric Motors: Torque determines the rotational force and efficiency.
- Magnetic Sensors: Precise torque measurements can be used to infer magnetic field strength.
- Electromagnetic Actuators: Maximal torque estimates guide the design for desired movement or force application.

In laboratory and industrial settings, engineers often optimize parameters—like the number of turns, current, and magnetic field—to achieve the desired torque within safety and material constraints.

Generalized Formula and Considerations

For complex scenarios where the magnetic field is not uniform or varies with position, more sophisticated models and numerical simulations are employed. Nonetheless, the core principles remain:

$$
\boxed{
\text{Maximum Torque} = N I A B
}
$$

when the magnetic moment is perpendicular to the magnetic field.

Final Thoughts

The calculation of the maximum torque on a 150-turn square loop of wire with each side measuring 18.0 cm and carrying 55.1 A illuminates fundamental electromagnetism principles. By leveraging the relationship between current, magnetic moment, and external magnetic field, engineers and physicists can predict the forces at play in many electromagnetic systems. While the actual maximum torque depends on the magnetic field strength—which must be specified or measured—the methodology remains consistent: determine the magnetic moment, identify the magnetic field, and apply the fundamental equations to find the torque.

In practical terms, this understanding enables the design of more efficient motors, sensors, and actuators, pushing forward innovations across various technological domains. Whether in industrial machinery or scientific instrumentation, mastering the interplay of current, magnetic fields, and geometry is key to harnessing the power of electromagnetism effectively.

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