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Understanding the relationship between torque, moment of inertia, and angular acceleration is fundamental in rotational dynamics. When a torque is applied to a rotating object, it causes the object to accelerate angularly, and this acceleration depends on its moment of inertia. In this article, we explore how to determine the angular acceleration of an object with a given moment of inertia when a specific torque is applied. We will analyze the problem step-by-step, provide relevant formulas, and discuss related concepts to deepen your understanding of rotational motion.

Fundamentals of Rotational Dynamics

Before diving into the calculation, it is essential to review some core principles of rotational motion, including key quantities such as torque, moment of inertia, and angular acceleration.

What Is Torque?

Torque, often denoted by τ , is a measure of the force causing an object to rotate about an axis. It is the rotational equivalent of force in linear motion. Torque depends on:

- The magnitude of the applied force.
- The lever arm or the perpendicular distance from the axis of rotation to the point where the force is applied.

The formula for torque is:

$$\tau = r \times F \times \sin \theta$$

where:

- r is the lever arm length.
- F is the magnitude of the applied force.
- θ is the angle between the force vector and the lever arm.

In many practical scenarios, torque is given directly, as in our problem.

Moment of Inertia (I)

Moment of inertia is a scalar value that quantifies an object's resistance to angular

acceleration about a specific axis. It depends on the mass distribution relative to the rotation axis:

- The farther the mass is from the axis, the larger the moment of inertia.
- It is analogous to mass in linear motion.

Mathematically, for discrete masses:

$$I = \sum m_i r_i^2$$

where:

- m_i is the mass of each component.
- r_i is the distance from the axis of rotation.

Angular Acceleration (α)

Angular acceleration is the rate at which the angular velocity changes with time:

$$\alpha = \frac{d\omega}{dt}$$

where ω is the angular velocity.

Relating Torque, Moment of Inertia, and Angular Acceleration

The fundamental equation linking these quantities is:

$$\tau = I \alpha$$

This equation states that the torque applied to an object equals its moment of inertia times its angular acceleration.

Using this relation, if all quantities are known except one, we can solve for the unknown.

Calculating the Angular Acceleration

Given:

- Moment of inertia, $I = 150 \, \text{kg} \cdot \text{m}^2$
- Applied torque, $\tau = 72 \, \text{Nm}$

We are asked to find the angular acceleration, α .

Applying the formula:

$$\alpha = \frac{\tau}{I}$$

Substituting the known values:

$$\alpha = \frac{72 \, \mathrm{Nm}}{150 \, \mathrm{kg} \cdot \mathrm{m}^2}$$

Performing the calculation:

$$\alpha = 0.48 \, \mathrm{rad/s}^2$$

Answer:

The object experiences an angular acceleration of 0.48 radians per second squared when a torque of 72 Nm is applied.

Implications and Applications of This Calculation

Understanding how torque influences angular acceleration has multiple practical applications across engineering, physics, and technology.

1. Mechanical Systems Design

Engineers utilize this relationship to design rotating machinery such as turbines, gears, and flywheels. Knowing the torque and moment of inertia helps in:

- Predicting how quickly a machine can accelerate or decelerate.
- Ensuring mechanical components can withstand the forces involved.

2. Robotics and Automation

Robotics involves precise control of rotational joints. Calculating angular acceleration helps in:

- Programming motor torques for desired movements.
- Optimizing response times and energy consumption.

3. Automotive Engineering

In vehicle dynamics, understanding rotational inertia and torque is vital for:

- Designing engine and transmission systems.
- Improving acceleration performance.

4. Aerospace Applications

Spacecraft and satellite attitude control systems rely on torque and inertia calculations to adjust orientation efficiently.

Additional Considerations in Rotational Dynamics

While the core calculation is straightforward, real-world scenarios often involve extra factors:

Friction and Damping

Frictional forces and damping effects can reduce the net torque leading to actual angular acceleration. When considering real systems:

- Account for resistive torques.
- Adjust calculations accordingly for more accurate predictions.

Variable Moment of Inertia

Some objects have a moment of inertia that changes with orientation or configuration, such as telescoping arms or linked systems.

Angular Velocity Limits

Applied torque must be balanced against other factors like material strength and safety limits to prevent damage.

Conclusion

In summary, when an object with a known moment of inertia is subjected to an applied torque, its angular acceleration can be directly calculated using the fundamental relation:

$$\alpha = \frac{\tau}{I}$$

For the specific case where $(I = 150 \, \mathrm{kg} \cdot \mathrm{m}^2)$ and $(\tau = 72 \, \mathrm{Nm})$, the angular acceleration is $0.48 \, \mathrm{rad/s}^2$. This insight is crucial across various engineering disciplines for designing efficient, safe, and effective rotational systems.

Understanding these principles allows engineers and scientists to predict motion, optimize performance, and troubleshoot issues in mechanical systems involving rotation. Whether in designing a robotic arm, tuning a vehicle's engine, or controlling satellite orientation, the relationship between torque, moment of inertia, and angular acceleration remains fundamental to successful engineering and physics applications.

Meta Description:

Learn how to calculate the angular acceleration of an object with a moment of inertia of $150 \text{ kg}\cdot\text{m}^2$ when a torque of 72 Nm is applied. Explore the fundamentals of rotational dynamics and practical applications.

Frequently Asked Questions

An object has a moment of inertia of $150 \text{ kg}\cdot\text{m}^2$ and a torque of 72 Nm is applied. What is the angular acceleration of the object?

The angular acceleration α is given by $\alpha = \tau / I = 72 \text{ Nm} / 150 \text{ kg}\cdot\text{m}^2 = 0.48 \text{ rad/s}^2$.

Given a moment of inertia of $150 \text{ kg}\cdot\text{m}^2$ and a torque of 72 Nm , what is the rotational acceleration in rad/s^2 ?

The rotational acceleration is 0.48 rad/s^2 , calculated by dividing torque (72 Nm) by moment of inertia ($150 \text{ kg}\cdot\text{m}^2$).

If an object with a moment of inertia of $150 \text{ kg}\cdot\text{m}^2$ experiences a torque of 72 Nm , what is its angular acceleration?

The angular acceleration is 0.48 rad/s^2 .

What is the angular acceleration of an object with a moment of inertia of $150 \text{ kg}\cdot\text{m}^2$ when a torque of 72 Nm is applied?

The angular acceleration is 0.48 radians per second squared.

How do you calculate the angular acceleration of an object given its moment of inertia and applied torque?

Angular acceleration is calculated using $\alpha = \tau / I$, where τ is the torque and I is the moment of inertia.

A torque of 72 Nm causes an object with $150 \text{ kg}\cdot\text{m}^2$ inertia to accelerate. What is the acceleration?

The angular acceleration is 0.48 rad/s^2 .

What is the significance of the moment of inertia value $150 \text{ kg}\cdot\text{m}^2$ in this problem?

It represents the object's resistance to rotational acceleration, used to calculate the angular acceleration when torque is applied.

If the applied torque increases, how does it affect the angular acceleration of the object?

The angular acceleration increases proportionally since $\alpha = \tau / I$, assuming the moment of inertia remains constant.

Additional Resources

Moment of Inertia: Unlocking the Dynamics of Rotational Motion

Understanding the principles of rotational motion is fundamental in fields ranging from mechanical engineering to physics. Central to this understanding is the concept of moment of inertia, a property that quantifies an object's resistance to changes in its rotational state. Today, we'll explore a practical scenario involving a moment of inertia of $150 \text{ kg}\cdot\text{m}^2$ and an applied torque of 72 Nm , delving into the calculations, implications, and real-world applications of these parameters.

Deciphering the Core Concepts

What is Moment of Inertia?

The moment of inertia (denoted as I) is a measure of an object's resistance to angular acceleration when subjected to a torque. It depends not only on the mass of the object but also on how that mass is distributed relative to the axis of rotation. Think of it as the rotational analogue of mass in linear motion.

Mathematically, for discrete masses:

$$I = \sum m_i r_i^2$$

where:

- m_i is the mass of each element,
- r_i is the distance from the axis of rotation.

For continuous bodies, this summation becomes an integral over the volume.

Key points:

- Higher moment of inertia implies greater resistance to change in rotational motion.
- It is dependent on the shape, size, and mass distribution.

What is Torque?

Torque (τ) is the rotational equivalent of force. It measures the tendency of a force to rotate an object about an axis, fulcrum, or pivot point. The magnitude of torque depends on:

- The force applied (F)
- The distance from the pivot point or axis of rotation (r)
- The angle between force direction and lever arm

Expressed as:

$$\tau = r \times F$$

or in terms of components:

$$\tau = r F \sin \theta$$

where θ is the angle between the force vector and the lever arm.

Applying the Principles: Calculating Rotational Dynamics

Let's analyze the given scenario: An object with a moment of inertia of $150 \text{ kg}\cdot\text{m}^2$ has a torque of 72 Nm applied to it. Our goal is to determine the resulting angular acceleration (α), which is crucial in understanding how quickly the object will start spinning or change its rotational velocity.

Fundamental Equation: Newton's Second Law for Rotation

The rotational analogue of Newton's second law is:

$$\tau = I \alpha$$

where:

- τ is the applied torque,
- I is the moment of inertia,
- α is the angular acceleration.

Rearranged to solve for α :

$$\alpha = \frac{\tau}{I}$$

Calculating the Angular Acceleration

Plugging in the known values:

$$\alpha = \frac{72 \text{ Nm}}{150 \text{ kg}\cdot\text{m}^2} = 0.48 \text{ rad/s}^2$$

This means the object experiences an angular acceleration of 0.48 radians per second squared when subjected to the 72 Nm torque.

Implication:

- The object will speed up its rotation at this rate, assuming no other external forces or torques act upon it.
- Over time, this acceleration influences its angular velocity, which can be calculated if the initial angular velocity is known.

Understanding the Dynamics Over Time

Suppose we want to determine how long it takes for the object to reach a certain angular velocity or how its rotational speed changes over time.

Angular Velocity After a Given Time

If the object starts from rest ($\omega_0 = 0$), then after time t :

$$\omega = \omega_0 + \alpha t = 0 + 0.48 t$$

\]

For example, after 5 seconds:

\[

$$\omega = 0.48 \times 5 = 2.4, \text{ rad/s}$$

\]

This straightforward calculation demonstrates how torque influences rotational speed over time.

Rotational Kinetic Energy

The kinetic energy associated with the rotation is:

\[

$$KE_{\text{rot}} = \frac{1}{2} I \omega^2$$

\]

Using the velocity after 5 seconds:

\[

$$KE_{\text{rot}} = \frac{1}{2} \times 150 \times (2.4)^2 = 75 \times 5.76 = 432, \text{ J}$$

\]

This energy reflects the work done on the object to accelerate it to that angular velocity.

Real-World Applications and Practical Considerations

Understanding the interplay between moment of inertia and torque is vital across numerous sectors.

1. Mechanical and Automotive Engineering

- Engine Rotors and Flywheels: Engineers design flywheels with specific moments of inertia to smooth engine power delivery.
- Steering Systems: Torque applied through steering mechanisms must overcome the moment of inertia of wheels and steering components.

2. Robotics and Automation

- Precise control of rotational components requires knowledge of moments of inertia to optimize motor selection and control algorithms.

3. Aerospace Engineering

- Spacecraft attitude control involves applying torques via reaction wheels or thrusters, where moments of inertia determine response times.

4. Manufacturing and Material Handling

- Rotating machinery, such as conveyors or mixers, depends on understanding and controlling moments of inertia for efficiency and safety.

Design and Optimization Insights

When designing systems that involve rotational motion, engineers often aim to balance the moment of inertia with the applied torque to achieve desired performance characteristics.

Key strategies include:

- Reducing Moment of Inertia: Using lighter materials or strategic mass distribution to make components easier to accelerate.
- Enhancing Torque: Upgrading motors or actuators to produce higher torque, especially when dealing with high moments of inertia.
- Control Systems: Implementing feedback mechanisms to manage angular acceleration and velocity effectively.

Advanced Considerations and Limitations

While the calculations above provide a clear picture, real-world scenarios involve additional complexities:

- Friction and Damping: Resistance in bearings or air resistance can reduce effective torque or introduce additional torque opposing motion.
- Variable Moments of Inertia: In some systems, the moment of inertia changes with position or configuration, requiring dynamic analysis.
- Non-ideal Torque Application: Torque might not be applied perfectly perpendicular or at

a fixed point, affecting the angular acceleration.

Understanding these factors is essential for precise control and safe operation.

Conclusion: From Theory to Practice

The scenario of an object with a moment of inertia of $150 \text{ kg}\cdot\text{m}^2$ subjected to a 72 Nm torque illuminates fundamental principles of rotational dynamics. The direct calculation of angular acceleration (0.48 rad/s^2) provides a basis for predicting how quickly an object will spin up, which is crucial in designing efficient, responsive mechanical systems.

Mastery of the relationship:

$$\alpha = \frac{\tau}{I}$$

enables engineers and physicists to tailor systems for optimal performance, safety, and energy efficiency. Whether in designing robust industrial machinery, optimizing robotic arms, or controlling spacecraft orientation, understanding the nuances of moment of inertia and torque is indispensable.

Ultimately, this knowledge empowers us to harness rotational motion with precision—transforming raw physics into practical, innovative solutions across countless technological domains.

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