A Flywheel Is Turned On And Attains An Angular Speed Of 45 Revolutions Per Minute In Just 4.10 S. Find

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Introduction

A flywheel is a mechanical device specifically designed to store rotational energy. It plays a crucial role in various engineering applications, such as in engines, turbines, and energy storage systems, by smoothing out fluctuations in power delivery and maintaining consistent rotational motion. When a flywheel is turned on, it begins to accelerate from a state of rest until it reaches a specific angular speed. Understanding the dynamics behind this acceleration involves concepts from rotational kinematics and dynamics.

In this article, we will delve into the detailed process of calculating the angular acceleration, the work done on the flywheel, the torque involved, and the moment of inertia based on the given data: the flywheel reaches an angular speed of 45 revolutions per minute (rpm) in 4.10 seconds. These calculations are fundamental in mechanical engineering, physics, and energy management, and they help in designing efficient rotational systems.

Understanding the Problem

Given Data
- Final angular speed, $\omega_f = 45\, \text{rpm}$
- Time taken to reach this speed, $t = 4.10\, \text{s}$
- Initial angular speed, $\omega_i = 0\, \text{rpm}$ (since the flywheel starts from rest)

Objectives
- Convert the given angular speed from revolutions per minute to radians per second.
- Calculate the angular acceleration during acceleration.
- Determine the angular displacement during this period.
- Find the work done on the flywheel.
- Calculate the torque applied.
- Deduce the moment of inertia of the flywheel.

Converting Units: Revolutions per Minute to Radians per Second

The first step involves converting the angular velocity from revolutions per minute to radians per second, which is the SI unit for angular velocity.

Conversion formula:
\[
\omega (\text{rad/sec}) = \text{revolutions per minute} \times \frac{2\pi\, \text{radians}}{1\, \text{revolution}} \times \frac{1\, \text{minute}}{60\, \text{seconds}}
\]

Calculation:
\[
\omega_f = 45\, \text{rpm} \times \frac{2\pi}{1} \times \frac{1}{60} = 45 \times \frac{2\pi}{60}
\]

\[
\omega_f = 45 \times \frac{\pi}{30} = \frac{45\pi}{30} = \frac{3\pi}{2} \approx 4.7124\, \text{rad/sec}
\]

Thus, the final angular velocity:
\[
\boxed{
\omega_f \approx 4.7124\, \text{rad/sec}
}
\]

Calculating Angular Acceleration

Since the flywheel accelerates uniformly from rest, we can use the rotational kinematic equation:

\[
\omega_f = \omega_i + \alpha t
\]

where:
- \(\omega_i = 0\, \text{rad/sec}\)
- \(\omega_f \approx 4.7124\, \text{rad/sec}\)
- \(t = 4.10\, \text{sec}\)

Rearranged to solve for \(\alpha\):

\[
\alpha = \frac{\omega_f - \omega_i}{t} = \frac{4.7124 - 0}{4.10} \approx 1.149 \, \text{rad/sec}^2
\]

Result:

$$
\boxed{
\alpha \approx 1.149\, \text{rad/sec}^2
}
$$

This is the angular acceleration the flywheel experiences during its acceleration.

Determining Angular Displacement

The angular displacement θ during acceleration is given by:

$$
\theta = \omega_i t + \frac{1}{2} \alpha t^2
$$

Since $\omega_i = 0$:

$$
\theta = \frac{1}{2} \alpha t^2 = \frac{1}{2} \times 1.149 \times (4.10)^2
$$

Calculating:

$$
\theta = 0.5745 \times 16.81 \approx 9.666\, \text{radians}
$$

Converting radians to revolutions:

$$
\text{Revolutions} = \frac{\theta}{2\pi} = \frac{9.666}{6.2832} \approx 1.54\, \text{revolutions}
$$

Interpretation:

During the acceleration period, the flywheel rotates approximately 1.54 revolutions before reaching the specified angular speed.

Calculating the Work Done on the Flywheel

The work done (W) in accelerating the flywheel is stored as rotational kinetic energy:

$$
W = \frac{1}{2} I \omega_f^2
$$

where:
- I is the moment of inertia,
- ω_f is the final angular speed.

However, since I is not specified, we can express the work in terms of known quantities and later relate it to the torque and inertia.

Expressing work in terms of torque:

$$
W = \tau \times \theta
$$

where:
- τ is the average torque applied during acceleration,
- θ is the angular displacement in radians.

Calculating Torque and Moment of Inertia

Torque (τ)

The torque applied to accelerate the flywheel is related to its moment of inertia and angular acceleration:

$$
\tau = I \alpha
$$

Since I is unknown, we need to find I based on the work-energy principle.

Linking work and kinetic energy:

$$
W = \frac{1}{2} I \omega_f^2
$$

From the earlier calculation, the work done is:

$$
W = \tau \times \theta
$$

But because $\tau = I \alpha$, and θ is known, we can write:

$$
W = I \alpha \times \theta
$$

Alternatively, express I directly from kinetic energy:

$$
I = \frac{2W}{\omega_f^2}
$$

To find W, we need the actual value of I or additional data.

Practical Calculation: Estimating Moment of Inertia

Suppose the problem provides or assumes a certain mass or dimensions of the flywheel; otherwise, the most straightforward approach is to compute the moment of inertia based on energy.

Using the kinetic energy formula:

$$
KE = \frac{1}{2} I \omega_f^2
$$

Given the work done $W = KE$, if we can estimate or are provided with the energy input, then:

$$
I = \frac{2W}{\omega_f^2}
$$

Example Calculation:

Assuming an external power source applies a torque over time, the total energy input W can be computed from the torque and angular displacement:

$$
W = \tau \times \theta
$$

If, for example, the torque applied is known or estimated, calculations can proceed accordingly.

Summary of Key Results

Quantity	Calculation / Value	Explanation

Final angular velocity, ω_f	$\approx 4.7124\, \text{rad/sec}$	Conversion from rpm
Angular acceleration, α	$\approx 1.149\, \text{rad/sec}^2$	From $\omega = \alpha t$
Angular displacement, θ	$\approx 9.666\, \text{radians}$	During acceleration period
Number of revolutions during acceleration	≈ 1.54 revolutions	Conversion from radians

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Applications and Relevance

Understanding the dynamics of flywheels has broad implications in mechanical engineering and energy management:

- Engine Design: Flywheels help smooth the power output of engines, especially in automotive and aircraft applications.
- Energy Storage: They serve as energy reservoirs in power grids and renewable energy systems.
- Rotational Machinery: Knowledge of angular acceleration and torque aids in designing systems that require controlled acceleration and deceleration.

Accurate calculations of these parameters ensure the safe and efficient operation of systems involving rotating components.

Conclusion

In this detailed exploration, we analyzed the process of turning on a flywheel, which attains an angular speed of 45 rpm in 4.10 seconds. Starting from unit conversions, we calculated the angular acceleration, the angular displacement during acceleration, and discussed the relationship between work, torque, and the moment of inertia. These calculations are fundamental in understanding rotational dynamics and are critical for designing and optimizing machinery that relies on flywheel systems.

By mastering these concepts, engineers and physicists can ensure that flywheels are designed for optimal performance, safety, and longevity in various industrial applications. Whether in energy storage, automotive systems, or industrial machinery, understanding the physics behind flywheel acceleration is essential for innovative and efficient engineering solutions.

References

- Hibbeler, R. C. (2016).

Frequently Asked Questions

What is the angular speed of the flywheel in radians per second when it reaches 45 revolutions per minute?

The angular speed in radians per second is approximately 4.712 rad/s, calculated as 45 rpm × (2π radians / 60 seconds).

How do you convert revolutions per minute to radians per second?

To convert rpm to rad/s, multiply the rpm value by 2π and divide by 60, i.e., (rpm × 2π) / 60.

What is the angular acceleration of the flywheel during its acceleration period?

Angular acceleration α = (final angular velocity - initial angular velocity) / time. Assuming initial angular velocity is 0, α = 4.712 rad/s / 4.10 s ≈ 1.15 rad/s².

Which physical concepts are involved in calculating the flywheel's acceleration from rest to a given angular speed?

The concepts include angular velocity, angular acceleration, and the relationship between time and change in angular velocity, typically involving kinematic equations for rotational motion.

Why is understanding the angular acceleration of a flywheel important in mechanical engineering?

It helps in designing systems that require controlled acceleration and deceleration, ensuring safety, efficiency, and optimal performance of rotating machinery.

Additional Resources

A Flywheel Is Turned On And Attains An Angular Speed Of 45 Revolutions Per Minute In Just 4.10 Seconds: An In-Depth Analysis

Understanding the dynamics of flywheels and their angular motion is fundamental in various engineering applications, from energy storage systems to automotive engines. When a flywheel is started, it accelerates from rest to a certain angular velocity within a specific period. Analyzing this process involves delving into concepts such as angular displacement, angular velocity, angular acceleration, moment of inertia, and energy considerations. This comprehensive review explores the problem of a flywheel reaching 45 revolutions per minute (rpm) in 4.10 seconds, providing insights into the underlying physics, calculations, and practical implications.

Understanding the Basic Concepts of Rotational Motion

Before addressing the specific problem, it is crucial to revisit the foundational principles that govern rotational kinematics and dynamics.

Angular Displacement and Angular Velocity

- Angular Displacement (θ): The measure of the angle through which an object has rotated, expressed in radians.
- Angular Velocity (ω): The rate at which an object rotates, measured in radians per second (rad/s).

Angular Acceleration (α)

- The rate of change of angular velocity over time, expressed as rad/s^2.
- If the flywheel accelerates uniformly, the angular acceleration remains constant during the acceleration phase.

Moment of Inertia (I)

- Represents the rotational inertia of the flywheel; it quantifies how resistant the flywheel is to changes in its rotational motion.
- For a given mass distribution, the moment of inertia depends on the shape and mass distribution.

Work, Energy, and Power in Rotational Motion

- Rotational kinetic energy: \(KE_{rot} = \frac{1}{2} I \omega^2 \)
- Power during acceleration: the rate at which work is done to increase the rotational kinetic energy.

Analyzing the Problem

The problem states:

- The flywheel starts from rest (initial angular velocity, $\omega_0 = 0$)
- It attains an angular speed of 45 revolutions per minute (rpm)
- The time taken to reach this speed is 4.10 seconds
- The goal: Find the angular acceleration, the angular displacement during this period, and related parameters such as the work done or energy stored.

Step 1: Converting Units for Consistency

Since rotational motion calculations are more straightforward in SI units, convert all quantities to radians and seconds.

Convert 45 rpm to radians per second

- 1 revolution = 2π radians
- Revolutions per minute (rpm) to radians per second:

$$
\omega = \text{rpm} \times \frac{2\pi}{60}
$$

Calculating:

$$
\omega = 45 \times \frac{2\pi}{60} = 45 \times \frac{\pi}{30} = \frac{45 \pi}{30} = 1.5 \pi \quad \text{rad/sec}
$$

Numerically:

$$
\omega \approx 1.5 \times 3.1416 \approx 4.7124 \text{ rad/sec}
$$

Thus, the final angular velocity:

$$
\boxed{\omega = 4.7124\, \text{rad/sec}}
$$

Step 2: Determining the Angular Acceleration

Assuming constant angular acceleration, initial angular velocity $\omega_0 = 0$, final angular velocity ω, over time $t = 4.10\, \text{sec}$, the angular acceleration α is:

$$
\alpha = \frac{\omega - \omega_0}{t}
$$

Since $\omega_0 = 0$:

$$
\alpha = \frac{4.7124\, \text{rad/sec}}{4.10\, \text{sec}} \approx 1.1496\, \text{rad/sec}^2
$$

Result:

$$
\boxed{\alpha \approx 1.15\, \text{rad/sec}^2}
$$

This uniform acceleration means that during the acceleration phase, the flywheel's angular velocity increases steadily at this rate.

Step 3: Calculating Angular Displacement

The angular displacement θ during acceleration can be found using the kinematic equation for rotational motion:

$$
\theta = \omega_0 t + \frac{1}{2} \alpha t^2
$$

Since $\omega_0 = 0$:

$$
\theta = \frac{1}{2} \alpha t^2
$$

Substituting the known values:

$$
\theta = \frac{1}{2} \times 1.1496 \times (4.10)^2
$$

Calculate:

$$
(4.10)^2 = 16.81
$$

$$
\theta = 0.5748 \times 16.81 \approx 9.67\, \text{radians}
$$

To interpret this in revolutions:

$$
\text{Number of revolutions} = \frac{\theta}{2\pi} \approx
\frac{9.67}{6.2832} \approx 1.54
$$

Result:

- The flywheel turns through approximately 1.54 revolutions during the acceleration phase.

Step 4: Energy Considerations and Power

The energy imparted to the flywheel during acceleration is stored as rotational kinetic energy:

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

To calculate this, we need the moment of inertia I. Since the problem does not specify the physical dimensions or mass distribution of the flywheel, we can analyze the energy in terms of I and discuss how to find it if the parameters are known.

Work Done / Energy Stored in the Flywheel

- Assuming no losses, the work done by the motor or external force is equal to the increase in rotational kinetic energy.

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

If we know I, this provides the energy stored after acceleration.

Power During Acceleration

- Power at any instant:

$$
P = \tau \omega
$$

where τ is the torque applied.

- For uniform angular acceleration:

$$
\tau = I \alpha
$$

Thus,

$$
P = I \alpha \omega
$$

The average power over the acceleration period:

$$
P_{avg} = \frac{W}{t} = \frac{\frac{1}{2} I \omega^2}{t}
$$

In practical applications, knowing the energy and power helps in designing motor systems capable of providing the necessary torque and energy over the specified time.

Step 5: Practical Implications and Real-World Applications

Understanding the dynamics of a flywheel reaching a certain angular speed in a given time is vital in many engineering fields.

Energy Storage and Release

- Flywheels serve as efficient energy storage devices, releasing or absorbing energy rapidly.
- Precise control of acceleration and deceleration is critical to prevent mechanical failure.

Automotive and Mechanical Systems

- In vehicles, flywheels smooth engine power delivery, absorbing shocks and maintaining rotational stability.
- In turbines and generators, they help stabilize rotational speed during transient conditions.

Design Considerations

- Material strength: The flywheel must withstand the stresses during rapid acceleration.
- Moment of inertia: Larger inertia allows for higher energy storage but may require more torque to accelerate.
- Safety margins: Sudden accelerations should be managed to prevent structural failure.

Efficiency and Losses

- Friction, air resistance, and bearing losses reduce the actual energy stored.
- Engineers aim to optimize the design to maximize energy retention and minimize losses.

Extensions and Further Analysis

While this analysis provides a fundamental understanding, further detailed studies may include:

- Calculating torque required: Using $\tau = I \alpha$, but for this, I must be known.
- Considering non-uniform acceleration: Real systems may not accelerate uniformly; analyzing variable acceleration profiles may be necessary.
- Thermal effects: Rapid acceleration can generate heat due to friction and internal damping.
- Structural analysis: Ensuring the flywheel can withstand the stresses during acceleration.

Summary and Final Remarks

In conclusion, the problem of a flywheel reaching 45 rpm in 4.10 seconds encapsulates key principles of rotational kinematics and dynamics. The

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critical steps involve converting units, calculating angular acceleration,
angular displacement, and understanding the energy stored within the
flywheel. Such analyses are fundamental for designing efficient and safe
mechanical systems involving rotational energy storage.

Recapitulating:

- Final angular velocity: approximately 4.7124 rad/sec
- Angular acceleration: approximately 1.15 rad/sec²
- Angular displacement during acceleration: about 1.
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