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Understanding the principles of springs and their applications is crucial in various engineering and mechanical contexts. In this article, we explore a specific scenario involving a spring with an unstretched length of 40 centimeters and a spring constant (k value) of 120 N/cm, used to lift a 0.5-kilogram object. We will discuss the fundamental concepts of springs, calculations involved, and practical implications, providing a comprehensive overview for enthusiasts and professionals alike.

Fundamentals of Springs and Spring Constants

What Is a Spring?

A spring is a mechanical device that stores and releases energy through elastic deformation. When a spring is compressed or stretched from its equilibrium position, it exerts a force proportional to the displacement, following Hooke's Law. Springs are widely used in various applications, from automotive suspensions to measuring devices like spring scales.

Hooke's Law and Spring Constant

Hooke's Law defines the relationship between the force exerted by a spring and its displacement:

$$F = -k x$$

Where:

- **F** is the restoring force exerted by the spring (in Newtons),
- **k** is the spring constant (in N/cm or N/m),
- **x** is the displacement from the spring's equilibrium position (in cm or m).

The negative sign indicates that the force exerted by the spring opposes the displacement.

Understanding the Spring Constant (k)

The spring constant, k, measures the stiffness of the spring:

- A higher k value indicates a stiffer spring that requires more force to produce a given displacement.

- Conversely, a lower k value indicates a more flexible spring.

In our scenario, the spring has a k value of 120 N/cm, which means it is relatively stiff.

Converting Units for Calculation

Before proceeding with calculations, it is essential to standardize units:

- Spring constant: 120 N/cm
- Unstretched length: 40 cm
- Mass to lift: 0.5 kg

Since 1 cm = 0.01 m, converting the spring constant to N/m:

$$k = 120 \text{ N/cm} \times 100 = 12,000 \text{ N/m}$$

This conversion simplifies calculations using SI units.

Calculating the Displacement Needed to Lift the Object

Determining the Weight of the Object

The weight (force due to gravity) of the object is calculated as:

$$F_{\text{gravity}} = m \times g$$

Where:

- $m = 0.5 \text{ kg}$
- $g = 9.81 \text{ m/s}^2$ (acceleration due to gravity)

Calculating:

$$F_{\text{gravity}} = 0.5 \text{ kg} \times 9.81 \text{ m/s}^2 = 4.905 \text{ N}$$

Thus, the spring must exert at least 4.905 N of force to lift the object.

Finding the Displacement (x)

Using Hooke's Law:

$$F = k \times x$$

Rearranged:

$$x = F / k$$

Plugging in the values:

$$x = 4.905 \text{ N} / 12,000 \text{ N/m} \approx 0.00040875 \text{ m} \approx 0.409 \text{ mm}$$

Interpretation: The spring needs to be compressed (or stretched) by approximately 0.409 millimeters to lift the 0.5 kg object.

Implications of the Displacement and Spring Behavior

Minimal Displacement for Lifting

The calculated displacement of approximately 0.409 mm indicates that even a tiny compression or extension of the spring can lift a 0.5 kg object. This demonstrates the high stiffness of the spring due to its large k value.

Practical Considerations in Using Such a Spring

Because the displacement is minimal, practical applications require precise control and measurement. Small variances in force or spring properties can significantly affect the lifting capability.

Energy Stored in the Spring

Calculating Potential Energy

The energy stored in a compressed or stretched spring is given by:

$$U = \frac{1}{2} k x^2$$

Substituting our values:

$$U = 0.5 \times 12,000 \text{ N/m} \times (0.00040875 \text{ m})^2$$

Calculating:

$$U \approx 0.5 \times 12,000 \times 1.672 \times 10^{-7} \approx 0.001003 \text{ J}$$

This energy is approximately 1 millijoule, indicating that only a tiny amount of energy is stored in the spring when lifting such a lightweight object.

Design and Application Insights

Designing Spring-Based Lifting Systems

When designing systems involving springs to lift objects, engineers must consider:

- The required force to lift the object,
- The displacement needed,
- The spring's material and fatigue limits,
- The precision of movement, especially when minimal displacements are involved.

Given the high stiffness of this spring, it is suitable for applications requiring precise, small displacements, such as micro-mechanical devices or sensitive measurement instruments.

Advantages of Using Such Springs

- High precision: Small displacements allow fine control.
- Energy efficiency: Minimal energy storage when lifting lightweight objects.
- Durability: Properly designed springs can perform thousands of cycles without fatigue.

Limitations and Considerations

- Manufacturing tolerances: Slight variances can significantly impact performance.
- Material fatigue: Repeated compression or extension can weaken the spring over time.
- Environmental factors: Temperature and corrosion can alter spring properties.

Real-World Applications

Springs with high stiffness and precise displacement capabilities are used in various fields:

- Micro-electromechanical systems (MEMS)
- Precision measurement devices
- Medical instruments
- Aerospace components
- Robotics, especially in fine movement controls

Summary and Key Takeaways

- The specific spring in question has an unstressed length of 40 cm and a spring constant of 120 N/cm (converted to 12,000 N/m).
- It can lift a 0.5 kg object with a force of approximately 4.905 N.
- The required displacement to achieve this lift is roughly 0.409 mm, demonstrating the spring's high stiffness.
- The energy stored during this process is minimal, about 1 millijoule.
- Such springs are ideal for applications demanding high precision and minimal displacement.

Conclusion

The analysis of a spring with an unstressed length of 40 centimeters and a spring constant of 120 N/cm illustrates the importance of understanding mechanical properties for practical applications. By converting units and applying fundamental physics principles, engineers can accurately determine the displacement and energy involved in lifting objects using springs. Whether in designing delicate instrumentation or advanced mechanical systems, appreciating these detailed calculations ensures optimal performance and longevity of spring-based components.

Keywords: spring constant, Hooke's law, stiffness, displacement, energy stored, mechanical engineering, precision devices, micro-mechanics, spring design

Frequently Asked Questions

What is the natural (unstretched) length of the spring in the problem?

The natural (unstretched) length of the spring is 40 cm.

What is the spring constant (k) provided in the problem?

The spring constant (k) is 120 N/cm.

What is the mass of the object being lifted by the spring?

The mass of the object is 0.5 kilograms.

How do you convert the spring constant from N/cm to N/m?

Multiply the given k value by 100, so 120 N/cm equals 12,000 N/m.

What is the weight of the 0.5 kg object in Newtons?

The weight is calculated as mass $\times$ acceleration due to gravity: $0.5 \text{ kg} \times 9.8 \text{ m/s}^2 = 4.9 \text{ N}$.

How do you determine the extension of the spring when lifting the object?

Use Hooke's Law: extension (x) = force / k . The force is the weight of the object, 4.9 N, and k is 12,000 N/m, so $x = 4.9 / 12,000$ meters.

What is the extension of the spring in meters when lifting the 0.5 kg object?

Extension $x = 4.9 \text{ N} / 12,000 \text{ N/m} \approx 0.000408$ meters or approximately 0.408 mm.

What is the total length of the spring when the object is lifted and the spring is extended?

Total length = natural length + extension = 40 cm + 0.0408 cm $\approx$ 40.0408 cm.

Why is understanding the spring extension important in this context?

Knowing the extension helps determine how much the spring stretches under load, which is essential for designing systems that rely on precise displacement measurements.

If the spring is used repeatedly for lifting objects, what factors should be considered to ensure its longevity?

Factors include avoiding overstretching beyond its elastic limit, regular inspections for deformation, and ensuring the load does not exceed its maximum rated capacity to prevent permanent deformation or failure.

Additional Resources

A spring with an unstretched length of 40 cm and a k value of 120 N/cm is used to lift a 0.5 kilogram mass — this scenario encapsulates fundamental principles of spring mechanics, offering a rich context for exploring various aspects of elastic behavior, practical applications, and theoretical considerations. This detailed review aims to analyze the characteristics, performance, and implications of such a spring in a lifting context, providing insights for students, engineers, and enthusiasts interested in the mechanics of springs.

Understanding the Spring's Basic Properties

Before delving into the application, it is essential to comprehend the fundamental properties of the spring in question.

Unstretched Length

The spring's unstretched length is 40 cm, which establishes a baseline measurement. This length indicates the natural, relaxed state of the spring when no external forces are applied. It is critical when assessing how much the spring elongates under load and influences the overall design considerations, such as the available travel range and potential for deformation.

Spring Constant (k)

The spring constant, given as 120 N/cm, indicates the stiffness of the spring — how much force is needed to produce a unit of extension or compression. A high k value signifies a stiff spring, requiring more force to stretch it by a certain amount, which directly affects the lifting capacity and energy storage.

- Features:
 - High stiffness ensures minimal elongation under load, providing precise control.
 - Limits the maximum stretch, preventing over-extension or damage.
 - Suitable for applications requiring firm support or precise force application.
- Pros:
 - Predictable behavior under load.
 - Less susceptible to deformation under small displacements.
- Cons:
 - Requires significant force to produce noticeable extension.
 - Less energy storage capacity compared to softer springs.

Calculating the Extension Under Load

A key aspect of spring mechanics is determining how much the spring extends when a weight is applied.

Force Exerted by the Load

Using Newton's second law:

$$F = m \times g$$

where:

- $m = 0.5, \text{ kg}$

- $(g \approx 9.81, \text{m/s}^2)$

$[F = 0.5 \times 9.81 \approx 4.905, \text{N}]$

This is the force exerted downward by the mass.

Extension Calculation

Hooke's Law relates force and extension:

$$[F = k \times x]$$

where:

- (F) is the applied force,
- (k) is the spring constant,
- (x) is the extension.

Since the spring constant is provided in N/cm, convert it to N/m for consistency:

$$[120, \text{N/cm} = 12,000, \text{N/m}]$$

Now, solve for (x) :

$$[x = \frac{F}{k} = \frac{4.905}{12,000} \approx 0.00040875, \text{m}]$$

or approximately 0.409 mm.

Implication:

The extension is very small, less than half a millimeter, indicating that the spring exhibits minimal elongation under such a light load, which highlights its stiffness.

Practical Applications and Considerations

Understanding how the spring responds under load is vital when integrating it into real-world systems.

Application Suitability

Given its high k value and minimal extension under small loads, this spring is ideal for applications requiring precise force control rather than large displacements.

- Suitable uses include:
 - Tensioning devices where minimal movement is desired.
 - Calibration tools measuring force with high sensitivity.
 - Mechanical systems where stiffness is essential to prevent sagging or excessive movement.
- Less suitable for:
 - Lifting heavy objects, where larger extensions are needed.
 - Absorbing shocks or impacts, due to limited energy storage.

Design Features and Limitations

Features:

- High stiffness ensures stability.
- Compact size due to minimal elongation.
- Predictable and linear response within elastic limits.

Limitations:

- Limited extension capacity; may not accommodate larger loads.
- Potential for material fatigue if overstressed.
- Not ideal for applications requiring significant deformation.

Energy Storage and Mechanical Efficiency

A spring's ability to store and release energy is a critical feature, especially in lifting and shock absorption.

Potential Energy Stored

The elastic potential energy stored in the spring when stretched is:

$$PE = \frac{1}{2} k x^2$$

Using the calculated extension:

$$PE = \frac{1}{2} \times 12,000 \, \text{N/m} \times (0.00040875 \, \text{m})^2$$

$$PE \approx 1.0 \times 10^{-3} \, \text{J}$$

This is an extremely small amount of energy, indicating that under the given load, the spring stores negligible energy.

Implication:

Such a spring is not suitable for energy storage applications but excels in providing consistent force.

Analysis of the Mechanical Behavior Under Different Loads

While the initial load is small, examining the spring's response under increased or decreased loads provides insights into its versatility.

Scaling Up the Load

Suppose the load increases to 10 kg:

- Force:

$$F = 10 \times 9.81 = 98.1, \text{N}$$

- Extension:

$$x = \frac{98.1}{12,000} \approx 0.008175, \text{m}$$

- Approximate extension: 8.2 mm.

This demonstrates the linearity of the spring's response within the elastic limit, with extension increasing proportionally with load.

Limitations and Safety Margin

Given the spring's high stiffness, it can handle substantial loads before reaching its elastic limit, but excessive force can cause permanent deformation or failure. Proper safety margins should be considered in design.

Comparative Analysis With Other Springs

Examining this spring in context with alternative springs can highlight its features.

Soft Springs (Low k value)

- Larger extensions under lighter loads.
- Greater energy storage.
- Less precise force control.

Hard Springs (High k value, like this one)

- Minimal extension under small loads.
- Precise force application.
- Limited displacement and energy storage.

Pros of this Spring:

- High stiffness for stability.
- Small, predictable deformations.
- Suitable for precision applications.

Cons:

- Limited flexibility.
- Not suitable for absorbing shocks or large displacements.
- Potential for material fatigue if overstressed.

Conclusion and Final Thoughts

The spring with an unstretched length of 40 cm and a k value of 120 N/cm exemplifies a high-stiffness component suitable for applications requiring minimal movement and precise force control. When used to lift a 0.5 kg mass, the extension is negligible, underscoring its rigidity. Its capacity to withstand substantial forces with minimal deformation makes it ideal for specialized mechanical systems, calibration devices, or tensioning applications.

However, this stiffness also introduces limitations, particularly in applications where flexibility, energy storage, or shock absorption are necessary. Proper understanding of its properties, load capacities, and elastic limits ensures optimal utilization and longevity.

In summary, this spring's features shine in contexts demanding stability and precision, but careful consideration must be given to its limitations. Its characteristics reflect a balance of strength, predictability, and minimal deformation, making it a valuable component in the engineer's toolkit, especially when used within its elastic and safety limits.

Key Takeaways:

- The high spring constant results in minimal extension under small loads.
- Suitable for precision applications rather than energy storage or shock absorption.
- Linear elastic behavior within its elastic limit ensures predictable performance.
- Proper load management and safety considerations are essential for longevity.

This comprehensive review underscores the importance of understanding spring mechanics for effective application and highlights the nuanced trade-offs between stiffness, flexibility, and energy storage in spring design.

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