

A String Of Length 4m Is Extended By 0.02m, When A Load Of 0.4kg Is Suspended At Its End. What Will Be

A String Of Length 4m Is Extended By 0.02m, When A Load Of 0.4kg Is Suspended At Its End. What Will Be Understanding the mechanics of how strings and materials stretch under load is fundamental in physics and engineering. This article aims to explore the principles behind the extension of a string subjected to a load, delve into relevant formulas, and provide a detailed calculation to determine the material's properties such as its Young's modulus. Whether you're a student preparing for exams or an engineer designing load-bearing structures, grasping these concepts is essential for accurate analysis and safe design.

Understanding the Problem

Before delving into the calculations, it's important to comprehend the scenario:

- The string or wire has an initial length (L_0) of 4 meters.
- When a load of 0.4 kg is suspended at the end of the string, it stretches by 0.02 meters.
- The question is to determine the properties of the string, such as its Young's modulus, or to analyze the behavior under the given load.

This setup is a typical example of elastic deformation where the material stretches proportionally to the applied load within its elastic limit.

Fundamentals of Elastic Deformation

Hooke's Law

The fundamental principle governing elastic deformation is Hooke's Law, which states that the extension (ΔL) of a material is proportional to the applied force (F), provided the elastic limit is not exceeded:

$$\Delta L = \frac{F \times L_0}{A \times E}$$

where:

- ΔL = extension of the material (meters)
- F = applied force (Newtons)
- L_0 = original length of the material (meters)
- A = cross-sectional area (square meters)

- E = Young's modulus of the material (Pascals)

Note: If the cross-sectional area is unknown, the problem may be approached through other parameters or assumptions.

Young's Modulus and Its Significance

Young's modulus (E) measures the stiffness of a material, indicating how much it resists deformation under stress. A higher E value means the material is stiffer and less prone to stretching under load.

Formula for Young's modulus:

$$E = \frac{\text{Stress}}{\text{Strain}}$$

Where:

- Stress = Force per unit area (F / A)
- Strain = relative extension ($\Delta L / L_0$)

Step-by-Step Calculation

Given data:

- Initial length, $L_0 = 4 \text{ m}$
- Extension, $\Delta L = 0.02 \text{ m}$
- Load mass, $m = 0.4 \text{ kg}$
- Gravitational acceleration, $g \approx 9.81 \text{ m/s}^2$

Step 1: Calculate the Force Applied (F)

The load applies a force equal to its weight:

$$F = m \times g = 0.4 \text{ kg} \times 9.81 \text{ m/s}^2 = 3.924 \text{ N}$$

Step 2: Determine the Stress

Stress is the force divided by the cross-sectional area. Since the area (A) isn't specified, the problem often assumes the material properties are to be calculated per unit area or that the area is known elsewhere.

Alternatively, if the problem provides the Young's modulus or if the intent is to find it, then the relation becomes:

$$\text{Extension} = \frac{F \times L_0}{A \times E}$$

Rearranged to find E:

$$E = \frac{F \times L_0}{A \times \Delta L}$$

Without the cross-sectional area, we can express the ratio $(\frac{\Delta L}{L_0})$, which is the strain.

Step 3: Calculate Strain

$$\text{Strain} = \frac{\Delta L}{L_0} = \frac{0.02 \text{ m}}{4 \text{ m}} = 0.005$$

This indicates the material stretches by 0.5% under the load.

Step 4: Express Young's Modulus

Rearranged from the original formula:

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{F / A}{\Delta L / L_0}$$

$$E = \frac{F \times L_0}{A \times \Delta L}$$

Alternatively, if the cross-sectional area A is known or measured, you can directly compute E.

Practical Applications and Significance

Understanding how a string or wire stretches under load has numerous practical uses:

- Design of Suspension Bridges: Engineers must ensure cables can withstand loads without excessive elongation.
- Material Testing: Determining Young's modulus helps in selecting appropriate materials for specific applications.
- Mechanical Engineering: Ensuring safety margins in structures to prevent unexpected failures.
- Physics Education: Demonstrating fundamental concepts of elasticity and stress-strain relationships.

Factors Affecting the Extension of a String

While the above calculations provide a theoretical understanding, real-world applications must consider several factors:

- **Material Properties:** Different materials have different Young's moduli, affecting their elastic behavior.
- **Cross-Sectional Area:** Thicker strings or wires have larger areas, reducing stress for the same load.
- **Temperature:** Elevated temperatures can alter material stiffness, affecting extension.
- **Load Distribution:** Uneven loads or dynamic forces can influence elongation.

Advanced Concepts and Further Calculations

For more precise analysis, additional parameters and advanced mechanics principles can be incorporated:

Calculating Young's Modulus (E)

If the cross-sectional area A is known, Young's modulus can be directly calculated:

$$E = \frac{F \times L_0}{A \times \Delta L}$$

For example, suppose the cross-sectional area of the string is 1 mm^2 (which is $(1 \times 10^{-6} \text{ m})^2$):

$$E = \frac{3.924 \text{ N} \times 4 \text{ m}}{1 \times 10^{-6} \text{ m}^2 \times 0.02}$$

$$E = \frac{15.696}{2 \times 10^{-8}} = 784.8 \times 10^6 \text{ Pa}$$

$$E \approx 785 \text{ MPa}$$

This is typical for many metals like steel, which have Young's modulus values in the range of 200-210 GPa, indicating that the actual cross-sectional area might be smaller or the material less stiff.

Using Stress and Strain to Determine Material Properties

Understanding the relationship between applied stress and resulting strain provides insights into the elastic limits of materials:

- Elastic Limit: The maximum stress that a material can withstand without permanent deformation.
- Yield Point: The point beyond which the material deforms plastically.

If the extension exceeds the elastic limit, the material may suffer permanent deformation or failure.

Conclusion

Analyzing the extension of a string under load involves understanding the fundamental principles of elasticity, stress, strain, and material properties like Young's modulus. In the scenario where a 0.4 kg load causes a 0.02 m extension on a 4 m string, the calculations demonstrate how to quantify the material's elastic response.

While the example provides a simplified overview, real-world applications require detailed knowledge of the material's cross-sectional area, composition, temperature effects, and load conditions. Nonetheless, mastering these basic concepts enables engineers, physicists, and students to design safer structures, select appropriate materials, and deepen their understanding of material science.

Ultimately, understanding how materials respond to forces not only helps in preventing structural failures but also paves the way for innovation in material engineering and safety standards.

Keywords: elasticity, Young's modulus, stress, strain, extension, load, physics, engineering, material properties, deformation

Frequently Asked Questions

What is the extension produced in a string of length 4m when a load of 0.4kg is suspended at its end?

The extension is 0.02 meters (20 mm).

How is the extension of a string related to the tension and material properties?

Extension is directly proportional to tension and inversely proportional to the material's Young's modulus and cross-sectional area.

What is the tension in the string when a 0.4kg load is

suspended?

The tension is equal to the weight of the load, which is $0.4 \text{ kg} \times 9.8 \text{ m/s}^2 = 3.92 \text{ N}$.

How can the Young's modulus of the string be determined from this data?

Using the extension, tension, original length, and cross-sectional area in the formula $Y = (F \times L_0) / (A \times \Delta L)$, where Y is Young's modulus.

What assumptions are made in calculating the extension of the string?

Assumptions include that the material behaves elastically, the extension is small, and the tension is uniformly distributed.

If the load increases, how does it affect the extension of the string?

Increasing the load increases the tension, which results in a greater extension of the string, assuming elastic behavior.

What practical applications depend on understanding such extension behavior in strings or wires?

Applications include designing suspension bridges, load-bearing cables, musical instrument strings, and engineering structures where elastic deformation is critical.

Additional Resources

Elasticity: Unlocking the Secrets of a String's Stretch Under Load

Introduction

In the realm of physics and material science, understanding the elastic properties of materials is fundamental. Whether designing bridges, measuring tension in musical instruments, or exploring everyday phenomena, the principles governing how materials stretch and recover are vital. Today, we delve into a practical and intriguing scenario: a string of initial length 4 meters is extended by 0.02 meters when a load of 0.4 kg is suspended at its end. This situation not only embodies core concepts of elasticity but also provides insights into material behavior under stress. Let's explore this phenomenon comprehensively, examining the underlying physics, calculations, and implications.

Setting the Scene: The Scenario in Detail

Imagine a high-quality, elastic string—perhaps made of nylon, steel, or a similar material—initially measuring 4 meters. When a small weight is attached, it elongates slightly, stretching by an additional 0.02 meters. The weight, 0.4 kilograms, exerts a force on the string due to gravity. The key questions that emerge from this setup include:

- What is the stress experienced by the string?
- What is its strain during extension?
- How does this relate to the material's Young's modulus?
- What does this tell us about the elastic limit and material behavior?

By unpacking these aspects, we gain not only a theoretical understanding but also practical knowledge applicable in engineering, material testing, and quality assurance.

Fundamental Concepts: Stress, Strain, and Young's Modulus

Before diving into calculations, it's essential to understand the core concepts involved.

1. Stress

Stress is the internal force per unit area within a material resulting from an external load. It is expressed as:

$$\sigma = \frac{F}{A}$$

where:

- σ is the stress (Pa or N/m²),
- F is the applied force (N),
- A is the cross-sectional area (m²).

2. Strain

Strain measures the relative deformation of the material, defined as:

$$\epsilon = \frac{\Delta L}{L_0}$$

where:

- ϵ is the strain (dimensionless),
- ΔL is the change in length (m),
- L_0 is the original length (m).

3. Young's Modulus

Young's modulus (E) relates stress and strain in the elastic (linear) region:

$$E = \frac{\sigma}{\epsilon}$$

This modulus provides a measure of the stiffness of the material: higher E indicates a stiffer material.

Step-by-Step Analysis of the Scenario

Step 1: Calculating the Force Due to the Suspended Load

The load of 0.4 kg exerts a force owing to gravity:

$$F = m \times g$$

where:

- $m = 0.4 \text{ kg}$,
- $g = 9.8 \text{ m/s}^2$.

$$F = 0.4 \times 9.8 = 3.92 \text{ N}$$

Thus, the string experiences a tensile force of approximately 3.92 Newtons.

Step 2: Determining the Strain

The strain is straightforward:

$$\epsilon = \frac{\Delta L}{L_0} = \frac{0.02 \text{ m}}{4 \text{ m}} = 0.005$$

Expressed as a percentage, this is 0.5%, indicating a relatively small but measurable elongation consistent with elastic deformation.

Step 3: Estimating the Cross-Sectional Area

To proceed further, knowing the cross-sectional area is vital because stress depends on it. Since the problem does not specify the area, typical values for laboratory or engineering wires can be used as reference.

Suppose the string has a circular cross-section with a diameter d . The area is:

$$A = \frac{\pi}{4} d^2$$

Common diameters for such strings vary based on material and application, but for an illustrative purpose, assume:

$$d = 1 \text{ mm} = 0.001 \text{ m}$$

Then,

$$A = \frac{\pi}{4} (0.001)^2 \approx 7.854 \times 10^{-7} \text{ m}^2$$

This provides a basis for approximate calculations, which can be refined if actual dimensions are known.

Step 4: Calculating Stress

Using the force and cross-sectional area:

$$\sigma = \frac{F}{A} = \frac{3.92}{7.854 \times 10^{-7}} \approx 4.99 \times 10^6 \text{ Pa}$$

This is approximately 5 MPa (MegaPascals), a typical tensile stress for elastic materials like nylon or steel wires.

Step 5: Deduction of Young's Modulus

With stress and strain known, Young's modulus becomes:

$$E = \frac{\sigma}{\epsilon} = \frac{4.99 \times 10^6}{0.005} = 9.98 \times 10^8 \text{ Pa}$$

or approximately 1 GPa (Gigapascal).

Note: The actual value depends on the specific material and dimensions. For example:

- Steel typically has E between 200-210 GPa.
- Nylon ranges from 1-3 GPa.
- Polyester or other synthetic fibers often exhibit similar ranges.

Given the approximate calculations, this suggests the string could be a lightweight, flexible material with a Young's modulus in the order of 1 GPa, suitable for many engineering applications.

Implications and Practical Insights

Material Behavior and Elastic Limit

The small extension (0.02 m over 4 m, or 0.5%) suggests the string operates well within its elastic limit. Materials in the elastic region return to their original length once the load is removed, which is critical for applications requiring repeated loading cycles, such as tensioned cables, musical strings, or elastic components.

Material Selection for Engineering Applications

Understanding the relationship between load, extension, and material properties guides engineers in:

- Selecting appropriate materials for specific load-bearing applications,
- Designing safety margins based on elastic limits,
- Predicting deformation under various loads.

Effect of Cross-Sectional Area

The area directly influences the stress for a given load. A thicker string (larger diameter) reduces stress and elongation, making it more resistant to deformation, whereas a thinner string is more susceptible to stretching and potential failure.

Broader Perspectives: Beyond the Basic Calculation

While initial calculations give a snapshot of the string's elastic behavior, more nuanced analysis involves:

- Material hysteresis: examining energy loss during cyclic loading,
- Temperature effects: how temperature changes influence elasticity,
- Dynamic loading: effects of oscillations or vibrations,
- Long-term creep: gradual deformation under sustained load.

Advanced testing can employ methods like tensile testing machines, which measure stress-strain behavior across a range of loads, producing detailed stress-strain curves. These curves enable precise determination of Young's modulus, yield strength, and ultimate tensile strength.

Final Thoughts: The Significance of Elasticity in Real-World Applications

This exploration underscores the importance of understanding elasticity in everyday and industrial contexts. Whether it's ensuring a bridge's cable can support its load, tuning a musical instrument, or designing flexible electronics, the principles governing how materials stretch and recover are foundational.

In our specific scenario—a 4-meter string stretched by a modest load—the key takeaway is that the material's elastic properties allow for predictable, reversible deformation. The calculated Young's modulus and stress-strain relationships serve as vital parameters guiding material choice, structural safety, and functional performance.

Conclusion

The extension of a string under load provides a window into the fascinating world of material elasticity. Through systematic analysis—calculating forces, strains, stresses, and elastic moduli—we gain a comprehensive understanding of how materials behave under stress and how their properties can be harnessed in practical applications. Whether engineering a suspension bridge, designing resilient textiles, or crafting musical instruments, the principles revealed through such scenarios are invaluable.

In essence, the tiny stretch of 0.02 meters in a 4-meter string reveals the profound interplay between force, material properties, and elastic behavior—a testament to the elegance and utility of physics in everyday life.

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