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Section 14.3 Mechanical Advantage and Efficiency

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Calculating Mechanical Advantage and Efficiency

Content and Vocabulary Support

Mechanical Advantage

The input force of a machine is the force exerted on a machine, and the output force is the force produced by the machine. The number of times that a machine increases an input force to produce an output force is called its **mechanical advantage**. The higher the output force relative to the input force, the greater the mechanical advantage. There are two different types of mechanical advantage: actual mechanical advantage and ideal mechanical advantage.

Actual Mechanical Advantage

The **actual mechanical advantage** of a machine is determined by measuring the actual forces acting on the machine. It equals the ratio of output force to input force:

$$\text{Actual mechanical advantage (AMA)} = \frac{\text{Output force}}{\text{Input force}}$$

The actual mechanical advantage is a measure of the performance of the machine in the real world. It includes the effect of friction on mechanical advantage.

Ideal Mechanical Advantage

The **ideal mechanical advantage** of a machine is the mechanical advantage in the absence of friction. Ideal mechanical advantage equals the ratio of input distance to output distance:

$$\text{Ideal mechanical advantage (IMA)} = \frac{\text{Input distance}}{\text{Output distance}}$$

Recall that input distance is the distance through which the input force is exerted, and output distance is the distance through which the output force is exerted.

Because friction is always present, the actual mechanical advantage of a machine is always less than the ideal mechanical advantage. The greater the difference, the less efficient the machine.

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Efficiency

Because some of the work input to a machine is used to overcome friction, work output is always less than work input. The percent of work input that becomes work output is called **efficiency**. It is calculated by:

$$\text{Efficiency} = \frac{\text{Work ouput}}{\text{Work input}} \times 100\%$$

Due to friction, the efficiency of a machine is always less than 100 percent.

Solved Examples

Example 1: Tamara rides her skateboard 1.5 meters up a ramp to a height of 0.5 meters above the ground. What is the ideal mechanical advantage of the ramp?

Given: Input distance = 1.5 m
Output distance = 0.5 m

Unknown: Ideal mechanical advantage (IMA)

Equation: $\text{IMA} = \frac{\text{Input distance}}{\text{Output distance}}$

Solution: $\text{IMA} = \frac{1.5\text{ m}}{0.5\text{ m}} = 3$

Example 2: What is the output distance of a machine with an input distance of 3.0 centimeters and an ideal mechanical advantage of 12?

Given: Input distance = 3.0 cm
IMA = 6

Unknown: Output distance

Equation: $\text{IMA} = \frac{\text{Input distance}}{\text{Output distance}}$

Solution: Solve the equation for output distance, and substitute the given values:

$$\text{Output distance} = \frac{\text{Input distance}}{\text{IMA}};$$

$$\text{Output distance} = \frac{3\text{ cm}}{12} = 0.25\text{ cm}$$

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Example 3: A machine has a work output of 8 joules and requires 10 joules of work input to operate. What is the machine's efficiency?

Given: Work output = 8 J
Work input = 10 J

Unknown: Efficiency

Equation: $\text{Efficiency} = \frac{\text{Work output}}{\text{Work input}} \times 100\%$

Solution: $\text{Efficiency} = \frac{8\ \text{J}}{10\ \text{J}} \times 100\% = 80\%$

Example 4: What is the work output of a machine that has a work input of 2,800 joules and an efficiency of 92.3 percent?

Given: Work input: 2,800 J
Efficiency = 92.3%

Unknown: Work output

Equation: $\text{Efficiency} = \frac{\text{Work output}}{\text{Work input}}$

Solution: Solve the equation for work output:

$$\text{Work output} = \text{Efficiency} \times \text{Work input}$$

Substitute the given values in this equation:

$$\text{Work output} = 92.5\% \times 2{,}800\ \text{J} = 2{,}590\ \text{J}$$

Practice Exercises

Exercise 1: A ski lift carries people along a 220-meter cable up the side of a mountain. Riders are lifted a total of 110 meters in elevation. What is the ideal mechanical advantage of the ski lift?

Exercise 2: The ideal mechanical advantage of a machine is 3.2 and its output distance is 2.5 meters. What is the input distance?

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Exercise 3: Paco rode his skateboard up a ramp for a distance of 3.8 meters. If the ideal mechanical advantage of the ramp is 2, how far above the ground was Paco?

Exercise 4: The inventor of a new machine claims that its actual mechanical advantage is 4. Literature on the machine reports its input distance is 81 meters and its output distance is 27 meters. Find the machine's ideal mechanical advantage, and determine whether the developer's claim could be true.

Exercise 5: What is the efficiency of a machine that has work input of 40 joules and work output of 35 joules?

Exercise 6: Work output of a large machine in a factory is 89,000 joules, and its input is 102,000 joules. Work output of a similar machine is 92,000 joules, and its work input is 104,000 joules. Which machine has greater efficiency?

Exercise 7: Lucas has been challenged to increase the efficiency of a device he is redesigning. His goal is 90 percent efficiency. The work input of the device is fixed at 10 joules, so Lucas is trying to improve work output. How many joules of work output should Lucas aim for to attain his goal of 90 percent efficiency?

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