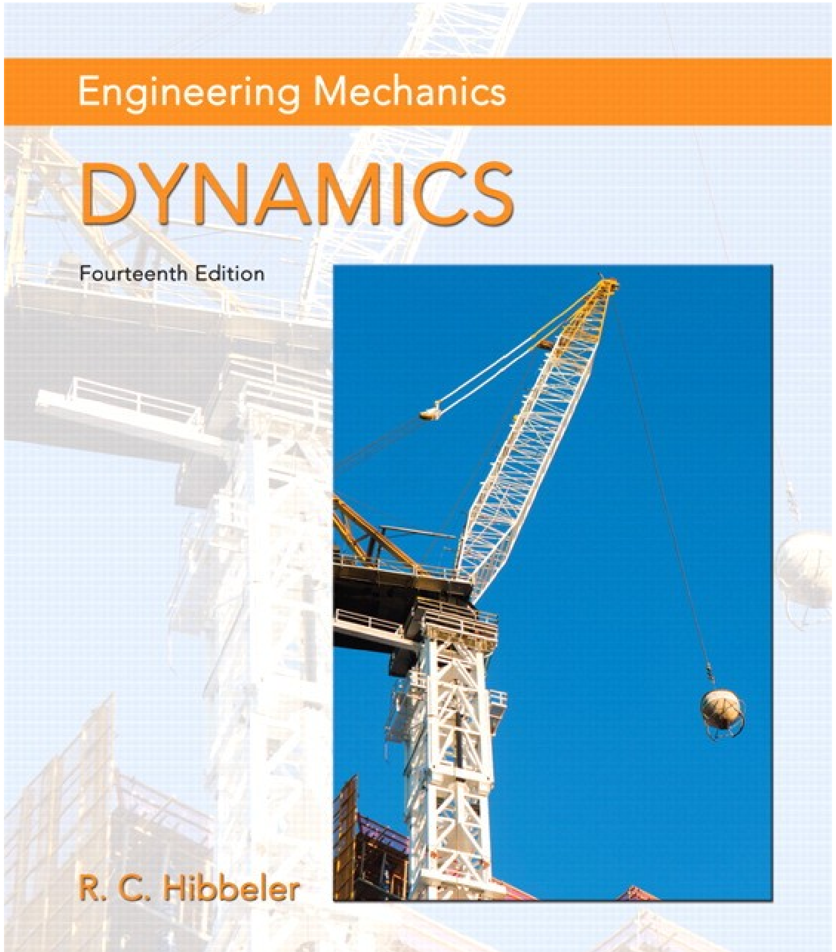
Engineering Mechanics: Dynamics

Fourteenth Edition



Chapter 14

Kinetics of a Particle: Work and Energy

Pearson

Power And Efficiency (1 of 2)

Today's Objectives:

Students will be able to:

1. Determine the power generated by a machine, engine, or motor.
2. Calculate the mechanical efficiency of a machine.

Power And Efficiency (2 of 2)

In-Class Activities:

- Check Homework
- Reading Quiz
- Applications
- Define & Find Power
- Define & Find Efficiency
- Concept Quiz
- Group Problem Solving
- Attention Quiz

Reading Quiz

1. The formula definition of power is ___________.

   A) dU / dt B) $F \cdot v$

   C) $F \cdot dr / dt$ D) All of the above.

2. Kinetic energy results from _______.

   A) displacement B) velocity

   C) gravity D) friction

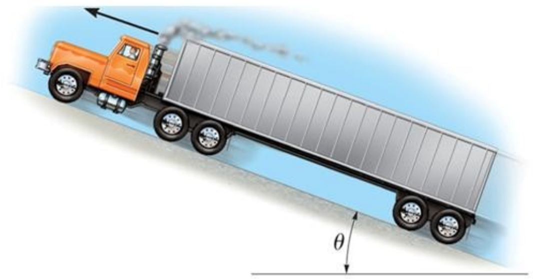
Applications (1 of 2)

Engines and motors are often rated in terms of their power output. The power output of the motor lifting this elevator is related to the vertical force ***F*** acting on the elevator, causing it to move upwards.

Given a desired lift velocity for the elevator (with a known maximum load), how can we determine the power requirement of the motor?

Applications (2 of 2)

The speed at which a truck can climb a hill depends in part on the power output of the engine and the angle of inclination of the hill.



For a given angle, how can we determine the speed of this truck, knowing the power transmitted by the engine to the wheels? Can we find the speed, if we know the power?

If we know the engine power output and speed of the truck, can we determine the maximum angle of climb for this truck?

Section 14.4

Power and Efficiency

Power and Efficiency

Power is defined as the amount of **work** performed **per unit of time.**

If a machine or engine performs a certain amount of work, dU, within a given time interval, dt, the power generated can be calculated as

$$P = dU / dt$$

Since the work can be expressed as dU = ***F*** • d***r***, the power can be written

$$\boldsymbol{P = dU / dt = (F.dr) / dt = F.(dr / dt) = F.v}$$

Thus, power is a **scalar** defined as the product of the **force** and **velocity** components acting in the **same direction**.

Power

Using scalar notation, power can be written

where q is the angle between the force and velocity vectors.

$$P = F.v = Fv\cos\theta$$

So if the velocity of a body acted on by a force F is known, the power can be determined by calculating the dot product or by multiplying force and velocity components.

The unit of power in the SI system is the **Watt** (W) where

$$1W = 1\,J/s = 1(N.m)/s$$

In the FPS system, power is usually expressed in units of **horsepower** (hp) where

$$1hp = 550(ft\ \ \mathrm{lb})/\mathrm{s} = 746\mathrm{W}$$

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Efficiency

The **mechanical efficiency** of a machine is the ratio of the useful power produced (**output power**) to the power supplied to the machine (**input power**) or

$$e = (power\ output)/(power\ input)$$

If energy input and removal occur at the same time, efficiency may also be expressed in terms of the ratio of **output energy** to **input energy** or

$$e = (energy\ output)/(energy\ input)$$

Machines will always have frictional forces. Since frictional forces **dissipate** energy, additional power will be required to overcome these forces. Consequently, the efficiency of a machine is always **less than 1**

Procedure for Analysis

Find the **resultant external force** acting on the body causing its motion. It may be necessary to draw a free-body diagram.

Determine the **velocity** of the **point** on the body **at which the force is applied**. Energy methods or the equation of motion and appropriate kinematic relations, may be necessary.

Multiply the **force magnitude** by the component of **velocity** acting **in the direction** of **F** to determine the power supplied to the body

$$(P = Fv\cos\theta)$$

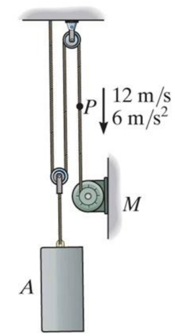
In some cases, **power** may be found by calculating the **work done per unit of time**

$$\boldsymbol{(P = dU / dt)}$$

If the **mechanical efficiency** of a machine is known, either the power input or output can be determined.

Example (1 of 3)

Given: A 50 kilogram block (A) is hoisted by the pulley system and motor M. The motor has an efficiency of 0.8. At this instant, point P on the cable has a velocity of $12\ m/s$ which is increasing at a rate of $6\ m/s^2$. Neglect the mass of the pulleys and cable.



Find: The power supplied to the motor at this instant.

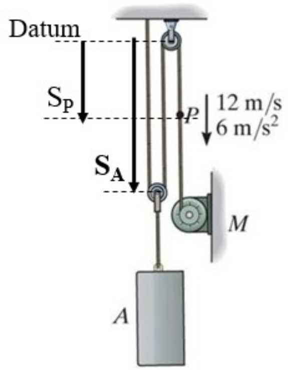
Plan:

1. Relate the cable and block velocities by defining position coordinates. Draw a FBD of the block.
2. Use the equation of motion to determine the cable tension.
3. Calculate the power supplied by the motor and then to the motor.

Example (2 of 3)

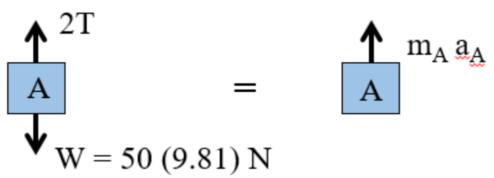
Solution:

1) **Define position coordinates** to relate velocities. Here s_p is defined to a point on the cable. Also s_A is defined only to the lower pulley, since the block moves with the pulley. From kinematics,



$$S_P + 2s_A = l$$
$$\Rightarrow a_P + 2a_A = 0$$
$$\Rightarrow a_A = -a_p/2 = -3m/s^2 = 3m/s^2(\uparrow)$$

Draw the FBD and kinetic diagram of the block:



Example (3 of 3)

2) The **tension of the cable** can be obtained by applying the equation of motion to the block.

$$+\uparrow \quad \sum \mathrm{F_v} = m_A a_A$$

$$2T - 50(9.81) = 50(3) \Rightarrow T = 320.3\ \mathrm{N}$$

3) The **power supplied by the motor** is the product of the force applied to the cable and the velocity of the cable.

$$P_o = F.v = (320.3)(12) = 3844\ \mathrm{W}$$

The **power supplied to the motor** is determined using the motor's efficiency and the basic efficiency equation.

$$P_i = P_o / \varepsilon = 3844/0.8 = 4804\ \mathrm{W} = 4.8\ \mathrm{kW}$$

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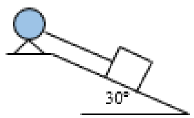
Concept Quiz

1. A motor pulls a 10 lb block up a smooth incline at a constant Velocity of 4 ft/s. Find the power supplied by the motor.

   A) $8.4\ ft \cdot lb/s$ B) $20\ ft \cdot lb/s$

   C) $34.6\ ft \cdot lb/s$ D) $40\ ft \cdot lb/s$

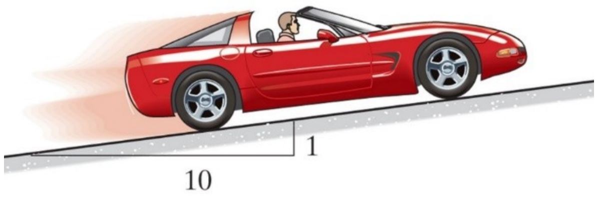


2. A twin engine jet aircraft is climbing at a 10 degree angle at $260\ ft/s$. The thrust developed by a jet engine is 1000 lb. The power developed by the aircraft is

   A) $(1000lb)(260\,ft/s)$ B) $(2000lb)(260\,ft/s)\ \cos 10$

   C) $(1000lb)(260\,ft/s)\ \cos\ 10$ D) $(2000lb)(260\,ft/s)$

Group Problem Solving (1 of 4)



Given: A 2000 kg sports car increases its speed **uniformly** from rest to $25\ m/s\ in\ 30\ s.$ The engine efficiency $\varepsilon = 0.8$

Find: The maximum power and the average power supplied by the engine.

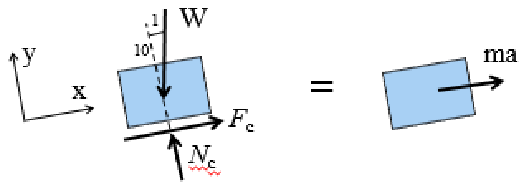
Plan:

1. Draw the car's free body and kinetic diagrams.
2. Apply the equation of motion and kinematic equations to find the force.
3. Determine the output power required.
4. Use the engine's efficiency to determine input power.

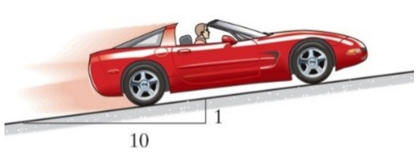
Group Problem Solving (2 of 4)

Solution:

1) Draw the FBD & Kinetic Diagram of the car as a particle.



The normal force $\boldsymbol{N}_c$ and frictional force $\boldsymbol{F}_c$ represent the resultant forces of all four wheels.



The frictional force between the wheels and road pushes the car forward. What are we neglecting with this approach?

Group Problem Solving (3 of 4)

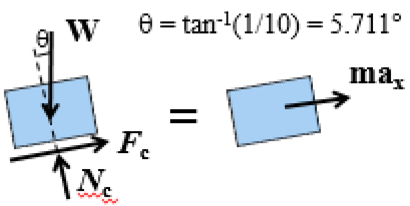
2) The equation of motion

$$\overset{+}{\rightarrow} \sum F_x = ma_x \Rightarrow -2000g(\sin 5.711^\circ) + F_c = 2000a_x$$

Determine a_x using constant acceleration equation

$$\Rightarrow v = v_o + a_x t$$

$$a_x = (25 - 0)/30 = 8.333 m/s^2$$



Substitute a_x into the equation of motion and determine frictional force F_c:

$$F_c = 2000\, a_x + 2000\, \text{g}(\sin 5.711^o)$$

$$= 2000(8.333) + 2000(9.81)(\sin 5.711) = 3619 \text{ N}$$

Group Problem Solving

3) **The max power output** of the car is calculated by multiplying the driving (frictional) force and the car's final speed:

$$(P_{out})_{\max} = (F_c)(v_{\max}) = 3619(25) = 90.47\ kW$$

The average power output is the force times the car's average speed:

$$(P_{out})_{\max} = (F_c)(v_{avg}) = 3619(25/2) = 45.28\ kW$$

4) **The power supplied by the engine** is obtained using the efficiency equation

$$(P_{in})_{\max} = (P_{out})_{\max} / \varepsilon = 90.47 / 0.8 = 113\ kW$$

$$(P_{in})_{avg} = (P_{out})_{avg} / \varepsilon = 45.28 / 0.8 = 56.5\ kW$$

Attention Quiz

1. The power supplied by a machine will always be __________ the power supplied to the machine.

   A) less than
   B) equal to
   C) greater than
   D) A or B

2. A car is traveling a level road at $88\,ft/s$. The power being supplied to the wheels is $52{,}800\,ft{\cdot}lb/s$. Find the combined friction force on the tires.

   A) $8.82\ lb$
   B) $400\ lb$
   C) $600\ lb$
   D) $4.64\ \times 10^{6}\ lb$

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