Cornerstone Electronics Technology and Robotics Week 9
Chapter 4, Energy

- Administration:
  - Prayer
  - Turn in quiz
  - Review quizzes
- Electricity and Electronics, **Section 4.1,** Work & Horsepower:
  - Terms & Definitions:
    - **Work:** Work is force applied over a distance. The formula for mechanical work is:

      W = F x D, where:

      W = Work in ft-lbs
      F = Force in lbs
      D = Distance in ft

      How are W and D related? How are D and F related?

      - According to the formula just given, are the following examples of work?
        - A teacher applies a force to a wall and becomes exhausted.
        - A book falls off a table and free falls to the ground.
        - A man holds up a beam from falling until everyone escapes.
        - A rocket accelerates through space.
      - Student demonstrates work by lifting two 20 pound weights and non-work by holding weights up
    - **Power:** Power is the amount of work done during a period of time such as second or minute. Power is the rate of doing work. For example, moving a pile of dirt using a front end loader vs. by hand. The formula for mechanical power is:

      P = W / T, where:

      P = Power in ft-lbs/sec or ft-lbs/min
      W = Work in ft-lbs
      T = Time in sec. or min.

      Also, W = P * T, and T = W / P

      How are P and T related?

    - The power equation suggests that a more powerful engine can do the same amount of work in less time, that is, time and power are inversely related.
    - Inverse of a number
      - The inverse of X is 1/X.

- Horsepower (hp): The term used to describe mechanical power.

  1 hp = 550 ft-lbs/second.

- Perform Energy Lab 1 – Power Comparison
- Watt (W): The unit of power in electricity. See Watts Law below.
  746 watts = 1 horsepower.
  - Converting watts to horsepower in equations
- Watt's Law:
  - The formula to calculate electrical power.

    P = E x I, where:

    P = Power (work/time), in watts
    E = Volts (work/charge), in volts
    I = Amperes (charge/time), in amperes

- (Answers to the above examples of work?)
  - No, the wall is not displaced. (Show me what work was accomplished.)
  - Yes, the force of gravity acts on the book causing it to go a distance downward.
  - No, the beam does not move through a distance.
  - Yes, the force of the expelled gases causes the rocket to move over a distance through space.)

- Electricity and Electronics, **Section 4.2,** Ohm's Law & Watt's Law:
  - By combining Ohm's law and Watt's law, you can make simple formulas that permit you to solve for current, voltage, resistance, or power if any two of those quantities are known.
  - Solving for several unknowns.
  - Most commonly used forms of the power equation:
    - $P = E \times I$
    - $P = I^2 \times R$
    - $P = V^2 / R$
  - Since $P = V^2 / R$, what is the minimum resistance value for a ½ watt resistor that you can put across a 9 volt battery and still operate within its power rating?

- Electricity and Electronics, **Section 4.3,** Wattmeter & Watt-Hours:
  - Measuring electrical energy consumption:
    - A wattmeter measures instantaneous power.
    - A watt-hour meter measures the amount of power used in a given time. The formula for electrical energy consumption is:

      Energy (watt-hours) = Power (watts) x Time (hours)

    - View GRU house meter operation
    - Demonstrate Watts Up? PRO power analyzer and data logger

- Electricity and Electronics, **Section 4.4,** Efficiency, Gears, Pulleys, and Power:
  - Efficiency: The comparison of input power to output power. It is defined as:

    %E = (Power out/Power in) x 100, where:

    E = Efficiency
    Power out = Useful power output from a device
    Power in = Power into a device

    - Example:
      - Input into a motor is 12 volts dc at 90 amps. The output of the motor under load is 1 hp. What is the efficiency of the motor? This example is on page 76 of your text.
    - Table from the Public Service of New Hampshire:

Typical Motor Efficiencies

Horsepower	Standard Efficiency	Premium Efficiency
1	78.0	82.5
2	78.5	84.0
5	84.0	89.6
10	84.0	91.1
15	87.5	91.7
25	90.2	93.0
50	91.7	94.1
100	91.7	95.0
250	94.1	95.8

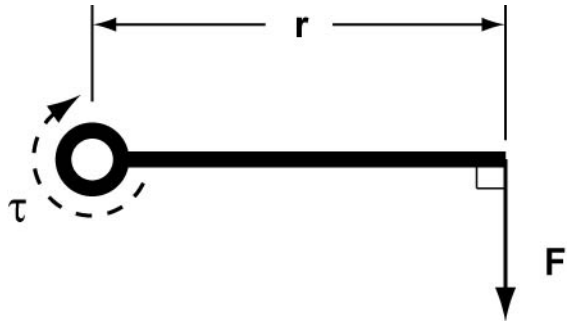
  - Gears, Pulleys, & Power:
    - Gears are used to transfer power. Gears can:
      - Increase/decrease rotational speed with a corresponding decrease/increase in torque.
      - Change the direction of rotation
      - Change the angle of rotation
      - Convert rotational motion to linear motion
      - Change the location of rotation
    - Types: See http://www.societyofrobots.com/mechanics_gears.shtml

- Two parameters or variables associated with gears are rotational speed and torque.
    - Rotational speed is measured in revolutions per minute or rpm.
    - Torque: Torque is the tendency of a force to rotate an object about an axis.

$$\tau = F \times r$$

Where:

τ = Torque
F = Force perpendicular to the radius
r = Radius



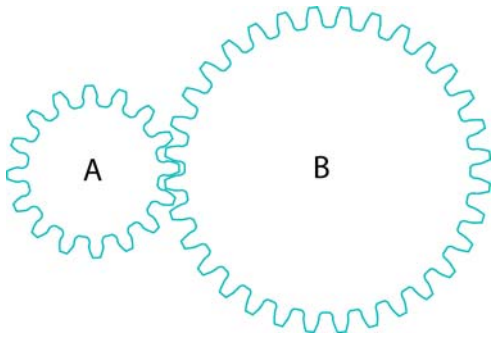
Units of Torque	
International System of Units (SI)	**English**
newton-meters (N·m)	inch-pounds (in·lb)
	foot-pounds (ft·lb)
	inch-ounces (in·oz)
1 N·m = 0.738 ft·lb	1 in·lb = 0.113 N·m
1 N·m = 0.113 in·lb	1 ft·lb = 1.356 N·m
1 N·m = 141.61 in·oz	1 in·oz = 7.062E-03 N·m

    - Torque wrench demonstration

- In robotics, motor torque is more useful than rotational speed. Motors commercially available do not normally have the desirable rotational speed or torque needed for robotics. Gears will convert high rotational velocity (rpm) from a motor to supply a better torque at a lower rotational velocity.
- The basic formula relating torque and rpm for a gear system is:

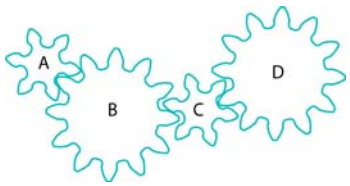
Input Torque x Input rpm = Output Torque x Output rpm

- Gear ratios:
  - Gear ratio = Number of teeth on Gear B / Number of teeth on Gear A

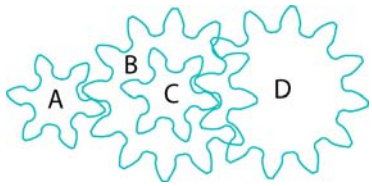


Gear ratio = 32/16
Gear ratio = 2:1

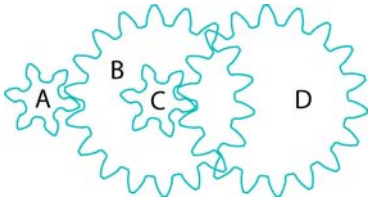
  - The rpm of gear B is ½ of A.
  - The torque from gear B is 2x gear A.
  - See: http://www.rkm.com.au/ANIMATIONS/animation-gear-ratio.html
- Idlers and higher gear ratios:



Gear Ratio = 2:1



Gear Ratio = 4:1
Gear A=6 teeth, B=12 teeth, C=6 teeth, D=12 teeth



Gear Ratio = 9:1
Gear A=6 teeth, B=18 teeth, C=6 teeth, D=18 teeth

- Unfortunately, by using gears, you lower your input to output power efficiency. When using two spur gears, typically expect efficiency to be around 90%.
- Bicycle gearing demonstration
- Efficiency of GH12-1641T-F gearhead motors used in Year 2:

Power In:

P_{IN} (watts) = E (V) x I (A)
P_{IN} (watts) = 12 V x .25 A
P_{IN} (watts) = 3.00 watts

Power Out:

P_{OUT} (watts) = (Torque (N-m) x 2Π x Rotational Speed (rpm)) / 60
P_{OUT} (watts) = (1000 gm-cm x 9.81 x 10^{-5} N-m / gm-cm x 2 Π x 71 rpm) / 60
P_{OUT} (watts) = 0.73 watts

Efficiency:

%E = ($Power_{OUT}$ / $Power_{IN}$) x 100
%E = 0.73 watts / 3.00 watts) x 100
%E = 24%

- Perform Energy Lab 2 – Function of Gears
- Related web sites:
  - http://www.societyofrobots.com/downloads/gearology.pdf

Electronics and Robotics I
Energy Lab 1 – Power Comparison

- **Purpose:** The purpose of this lab is to acquaint the student with the principles of work and power through competition.

- **Apparatus and Materials:**

  - 1 – 40 Pound Weight
  - 1 – Stop Watch
  - 1 – Tape Measure

- **Procedure:**
  - Measure the distance the students and instructor lift the 40 pound weight.
  - Count the number of lifts each makes in 1 minute.
  - Calculate the power in ft-lbs/min
  - Convert ft-lbs/min to ft-lbs/sec
  - Convert ft-lbs/sec to hp

- **Results:**

Power Comparison			
	Student 1	Student 2	Instructor
Force (lbs)	40 lbs	40 lbs	40 lbs
Distance/Lift (ft)	ft	ft	ft
Lifts/min			
Work (ft-lbs)			
Power (ft-lbs/min)			
Power (ft-lbs/sec)			
Power (hp)			

- **Conclusions:**

Electronics and Robotics I
Energy Lab 2 – Functions of Gears

- **Purpose:** The purpose of this lab is to acquaint the student with the 5 ways gears can transfer power.

- **Apparatus and Materials:**

    - An assortment of Lego gears, shafts, connectors, and other parts

- **Procedure:**
    - Each student must make a working model illustrating each of the gear functions:
        - Increase/decrease rotational speed with a corresponding decrease/increase in torque.
        - Change the direction of rotation
        - Change the angle of rotation
        - Convert rotational motion to linear motion
        - Change the location of rotation
    - Have the instructor check off each completed task.
    - Build a combination of gears with a 25:1 gear ratio.

- **Results:**

Task	Completed
Increase/decrease rotational speed	
Change the direction of rotation	
Change the angle of rotation	
Convert rotational motion to linear motion	
Change the location of rotation	