RoboJackets

CAT

THE ARTHUR M. BLANK FAMILY FOUNDATION

2007 TE Sessions – Mechanical Energy and Fluid Power

Oct. 30, 2007

CAT

MECH ENERGY STORAGE

RoboJackets

CAT

Energy

What is energy?

Energy

Units:

Foot-pounds; Newton-meters; Joules; BTU; Calories, etc

- **Energy is energy regardless of sign**
- **Non directional**

Sign significance

- **Energy can be stored in two ways**
- **Potential**
- **Kinetic**

Sign significance

- **Energy can be expended through work**
- **or dissipated (friction & heat)**

RoboJackets

Energy

Potential Storage

Potential

Energy can be stored as a force against gravity

- **Simplest way is a force at a distance (foot-pounds)**
- **Raising a mass against gravity**

No energy stored **E = mgh Joules stored**

Energy stored = mass x gravity x height
E = mgh

Energy

Potential Storage

Potential

Energy can be stored as inside mechanical devices through material deflection

- **Springs store energy**
- **Spring constant**

No energy stored **Energy stored by applying force**

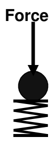
Energy

Potential Storage

Springs

Energy stored is a function of two things:
- Spring constant k
- Distance of spring deflection x

Spring constant
- **k = Force/Displacement = F/x**
- **Amount of force needed to deflect spring one inch**



Force causes spring to deflect

Energy

Potential Storage

Springs

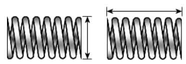
Other spring definitions, terms, and specs

Material

- Spring steel, music wire

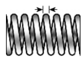
Specs

- Outside Diameter and length



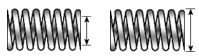
Specs

- Wire Size



Specs

- Rod and Hole Size



Energy

Potential Storage

Springs

Other spring definitions, terms, and specs

Compressed Length

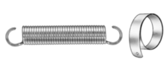
- Minimum length of spring under force

Compression springs

- Forces compress the spring

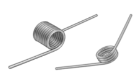
Tension

- Forces extend the spring



Torsion

- Torques compress the spring



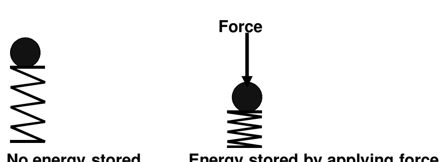
Energy

Potential Storage

Potential

Energy can be stored as inside mechanical devices through spring deflection

- **Energy stored = $\frac{1}{2} k x^2$**



Energy
Potential Storage

Example

- Energy stored = ½ k x^2
- k = 20 lbf/in
- Desired energy = 100 ft-lbf
- How far must spring be compressed?
  - 100 ft-lbf = ½ 20 lbf/in x^2
  - x = 3.16 inches

Energy storage is quadratic, not linear

RoboJackets

Energy
Potential Storage

Other Potential Storage Mechanisms

- Compressed gas
  Air compressors store air in large tanks
  Stored air is used in large quantities by tools
- Fuel
  Hydrocarbons (gasoline, propane, etc)
  Fuel is chemically stored energy
- Batteries
  Batteries store energy as chemical electricity
  Batteries can be recharged by adding energy

RoboJackets

Energy
Kinetic Energy

What is kinetic energy?

- Kinetic energy is in motion
- All mass in motion has kinetic energy

- Falling/Moving mass
  Mass in motion has energy proportional to its mass and speed

- Rotating mass
  Spinning mass has energy proportional to its inertia and rpm

RoboJackets

Energy
Kinetic Energy

- Kinetic energy is in motion
- All mass in motion has kinetic energy

- Falling/Moving mass
Mass in motion has energy proportional to its mass and speed

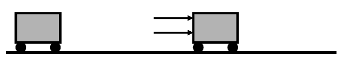
- Rotating mass
Spinning mass has energy proportional to its inertia and rpm

RoboJackets

Energy
Kinetic Energy

Mass in motion

- Energy = ½ mass x velocity^2
- $E = \frac{1}{2} mv^2$



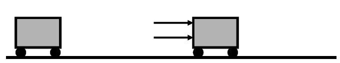
- Energy increases quadratically with velocity
- Energy increases linearly with mass

RoboJackets

Energy
Kinetic Energy

Example

- 20kg mass moving at 10 m/s
- $E = \frac{1}{2} mv^2$



Energy required = ½ x 20kg x (10m/s)^2
E = 1000 Joules (N-m)

RoboJackets

Energy
Kinetic Energy

- Flywheels
  - Flywheels store kinetic energy by spinning
  - Examples: engine flywheel, saw blade, governor

  - Rotating mass energy:

  Energy = ½ I w^2

  I = moment of inertia

  w = angular velocity (rad/s)

RoboJackets

Energy
Kinetic Energy

- Flywheels

Example:

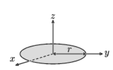
5kg, 0.2m diameter, thin disc spinning at 100 rad/s

How much energy is it storing?

First calculate its moment of inertia:

I_z = ½ m r^2

I_z = ½ 5kg $(0.1m)^2$ = 0.025kg-m^2



Calculate kinetic energy stored:

E = ½ Iw^2

E = ½ (0.025kg-m)$(100rad/s)^2$

E = 125 Joules

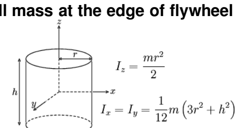
RoboJackets

Energy
Kinetic Energy

- Notes on spinning masses:
  - Energy increases quadratically with angular velocity (rpm)
  - Energy increases linearly with inertia

  - Inertia increases linearly with mass
  - Inertia increases quadratically with radius

- Greater inertia effects from having all mass at the edge of flywheel

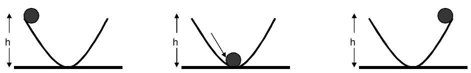


RoboJackets

Energy
Dissipation

Where does energy go???

First an example on ideal energy conversion:



PE = mgh
KE = 0 (v = 0)

PE = 0 (h = 0)
KE = ½ mv^2

PE = mgh
KE = 0 (v = 0)

Ideally, mgh = ½ mv^2 and potential is fully converted into kinetic, then back to potential, infinitely

RoboJackets

Energy
Dissipation

Conservation Of Energy

FOUNDING PRINCIPLE OF THE UNIVERSE!!!

Energy in = Energy out ALWAYS!!!

- Energy is never perfectly converted though
- Efficiency % = $\frac{\text{mechanical energy output}}{\text{mechanical energy input}}$

Sources of loss:

- Friction
- Heat loss
- Noise

Most energy is lost through friction and heat generation

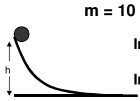
RoboJackets

Energy
Dissipation

Efficiency Example

A mass slides down a slope, reaching a final velocity

m = 10 kg, h = 2m, v_f = 5 m/s



PE = mgh
KE = ½ mv^2

Initial potential energy:
$PE_0 = mgh = (10kg)(9.81m/s^2)(2m) = 196.2$ J

Initial kinetic energy:
$KE_0 = ½ mv^2 = (1/2)(10kg)(0m/s) = 0$J

Final potential energy:
$PE_f = mgh = (10kg)(9.81m/s^2)(0m) = 0$ J

Final kinetic energy:
$KE_f = ½ mv^2 = (1/2)(10kg)(5m/s)^2 = 125$ J

Efficiency = Final total energy / Initial total energy:
eff% = (125 J)/(196.2 J) = 63.7%

RoboJackets

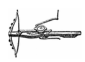
Energy

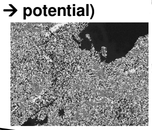
Storage and Conversion

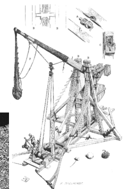
DEMO

Energy is stored in a spring, then released
Converting its potential energy to kinetic energy of a smaller body
Other energy converters:

- **Trebuchet, catapult (potential → kinetic)**
- **Generator (kinetic → electric potential)**
- **Engine (chemical potential → kinetic)**
- **Motor (electric potential → kinetic)**
- **Air compressor (kinetic → potential)**







RoboJackets

Activity # 1

30 minutes

CATAPULT!!!

Store some potential energy and convert it to kinetic energy!

Ammo: Vex gear (36 tooth)

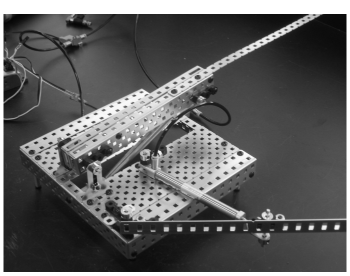
Build a catapult using gravity to fling a Vex gear

Distance will be judged from where the gear first hits ground

Be quick though! You have 25 MINUTES starting NOW

RoboJackets

Demo of example



RoboJackets

FLUID POWER

RoboJackets

What is Fluid Power?

- Pressurized fluid does the work
- Hydraulics
  - Oil
  - Water
  - Other fluids
- Pneumatics
  - Air
  - Nitrogen
  - Hot gases
  - Other gases

RoboJackets

When to use fluid power

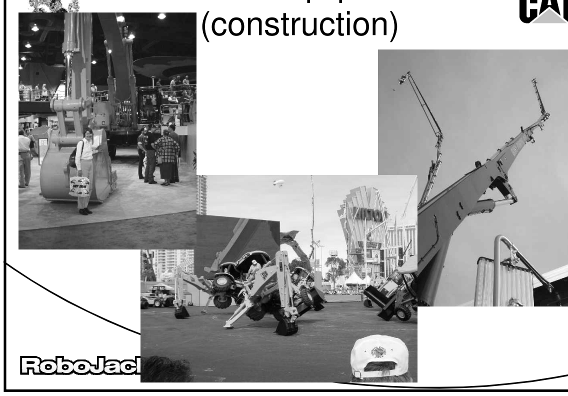
- Electric
  - High speed but low torque (force) → requires gears
  - Control is often more precise and rapid and less expensive
- Hydraulic and pneumatic
  - Speed/torque combo is well suited to many motion applications
  - Well suited to high forces
  - Can be delivered “around the corner”
  - Control is usually by throttling, hence wastes energy
- Center for Compact Efficient Fluid Power
  - A brazen commercial

RoboJackets

Hydraulics is Especially critical to the Mobile Equipment Industry

RoboJackets

Mobile equipment (construction)



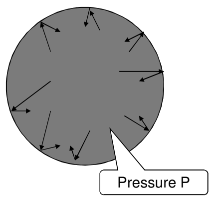
RoboJackets

Pneumatics compared to hydraulics

- No problems of a spills
- Compressibility stores energy
  - Available for your use
  - Dangerous if excessive volumes or pressures
- Difficult to control precisely
- Fluid is readily available
  - Should be filtered, dry
- Usually lower forces

RoboJackets

Pressure of an "ideal" Gas

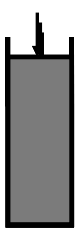


$$P \times V = mR \times T$$

- Pressure of a gas is due to the force of gas molecules bouncing off the walls.
- Pressure increases when molecules are moving faster, heavier, or if there are more molecules.
- Molecules move faster when they are hot.
- mR depends on molecule.

RoboJackets

Getting Work out of Air



- Work is force acting over a distance of motion, e.g. Newton x meters
- Put air in a container under pressure
- Allow part of the container to expand
- The expanding part does work

RoboJackets

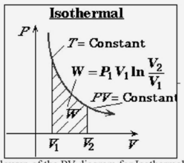
How much energy is in your tank?

- Tank Volume = 150 ml or 9.154 in^3
- Pressure = 413,700 Pa or 60 psi
- Atmospheric pressure = 101,325 Pa or 14.7 psi
- Answer:
  - Assume constant temperature: PV = mRT = constant
  - Work = PV $\ln(P/P_{atm})$
    = 0.15 x 413,700 x ln(4.083) = 87.3 kJ

RoboJackets

Alternative Work Possibilities

$$W = \int_{V_1}^{V_2} P(V)\,dV$$

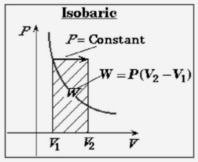


Blowup of the PV diagram for Isothermals

$$P = \frac{nRT}{V}$$

$$W = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \frac{nRT}{V}\,dV$$

$$= nRT \int_{V_1}^{V_2} \frac{dV}{V} = nRT \ln \frac{V_2}{V_1}$$



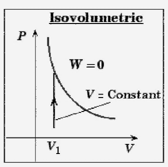
$$P = \text{Constant}$$

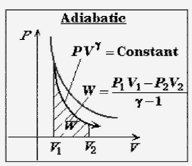
$$W = \int_{V_1}^{V_2} P\,dV = P \int_{V_1}^{V_2} dV$$

$$= P\,\Delta V$$

RoboJackets

More work possibilities





http://www.ac.wwu.edu/~vawter/PhysicsNet/Topics/Thermal/PV_WorkDiag.html (1 of 2)10/23/2006 1:07:17 PM

RoboJackets

How much energy in your tank can you use?

- Line losses:
  Pressure drop proportional to flow
- Throttling losses:
  Pressure drop proportional to flow squared
- Cylinder friction:
  Coulomb plus viscous friction, depends on seals

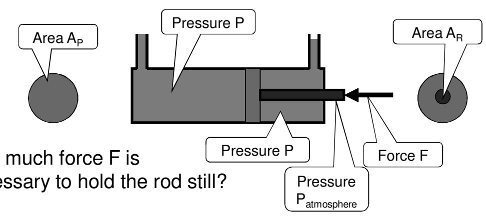
RoboJackets

Force available

- Pressure x Area = Force
- Area = pi x Bore^2 / 4
- For Vex cylinder:
  - Bore = 10 mm → Area = 78.5 mm^2
  - Force = 413,700 x 78.5 x 10^{-6} = 32.48 N
  - at 100 psi: F = 54 N

RoboJackets

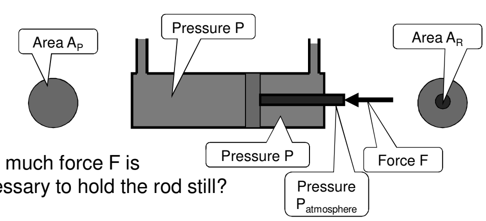
The Effect of Different Areas



How much force F is necessary to hold the rod still?

RoboJackets

The Effect of Different Areas



How much force F is necessary to hold the rod still?

Answer: Force to the right = Force to the left

$$P \times A_P = P \times (A_P - A_R) + P_{atm} \times A_R + F$$

$$F = A_R \times (P - P_{atm})$$

RoboJackets

Basic Operation of the Servo Valve (single stage)

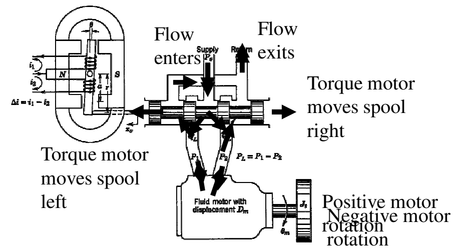


Figure 7-11 Schematic of a single stage electrohydraulic servovalve connected to a motor with inertia load.

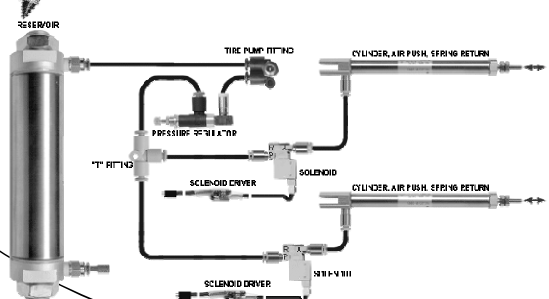
RoboJackets

Components for hands on task

- Cylinder: single acting, spring return
  - Max force: 54 N or 12 lbf
  - Stroke: 50 mm or 1.987 in
  - Bore: 10 mm or 0.394 in
- Valve: normally closed vents to atmosphere
- Tank:
  - Size: 150 ml or 9.154 in^3
  - Max pressure: 6.895 bar (10^5 bar) or 100 psi
- Mechanical parts

RoboJackets

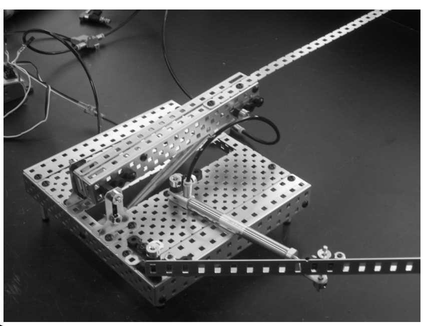
VEX Pneumatic Kit 1



RoboJackets

Today's Challenge

- Maximum distance launch of 1 Vex gear
- Rules
  - The reservoir shall be charged at 60 psi
  - The base shall remain immobile
  - Only fluid power actuators (pistons) shall be used
  - The best out of three launches shall be considered



An example design

- Consider different configurations than the one shown?
  - two cylinders in parallel or in series
  - different linkage configurations to achieve higher speeds
  - making the lever as light as possible
  - taking advantage of flexibility to achieve higher release speeds…

Today's Challenge # 2

- Maximum distance launch of 1 Vex gear
- Rules
  - – The reservoir shall be charged at 60 psi
  - – The base shall remain immobile
  - – Only fluid power actuators (pistons) shall be used
  - – The best out of three launches shall be considered

Some YouTube Videos

- http://www.youtube.com/watch?v=jkft2qaKv_o
- http://www.youtube.com/watch?v=0gk-yQ1H3M8
- http://www.youtube.com/watch?v=7l0qIO7y6Cc
- http://www.youtube.com/watch?v=2cIuuplWRIQ

Legal

These slides and more are available at

http://www.robojackets.org

For more information contact the RoboJackets.
(contact info available via the web)

Legal

Title 17 Chapter 1 § 107. Limitations on exclusive rights: Fair use

Notwithstanding the provisions of sections 106 and 106A, the fair use of a copyrighted work, including such use by reproduction in copies or phonorecords or by any other means specified by that section, for purposes such as criticism, comment, news reporting, teaching (including multiple copies for classroom use), scholarship, or research, is not an infringement of copyright. In determining whether the use made of a work in any particular case is a fair use the factors to be considered shall include—

(1) the purpose and character of the use, including whether such use is of a commercial nature or is for nonprofit educational purposes;
(2) the nature of the copyrighted work;
(3) the amount and substantiality of the portion used in relation to the copyrighted work as a whole; and
(4) the effect of the use upon the potential market for or value of the copyrighted work.

The fact that a work is unpublished shall not itself bar a finding of fair use if such finding is made upon consideration of all the above factors.

RoboJackets