UMassAmherst

Embedded Systems Motors

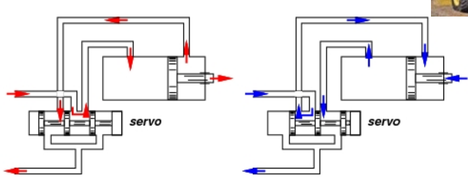
Actuators

...physical devices that transform electrical, chemical, or thermal energy into mechanical energy...

- hydraulic
- pneumatic
- electric
  - stepper
  - permanent magnet DC
- artificial muscles
  - shape memory alloys
  - polymers
  - biological
  - bucky tubes

Hydraulic

- 1000-3000 psi
- open-loop control
- 5KHz bandwidth
- great power-to-weight
- messy/high maintenance



Hydraulic

GRLA - Gorilla (SARCOS)

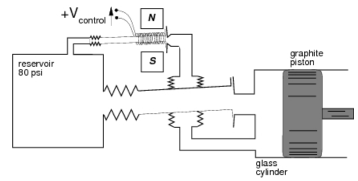
- 1.75 meters from shoulder to wrist
- 3000 psi hydraulic
- exoskeletal master

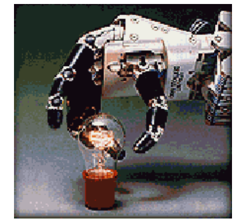
Hydraulic - Jumping Spiders

- spiders cannot extend their legs by activating muscles alone --- they generally have less developed extensor musculature
- blood acts as hydraulic fluid---BP is very high compared to other insects and animals
- special valves and muscles compress their forebodies and act as hydraulic actuators for their legs.

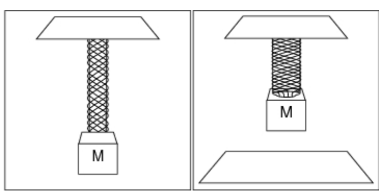
Pneumatic

- *pneuma* 300 BC - animal spirits
- 60-100 psi
- jet-pipe servo valves
- passively backdrivable
- delicate

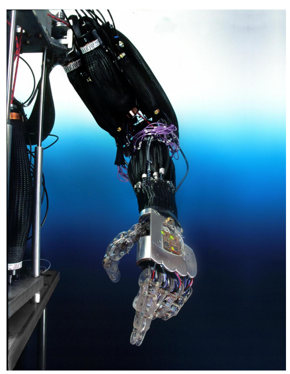




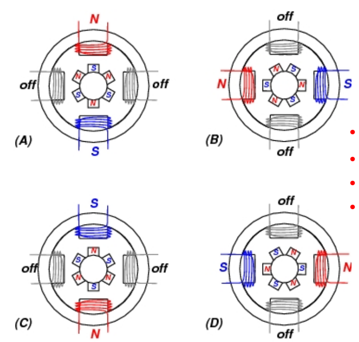
Pneumatic - McKibben Air Muscles



- stroke about 40% of free length
- 0-60 psi
- power-to-weight up to 100:1
- backdrivable
- easily packaged
- relatively slow

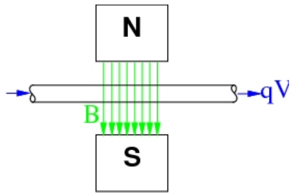


Electric Motors - Stepper



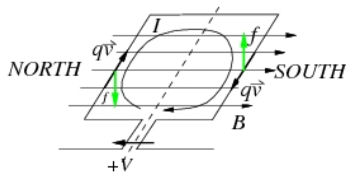
- precise open-loop
- low torque
- resonance (50-150 steps/sec)
- cogging

Electric Motors - Permanent Magnet DC



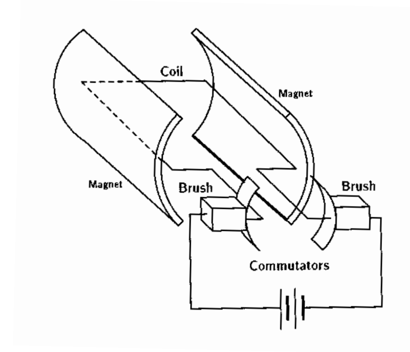
Lorentz force

$$F = qV \times B$$



- back emf
- commutation

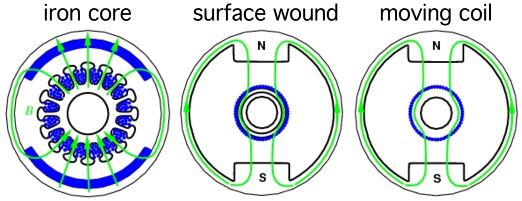
Electric Motors - Commutation



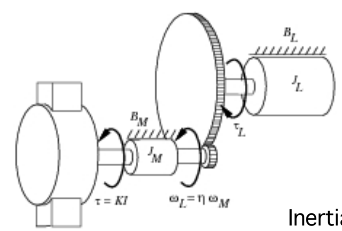
Electric Motors - Permanent Magnet DC

- cheap reliable
- cogging
- big torques
- good power-to-weight
- continuous operation
- high speeds

iron core surface wound moving coil



Electric Motors - Gearboxes

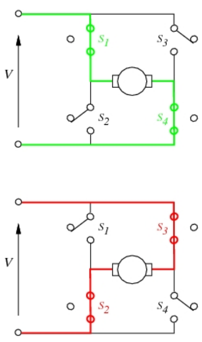


$$\tau_{out} = \frac{1}{\eta}\tau_{in}$$

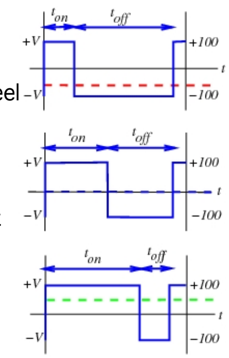
$$\theta_{out} = \eta\theta_{in}$$

Inertia of load can be dominated by the inertia of the rotor

Interfacing Electric Motors



- reversing polarity
- terminals floating - freewheel
- terminals shorted - brake
- switches are opened and closed at different rates and durations to supply different RMS voltages - pulse width modulation (PWM)



Artificial Muscles

Mechanical properties: elastic modulus, tensile strength, stress-strain, fatigue life, thermal and electrical conductivity

Thermodynamic issues: efficiency, power and force density, power limits

Packaging: power supply/delivery, device construction, manufacturing, control, integration

Artificial Muscles - Shape Memory Alloys

Nickel Titanium - *Nitinol*

- *crystalographic phase transformation from Martensite to Austenite*
- *contract (when heated) 5-7% of length - 100 times greater effect than thermal expansion*
- *relatively high forces*
- *about 1 Hz*

Artificial Muscles - New Technologies

Chemical polymers - gels (Jello, vitreous humor)

- 1000 fold volume change ~ temp, pH, electric fields
- force up to 100 N/cm^2
- *25 um fibers -> 1 Hz, 1 cm fiber -> 1 cycle/2.5 days*

Electroactive polymers

- *store electrons in large molecules*
- *change length of chemical bonds - batteries/capacitors*
- *deform ~ V^2*

Artificial Muscles - New Technologies

Biological Muscle Proteins

- actin and myosin
- 0.001 mm/sec in a petri dish

Fullerenes and Nanotubes

- graphitic carbon
- high elastic modulus -> large displacements, large forces
- macro-, micro-, and nano-scale
- extremely robust
- potentially superior to biological muscle