Actuators

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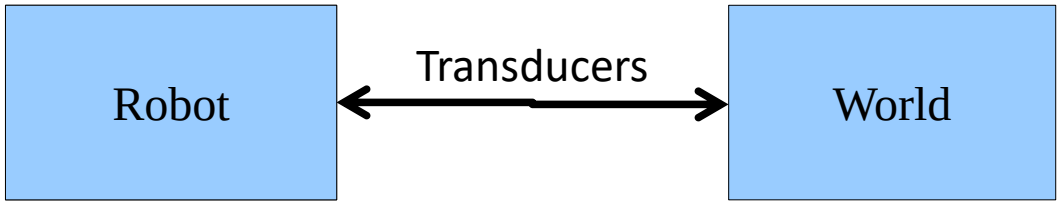
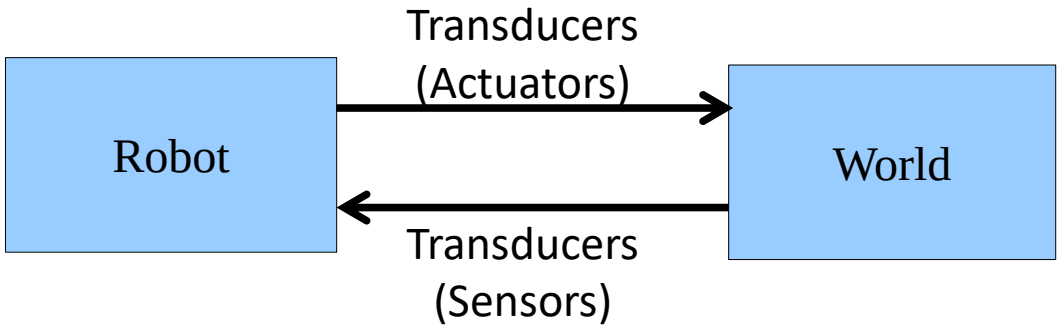
Obs: Language: English!

Robot & World


Robot
Transducers
World


Transducers
(Actuators)
Robot
World
Transducers
(Sensors)

Actuators

(including motors, etc.)

Principle of workings

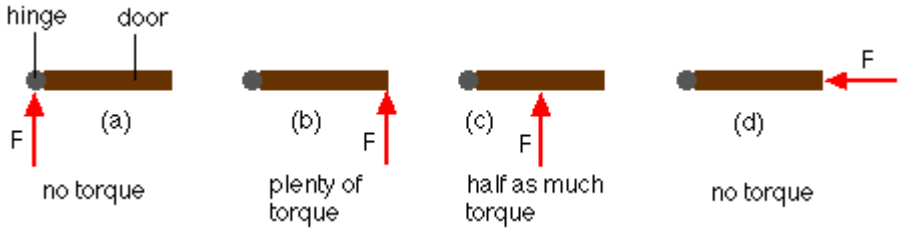
- Actuators + Motors are **transducers**
  - Rotative (torque)
  - Linear (force)

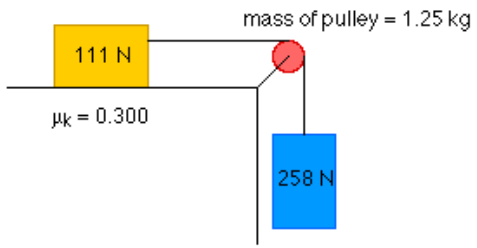
- Physics of producing torque / force
  - Electromagnetic (current + magnetic field)
  - Pneumatic + Hydraulic (pressure difference)
  - Piezoelectric+Ultra Sonic Motor (Shape Shifting Materials)
  - Internal Combustion (Diesel/Gasoline!) :(
    - Efficiency <30%

Simplified Physics

- Simplified Definitions:
  - Mechanical Power (P) = Speed (n) x Torque (M)
    Typically measured in Watts (W)
  - Electrical power (P) = Voltage (V) x Current (I)
    Typically measured in Watts (W)
  - Efficiency => $Power_{out}$ / $Power_{in}$ (percentage %)

  - … Torque … "rotational force" => force x distance

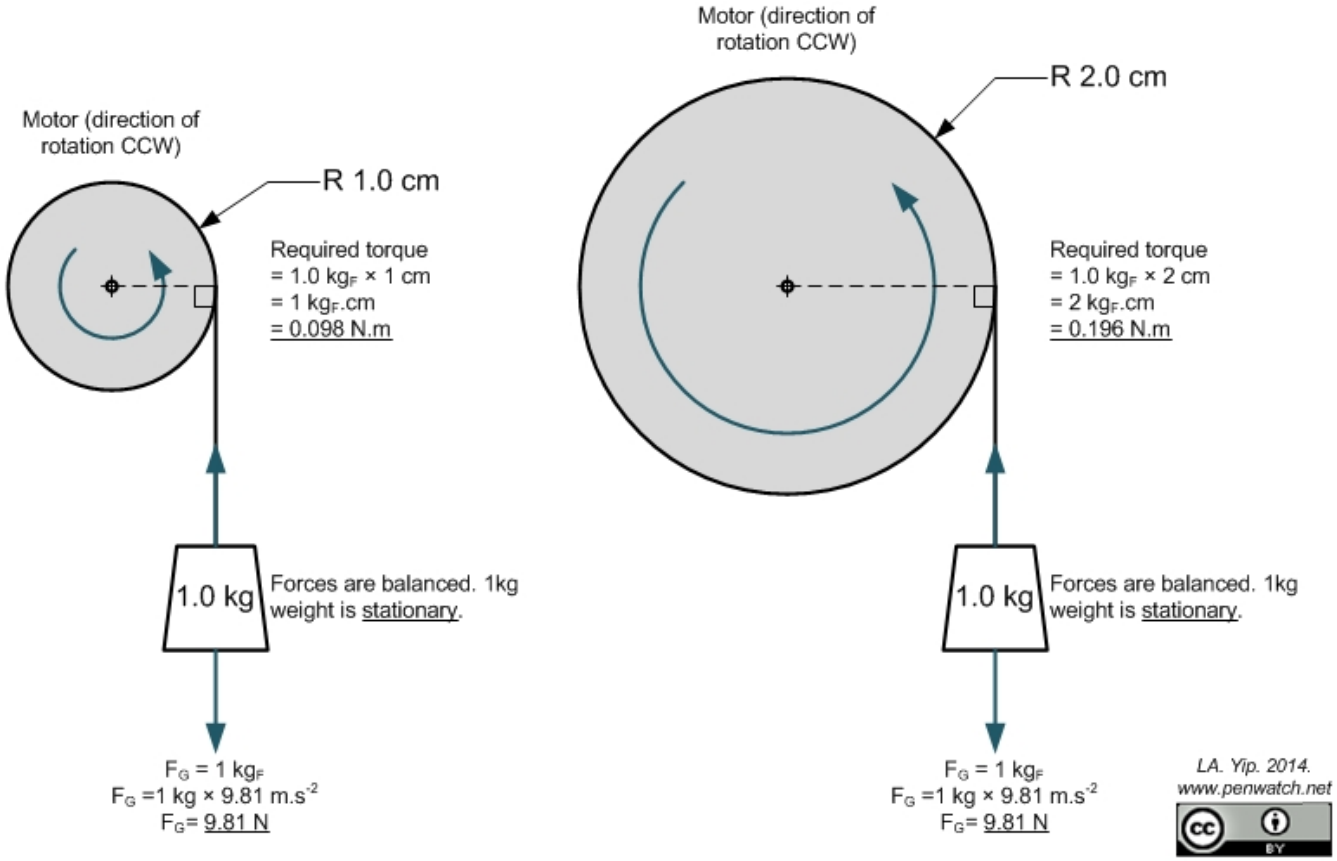




http://physics.bu.edu/~duffy/py105/notes/Torque.html

Simplified Physics

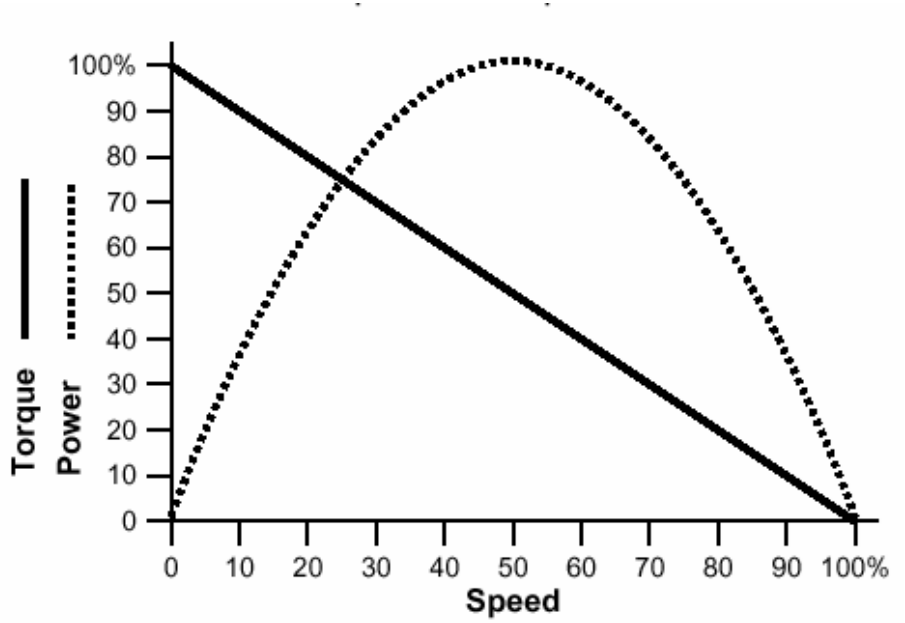
- … Torque … "rotational force" => force x distance



Mechanical

Issues:

- Start
- Stall
- Nominal
- Max mechanical
- Above nominal ?
- Life cycle
- Thermal
- Zero speed ?!



Plot the curve for the mechanical load and for the motor.

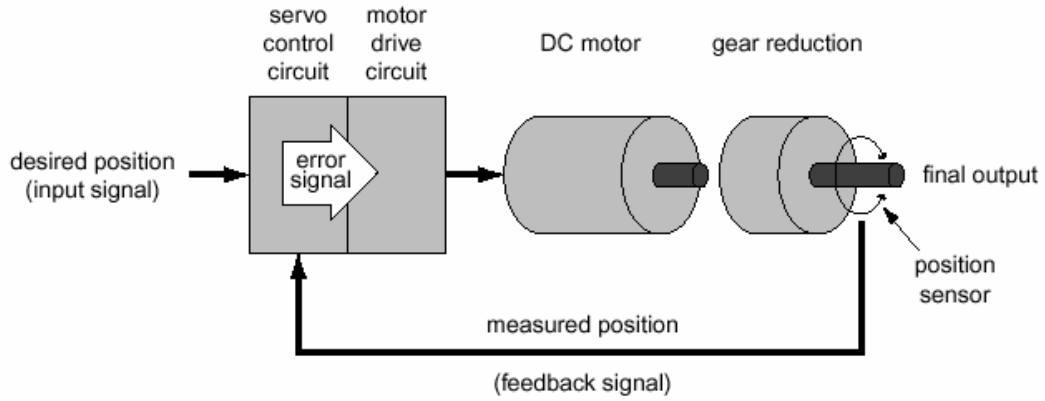
=> Intersection is the working point

General Considerations

- Each motor has different characteristics
  - Efficiency / size / safety / life cycle / max speed + max force
  - Start-Up + stall – start-up currents + *f.c.e.m.*
  - Electricity is nice for input, force / torque is output
  - Static / viscous / non-linear friction
  - Dead Zone / non linear
- Point of work of actuator is the interception of actuator curve and load curve – probably not very simple
  - Stable or dynamic point of working
- Actuators are mechanically complex
  - Throughout the actuator chain, several limitations will apply, all are dangerous
- Broken actuators are typically expensive and time consuming!!!

Servo Motor

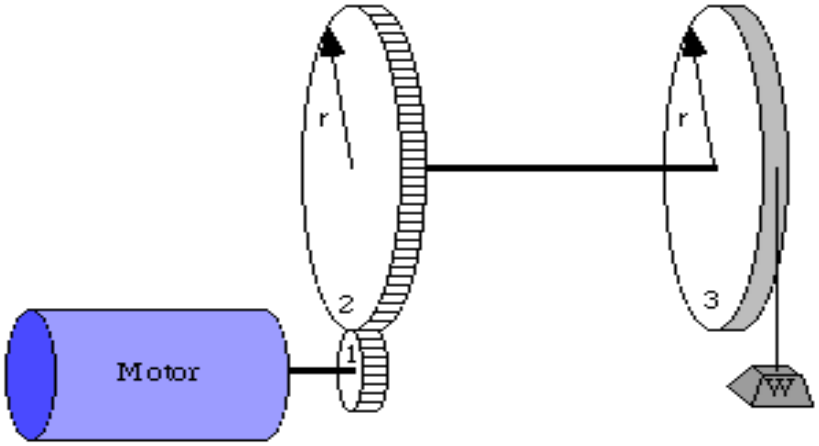
- A complex actuator that includes closed loop control
- Generally power and signal separated
- External behaviour similar to ideal actuator
  - Linear, fast, safe, reliable, “intelligent” (?!), “smart” (?!), ...
- Position controllers have extra complexity so servo position actuators are frequent:



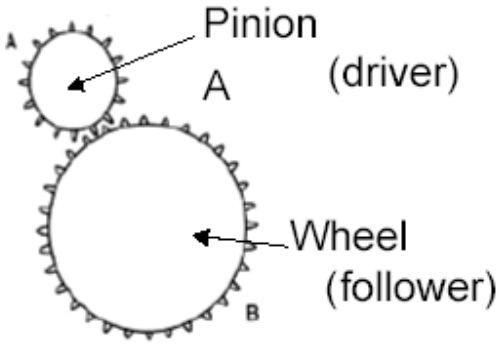
Actuator
“Chain”

Gears

- What for ? Exchange Speed for Torque
  - $T_{output} = T_{input} \times r_{output} / r_{input}$ *(reduce speed to get larger torque)*
- Types:
  - Spur, Bevel, Worm Gear, Rack and pinion, planetary ...
  - http://www.societyofrobots.com/mechanics_gears.shtml



Gear Math

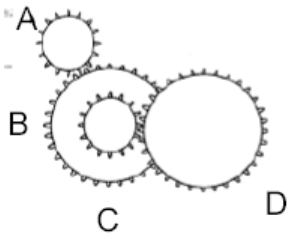


- Gear ratio

  $R = \#\,teeth_w / \#teeth_p$
- $T_w = e(T_p\ R)$
- $\omega_w = e(\omega_p / R)$

Spur Gear Reduction

A is attached to motor



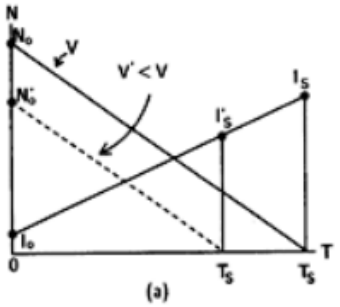
$\omega_{out} = (A/B)\ (C/D)\ \omega_{in}$

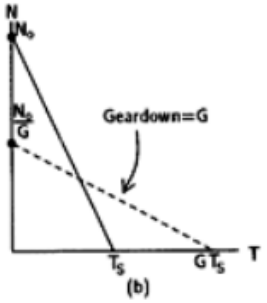
C is a pinion attached to B's output shaft
D is on output shaft

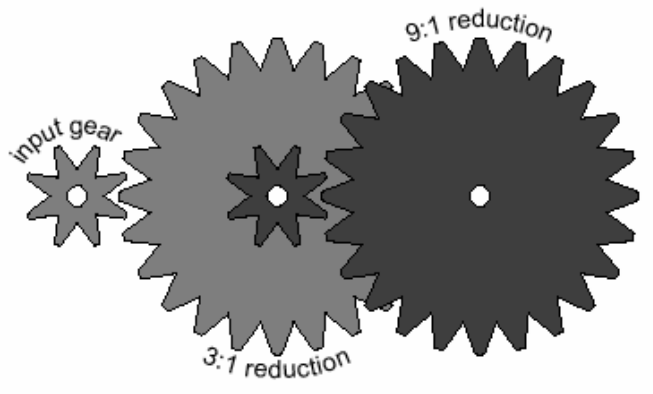
Some well-designed gears have high efficiency, so mechanical power is mostly kept and speed is exchanged with torque

Gear math (ii)

- Exchange speed for torque

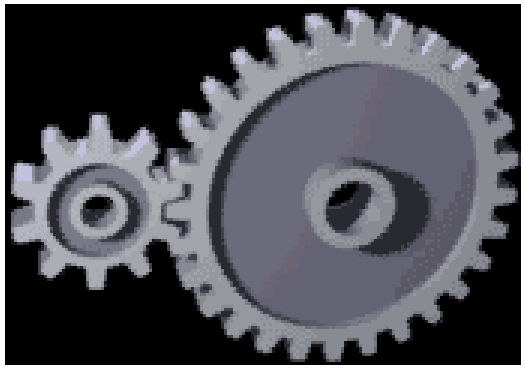


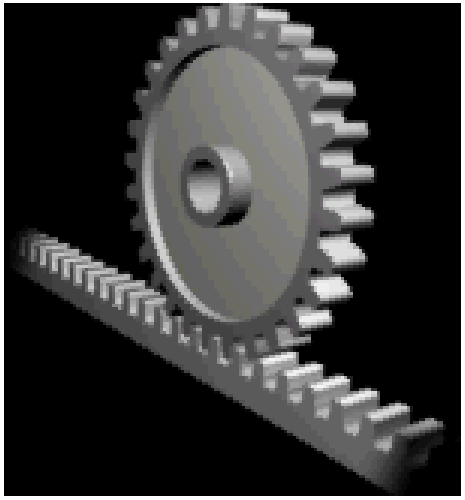




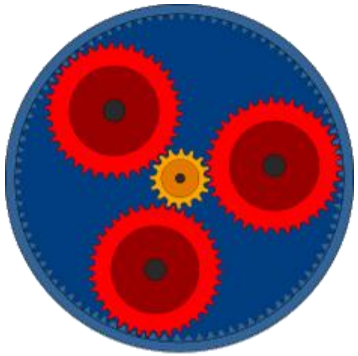
8-tooth gear on left; 24-tooth gear on right

Spur Gear / Rack pinion



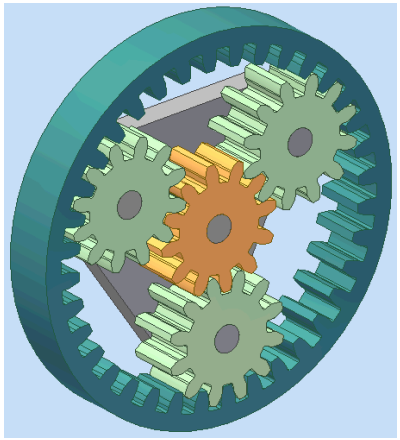


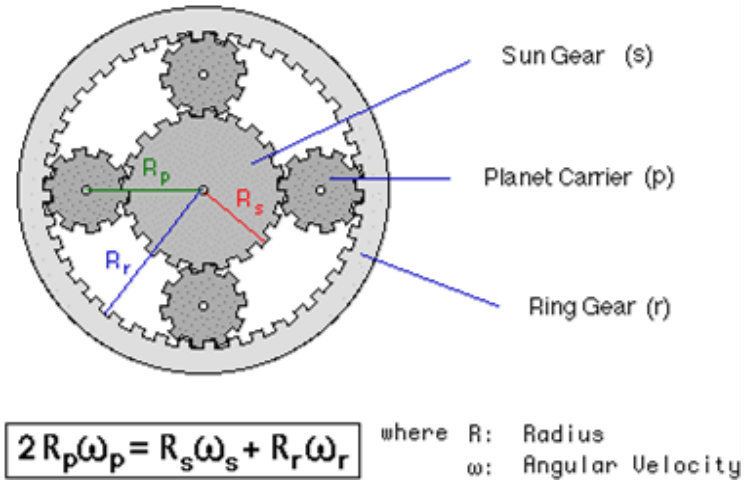
Planetary Gear



3D Printed example (video):

https://www.youtube.com/watch?v=P-Obt-9tZVo



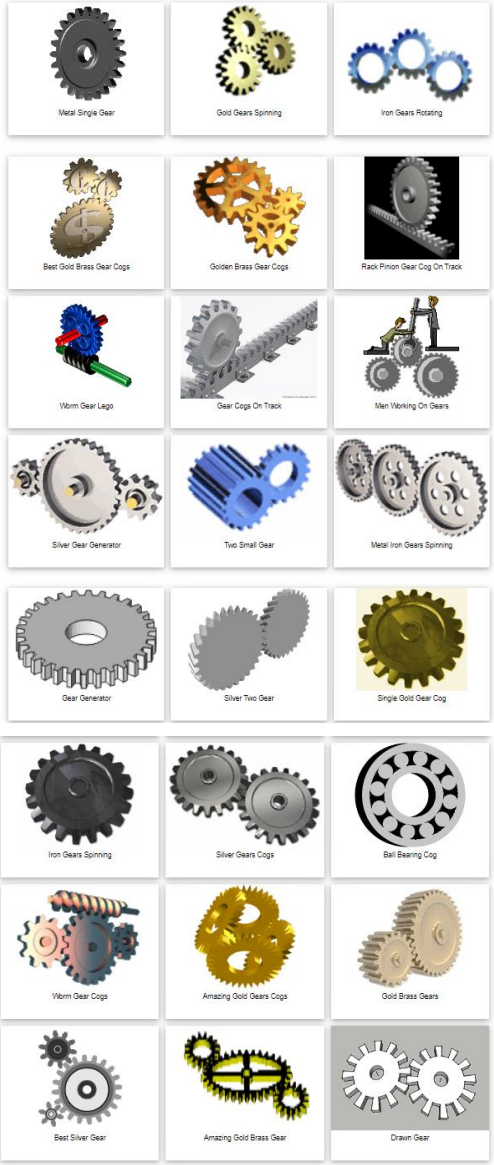


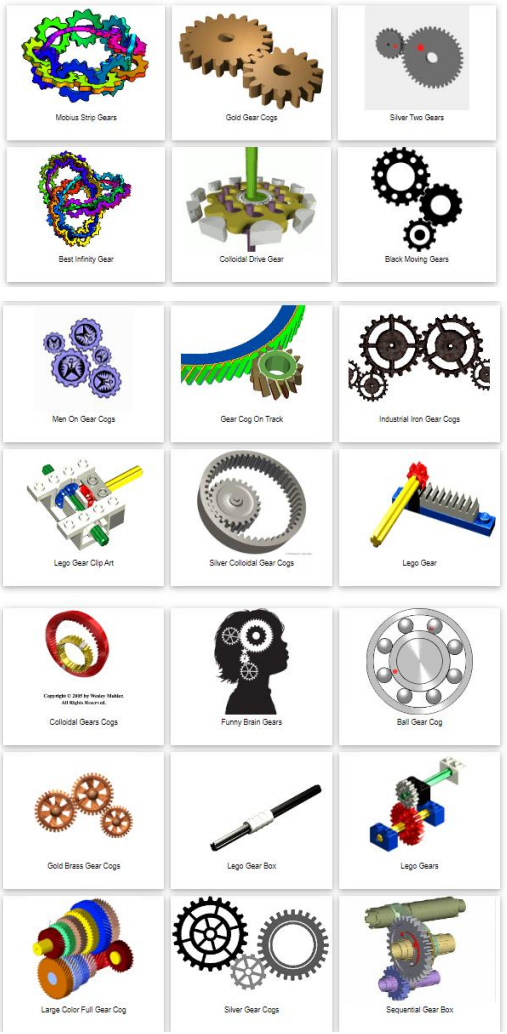
$$2R_p\omega_p = R_s\omega_s + R_r\omega_r$$

where R: Radius
ω: Angular Velocity

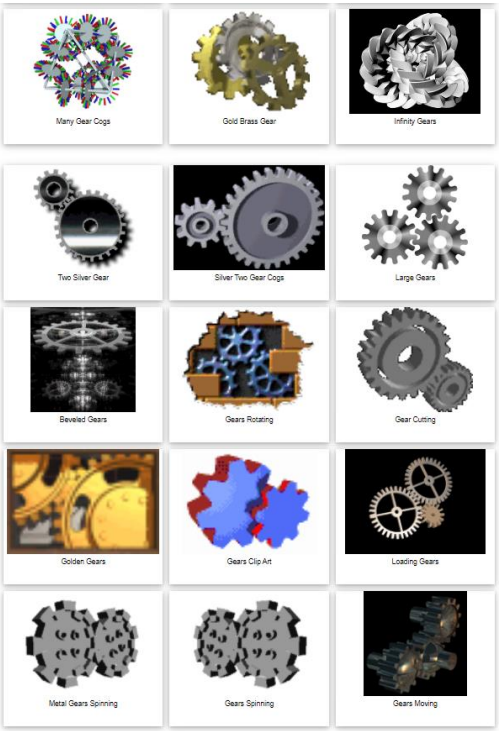
Many gears, briefly discussed / animations:
https://www.iqsdirectory.com/articles/gearbox/gear-drive.html

Many gear types…



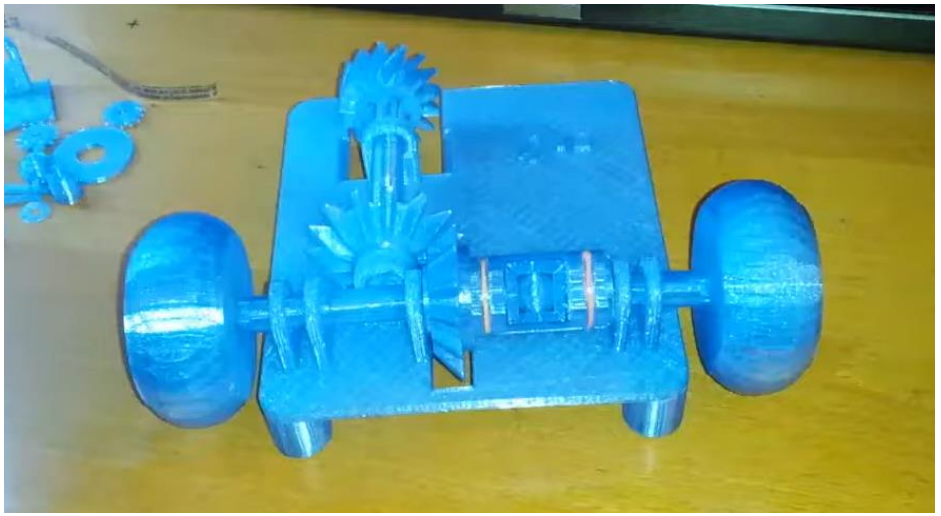


https://bestanimations.com/Science/Gears/Gears.html



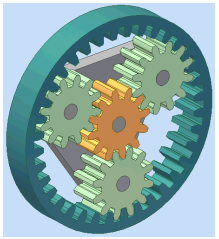
Gears

- Differential Gear:
  - http://www.youtube.com/watch?v=vBm-SzO3ggE
  - http://youtu.be/gIGvhvOhLHU

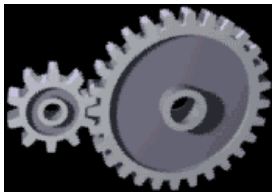


https://www.thingiverse.com/thing:724379

- Planetary Gear:
  - http://www.youtube.com/watch?v=ECljAo1q1RQ
  - http://www.youtube.com/watch?v=acXiebKExQM
  - http://www.youtube.com/watch?v=50uQriU1mCs

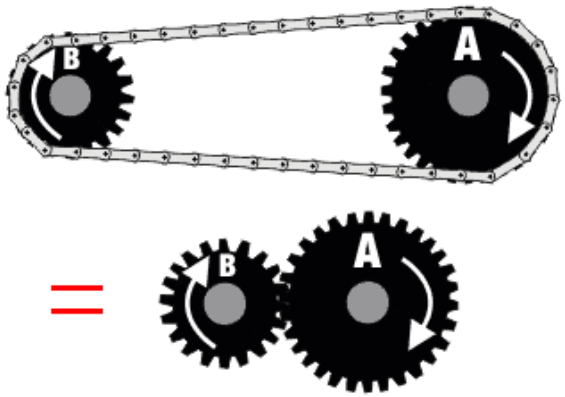


- Spur Gear:
  - http://www.youtube.com/watch?v=5QCvONWi4mk
  - http://www.youtube.com/watch?v=H1cfbv7iqsY

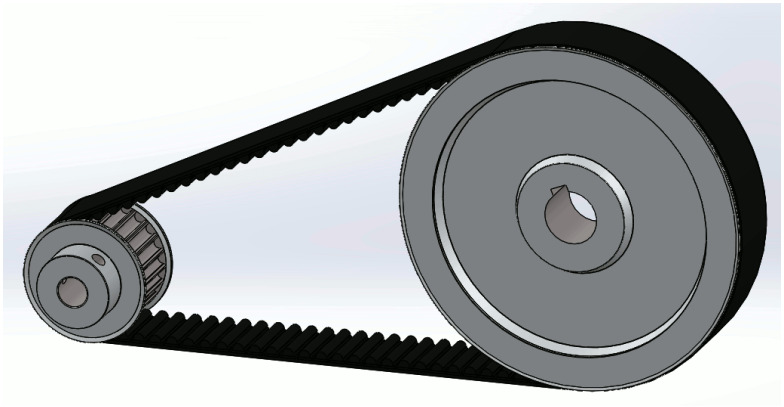


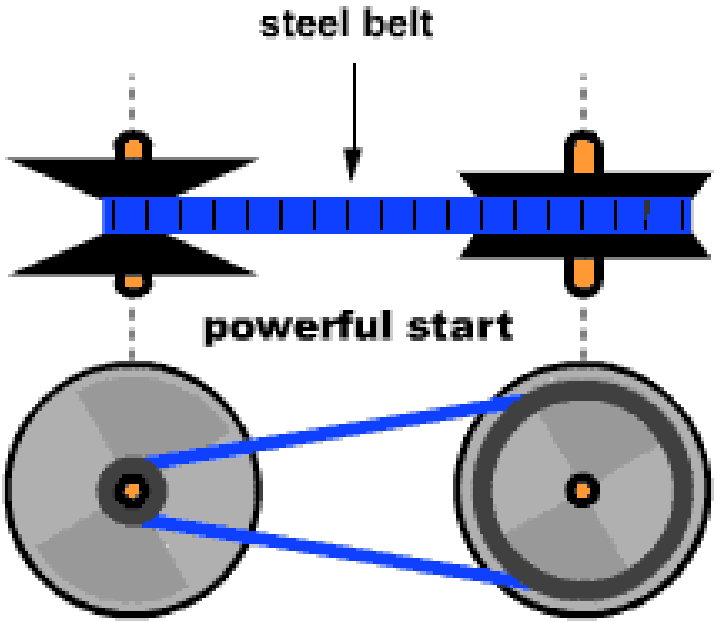
- Worm Gear:
  - http://www.youtube.com/watch?v=S3XAeMCeZr0&NR=1

Gear-chain / belt

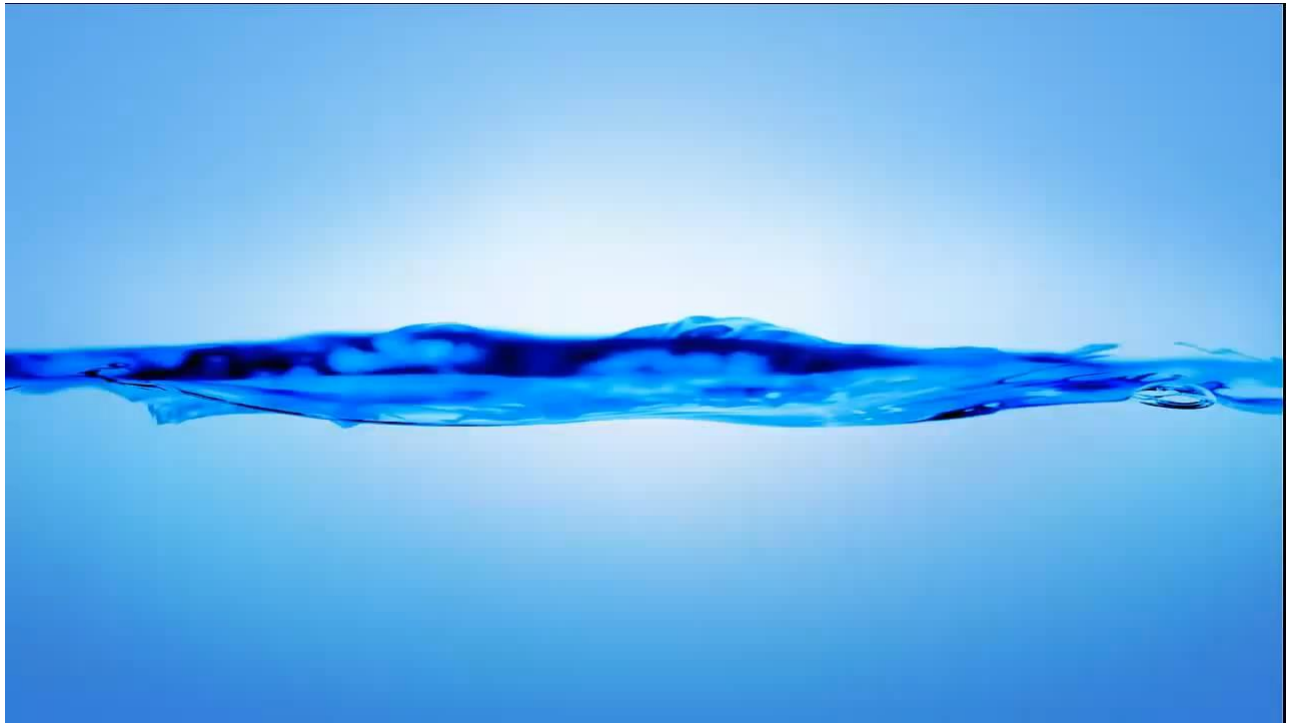


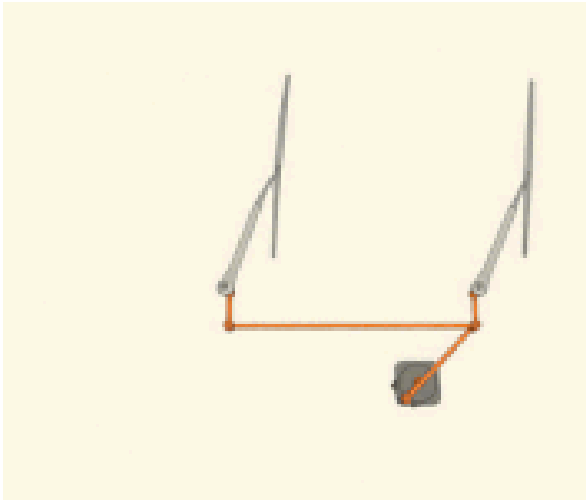
Mind Movement directions!





Example Actuator Chain: windshield wiper



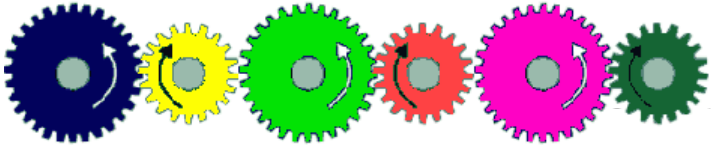


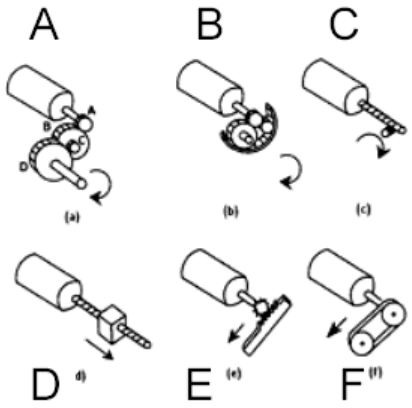
https://youtu.be/D_KIOr_TpcM - Taha Emara

Example Actuator Chain (ii)

Actuator Chain (iii)

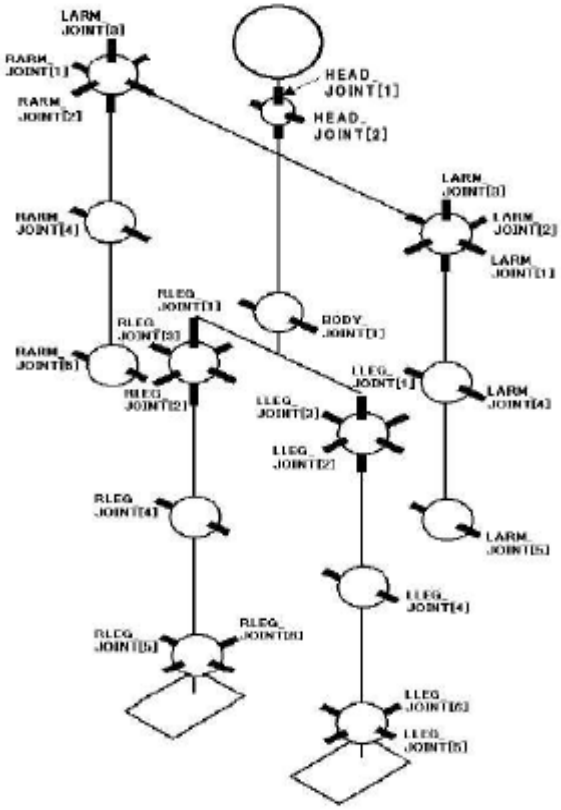
- Can change angle of rotation or direction of rotation: e.g. c
- Can convert rotational motion to linear motion (eg E)
- Can change location of rotational motion (eg a)

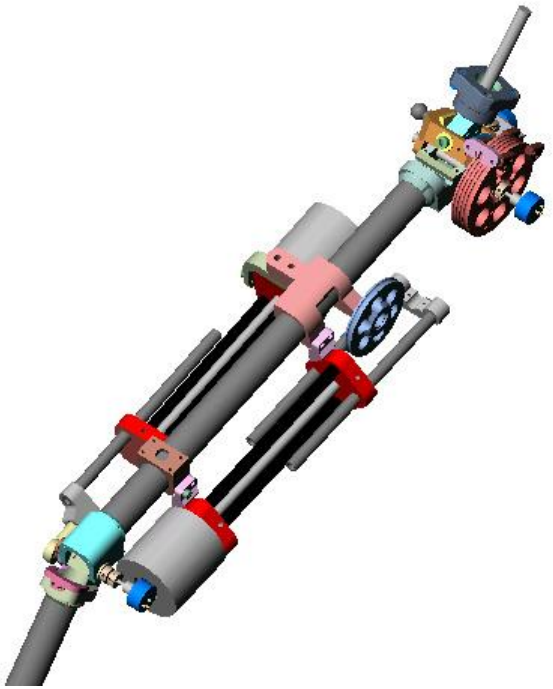




A: spur gear
B: Planetary gears
C: Worm gear
D: Ball screw
E: rack and pinion
F: belt and pulley

Actuator Chain - humanoid





Gear Knowledge

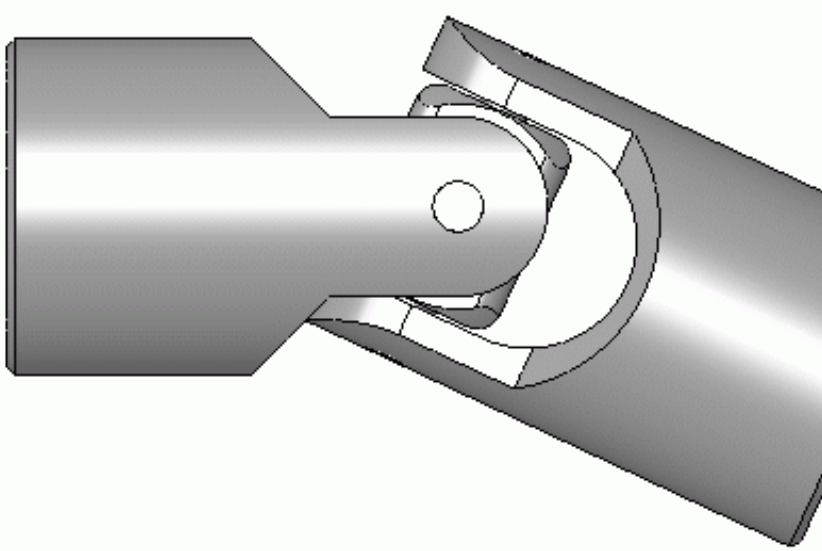
- Backlash
  - Amount of space between an engaging tooth and the tooth space of the mating gear
  - Proportional to lubricant flow (high is good)
  - Inverse to efficiency (high is good) – low efficiency generates heat
  - Backlash is a non linearity in control (makes control much harder)
- Other project considerations
  - Noise
  - Durability (life cycle time)
  - Breakdown
  - Friction

Cardan & Joints

http://www.youtube.com/watch?v=Dh5C4e4exhM

http://www.youtube.com/watch?v=TGvKS4bHgTk&feature=

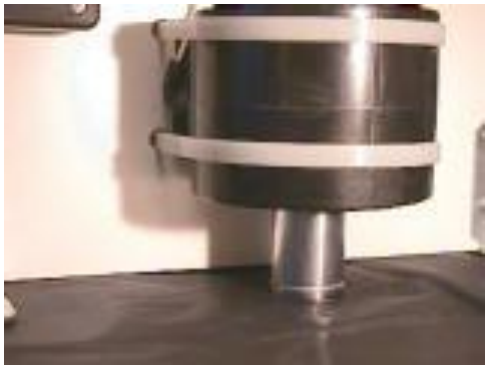
http://www.youtube.com/watch?v=R-NzQ21i-98

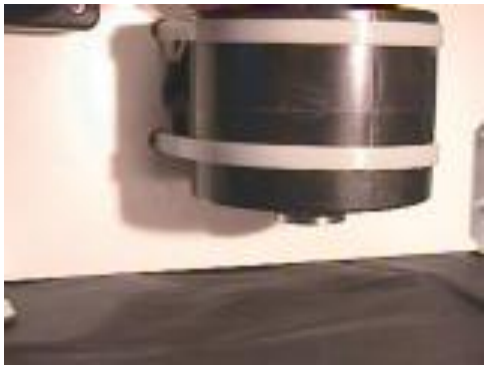


Some actuators (in-depth)

Solenoid Actuator

- Solenoid – electro magnet with air core
  - Simplest electric actuator
  - When energized, tends to minimize magnetic reluctance
  - Drop (off) / pull (on) - *and 50 % of the time on (PWM) ???*
  - Example: Kicker in robotic soccer

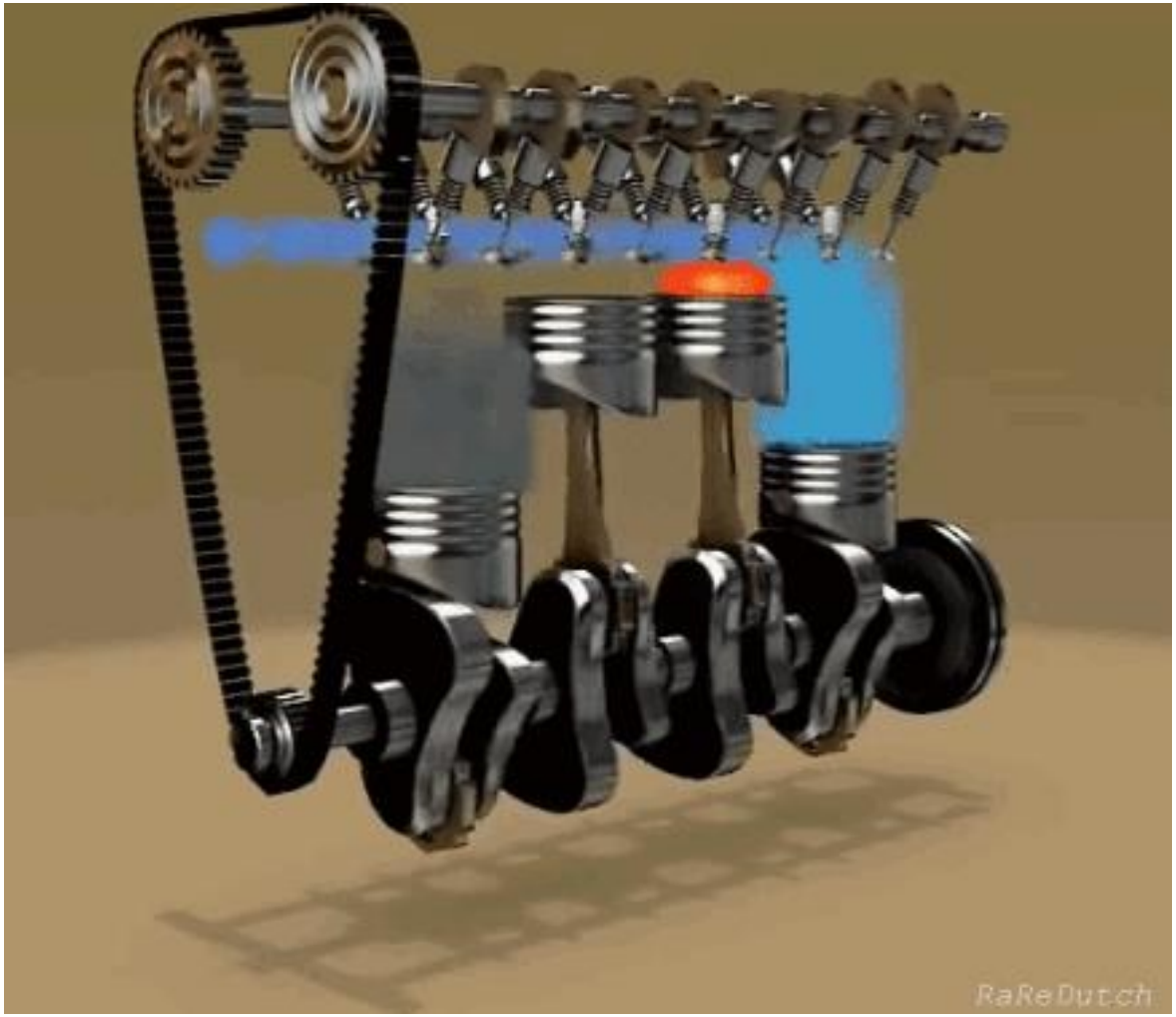




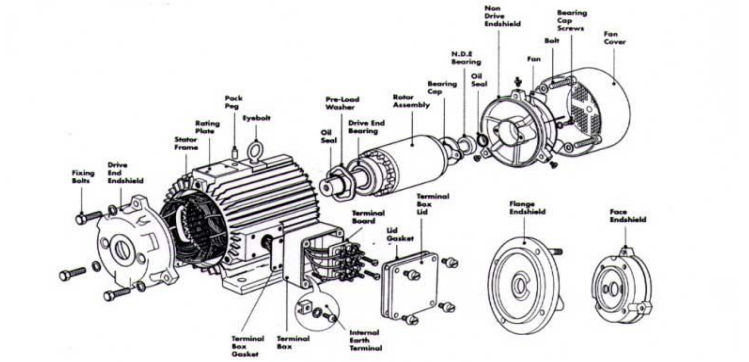
Motor Technologies

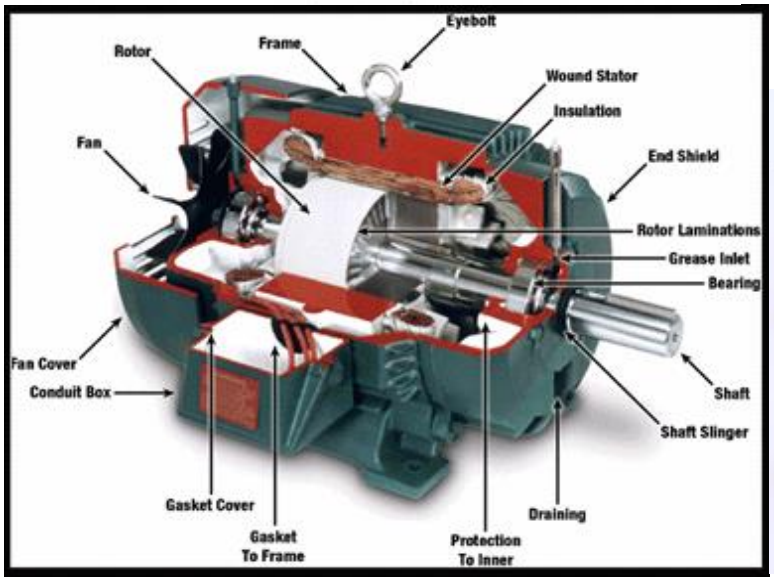
- AC Motors
  - synchronous, induction 1,3 phase, ...
- DC Motors
  - Perm Magnet/winding, brushless DC Motors
  - Piezo/Ultra Sonic Motors
- Stepper Motors

Not Internal Combustion

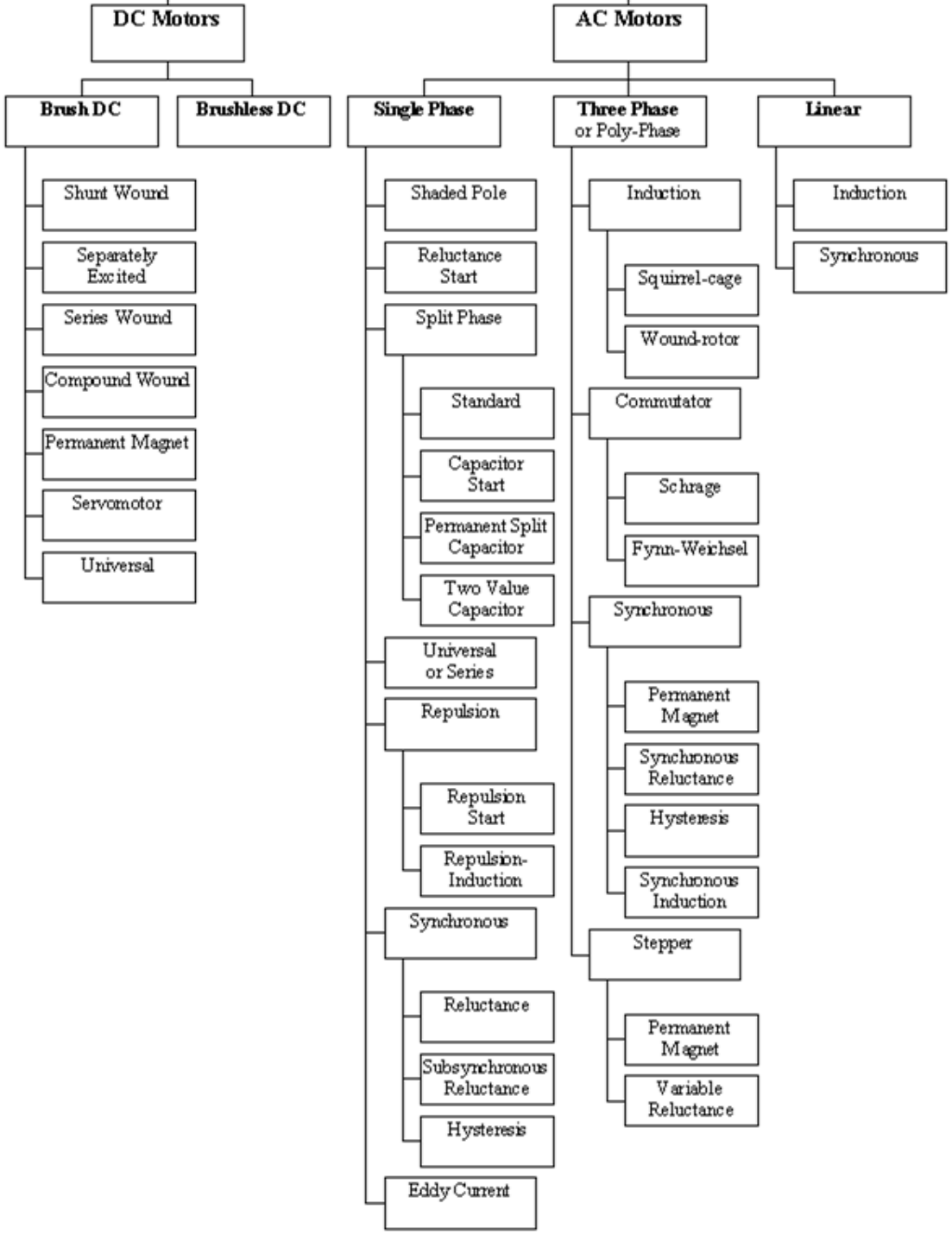


https://kaiserscience.wordpress.com/physics/heat/internal-combustion-engines/


Fixing Bolts
Drive End Endshield
Pack Peg
Rating Plate
Eyebolt
Stator Frame
Oil Seal
Pre-Load Washer
Drive End Bearing
Rotor Assembly
Bearing Cap
N.D.E Bearing
Oil Seal
Non Drive Endshield
Fan
Bolt
Bearing Cap Screws
Fan Cover
Terminal Board
Terminal Box Lid
Lid Gasket
Flange Endshield
Face Endshield
Terminal Box Gasket
Terminal Box
Internal Earth Terminal


Eyebolt
Rotor
Frame
Wound Stator
Insulation
Fan
End Shield
Rotor Laminations
Grease Inlet
Bearing
Fan Cover
Conduit Box
Shaft
Shaft Slinger
Gasket Cover
Gasket To Frame
Protection To Inner
Draining

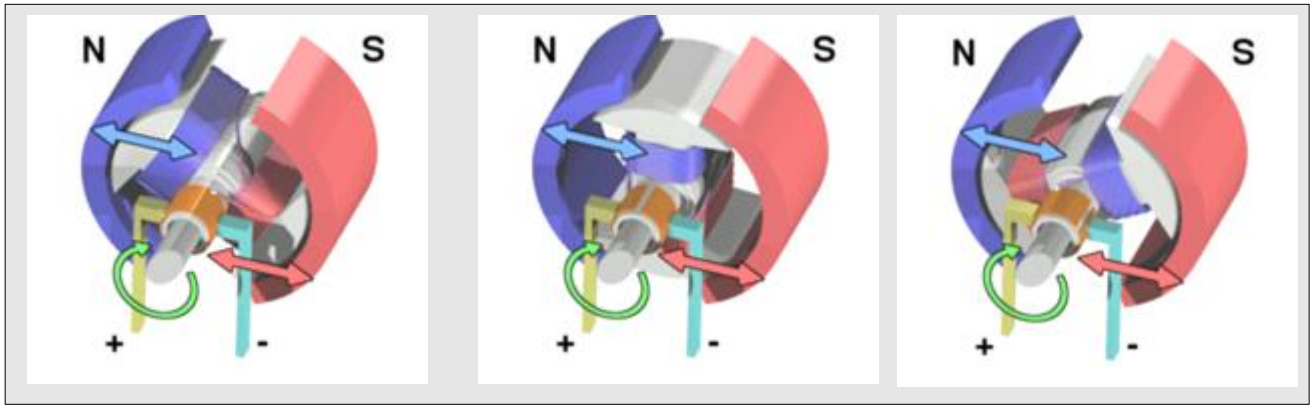
"World of electrical motors"



DC Motor

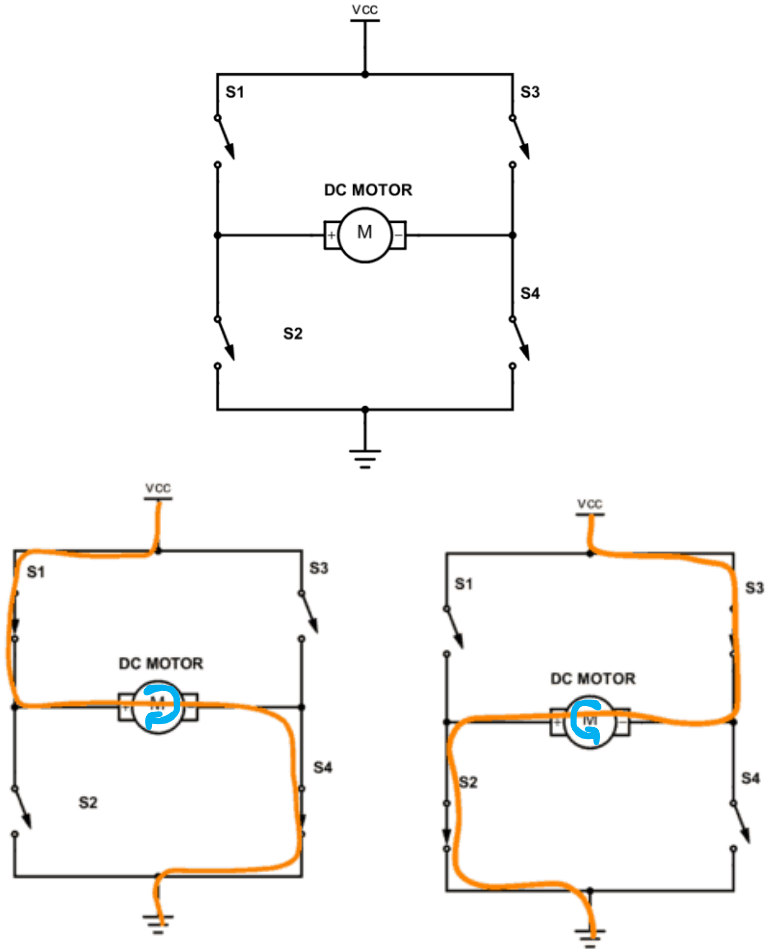
- Conventional brushed DC motor
  - Permanent magnets on the stator
  - Mechanical brushes on the rotor
  - Currents on the rotor drive the shaft to always rotate

- Brushless DC Motor
  - Rotor has permanent magnets
  - Stator windings are commutated by external electronics to keep motion
  - For perfect drive, needs position sensing in the shaft
  - (has same points in common with stepper motors)



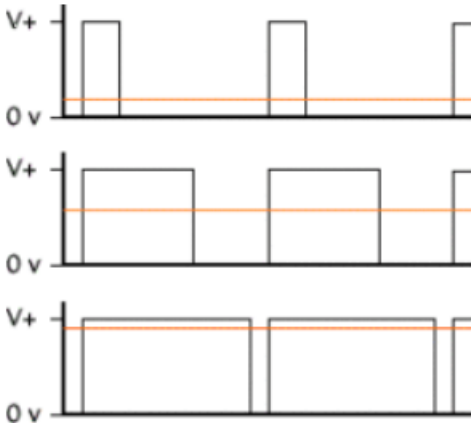
Drive Electronics – H Bridge

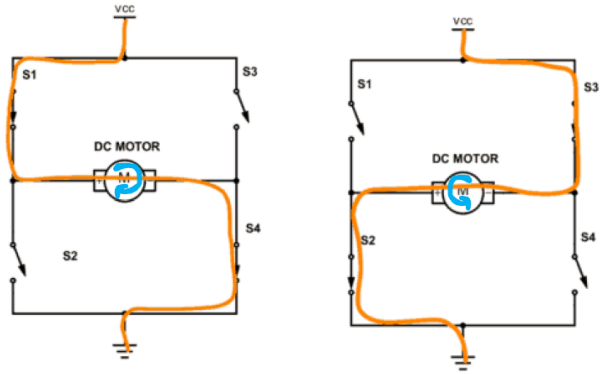
- H-brigde
  - PWM (AC or DC)
  - 2 way
  - …
- S1..S4 are very high speed electronic switches
- PWM ~ 20 kHz
- Input for a servo drive simply direction and analogue speed

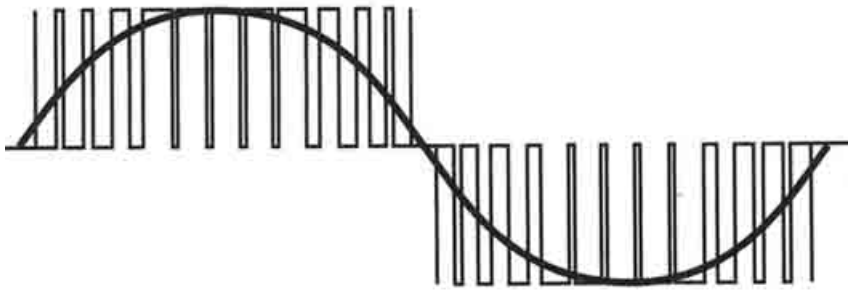


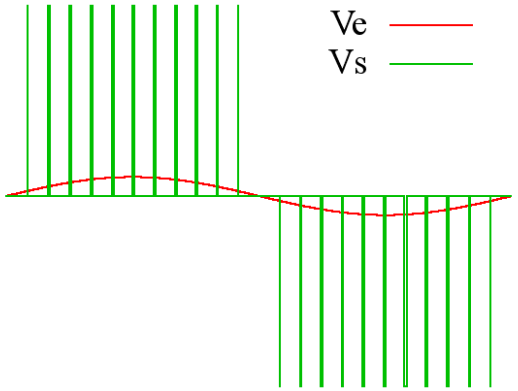
https://www.build-electronic-circuits.com/h-bridge/

H-Bridge & Pulse Width Modulation (PWM)





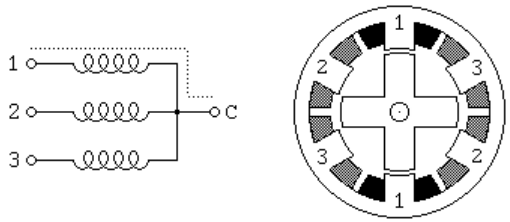


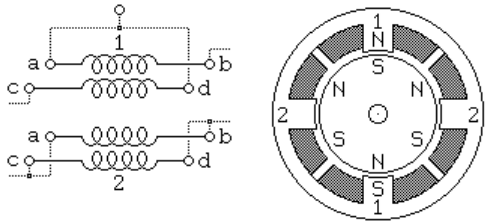


https://en.wikipedia.org/wiki/Pulse-width_modulation
https://commons.wikimedia.org/wiki/File:PWM_3L.gif

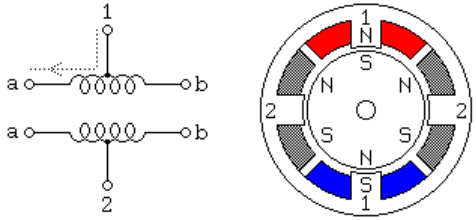
Stepper

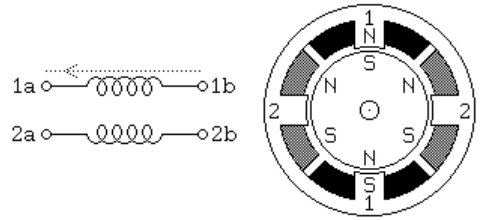
- Unipolar





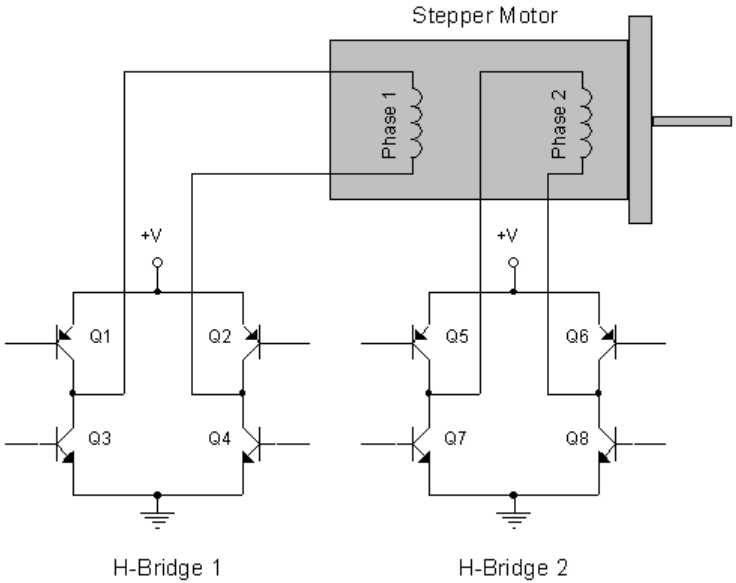
- Bipolar

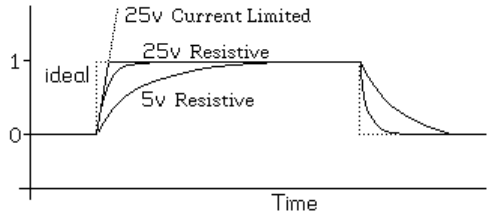


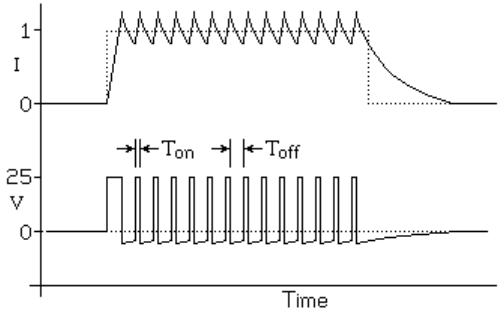


http://www.cs.uiowa.edu/~jones/step/

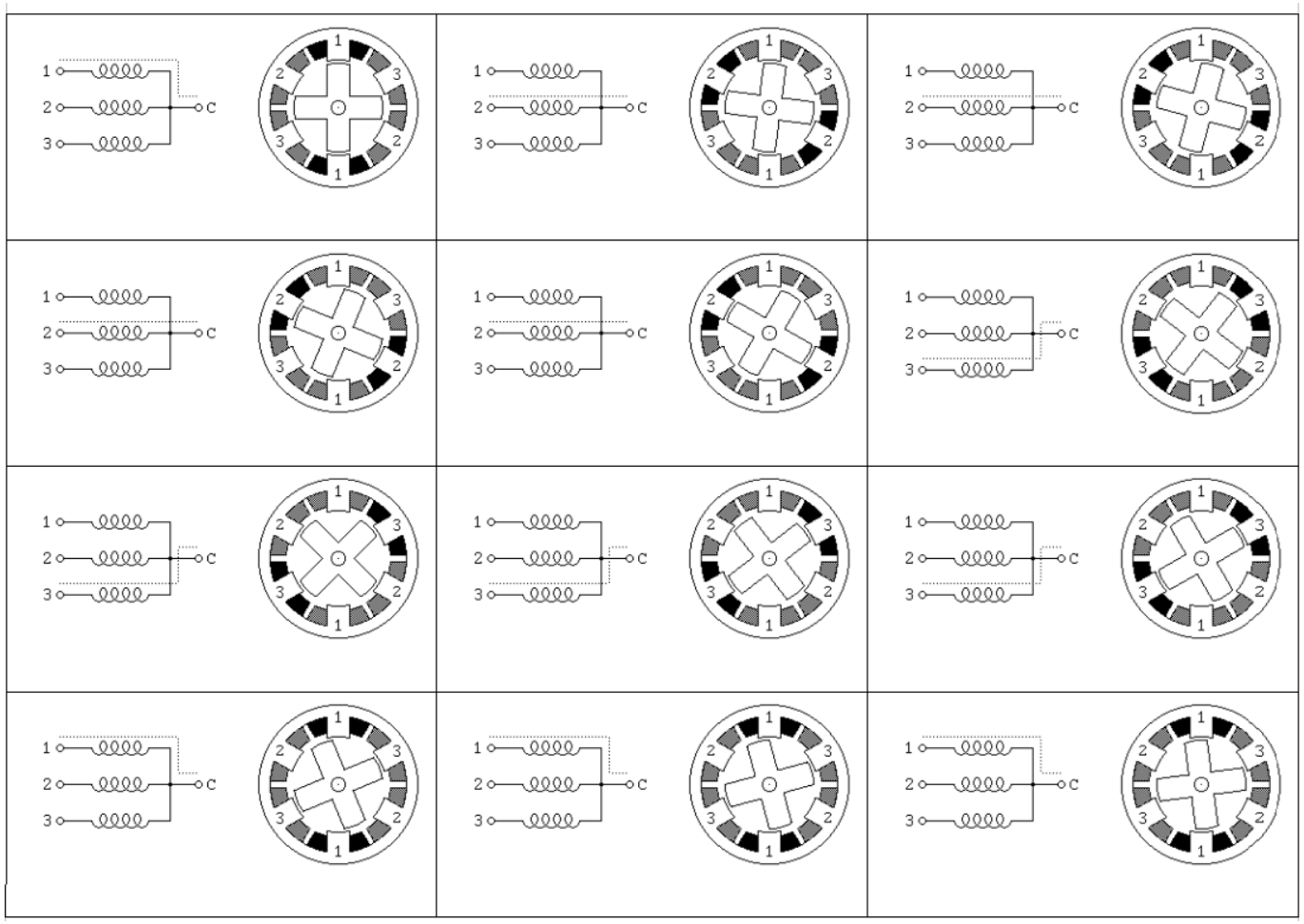
Stepper (ii) - electronics





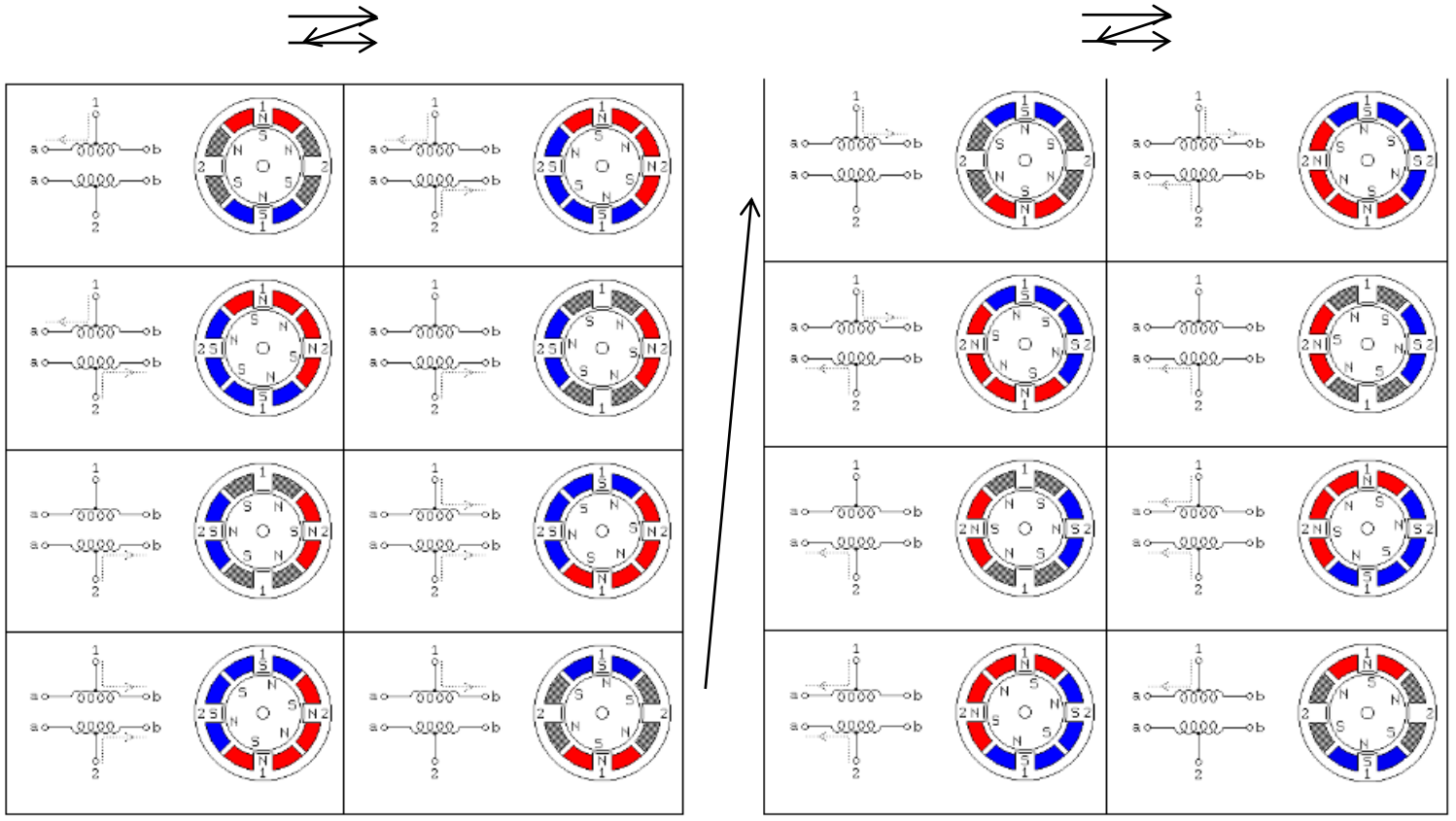


Stepper (iii) – unipolar sequence



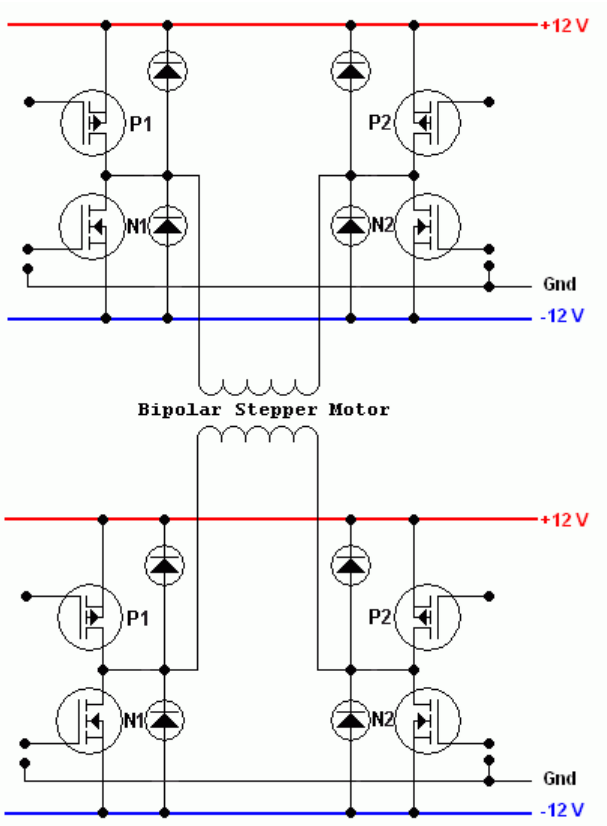
http://www.cs.uiowa.edu/~jones/step/

Stepper (iv) – bipolar sequence



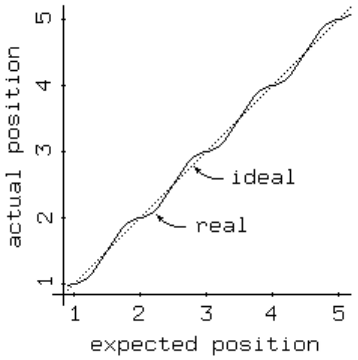
http://www.cs.uiowa.edu/~jones/step/

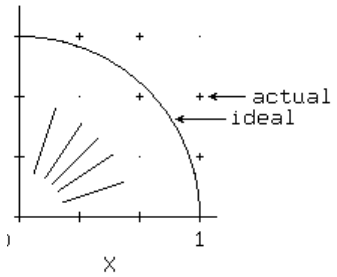
Driving a bipolar Stepper Motor

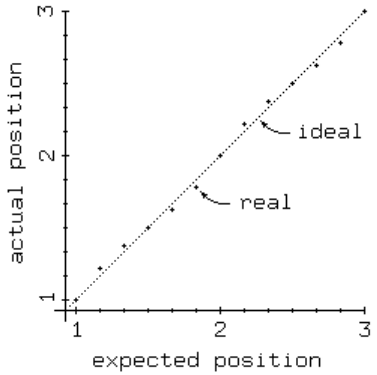


Microstepping

MicroStep

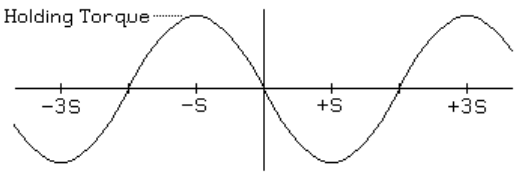


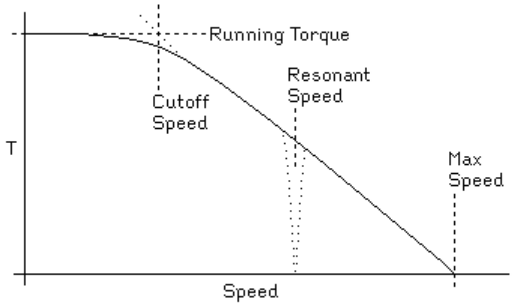


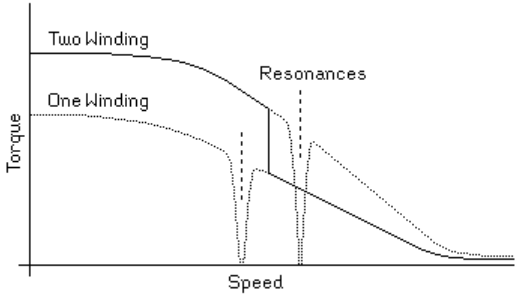


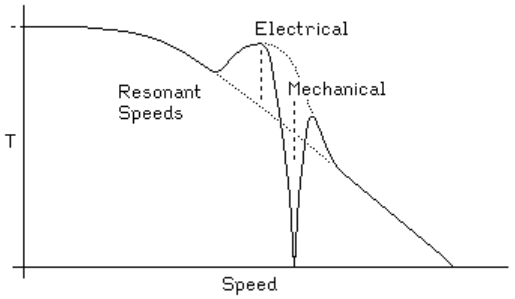
Stepper dynamics

- Poles & Static force & Dynamics...

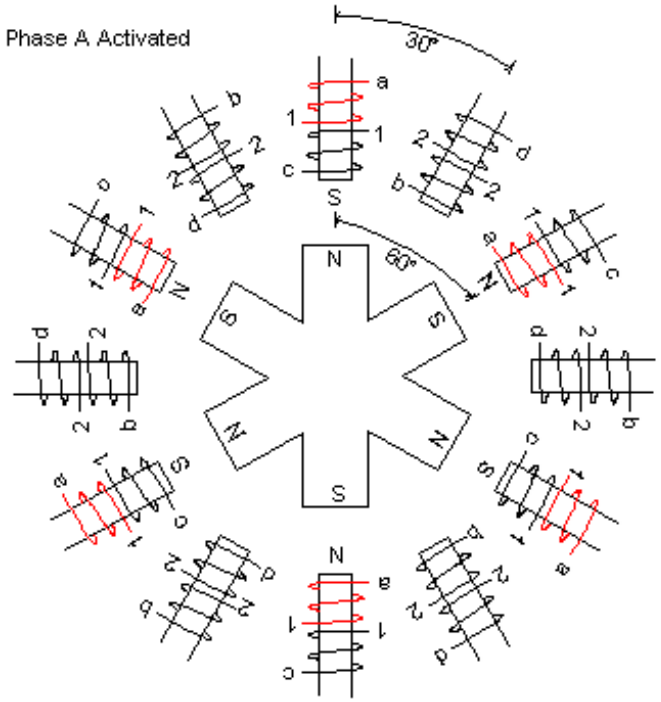


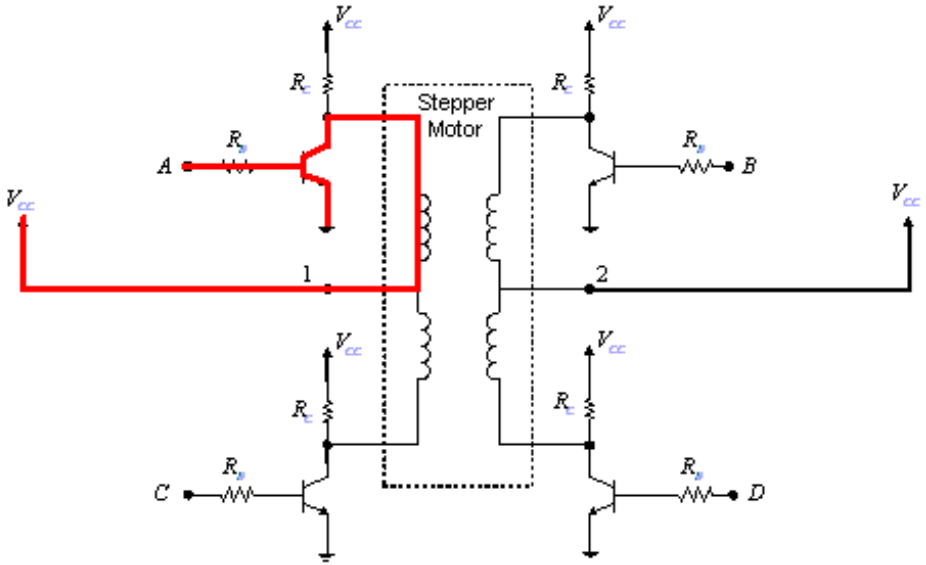






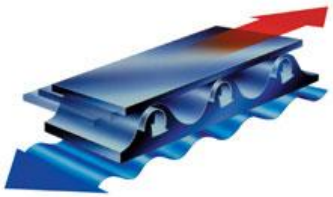
Stepper (animation)

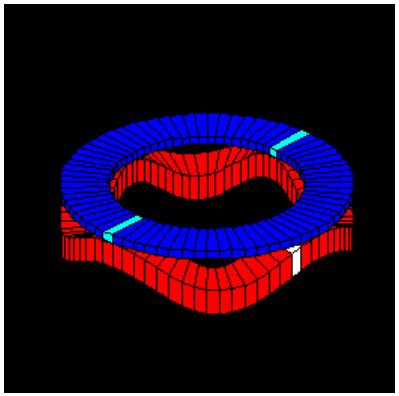




http://www.electric-motors-price.info/images/stepper-motor.jpg

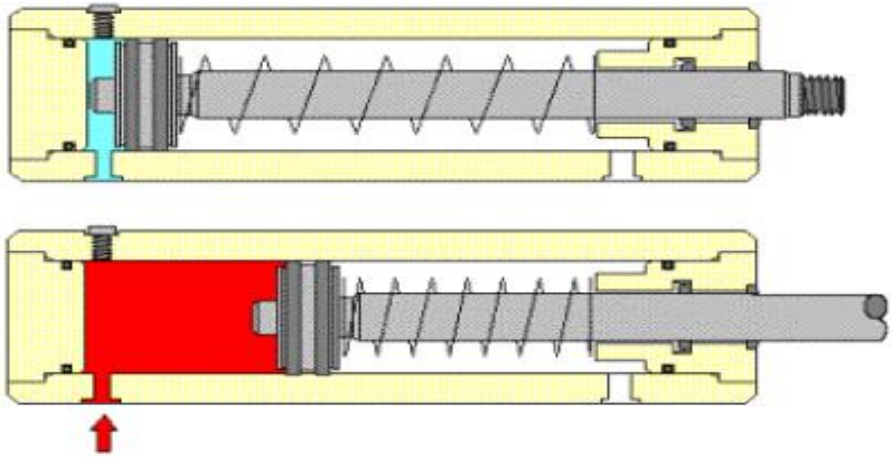
Ultra Sonic Motor (*piezo*)





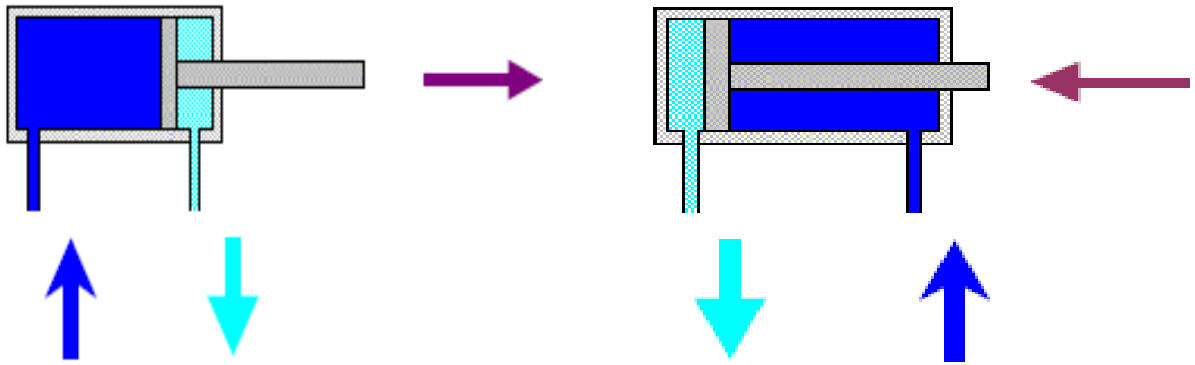
Pneumatic / Hydraulic Linear Actuator

- Single effect (+ spring)

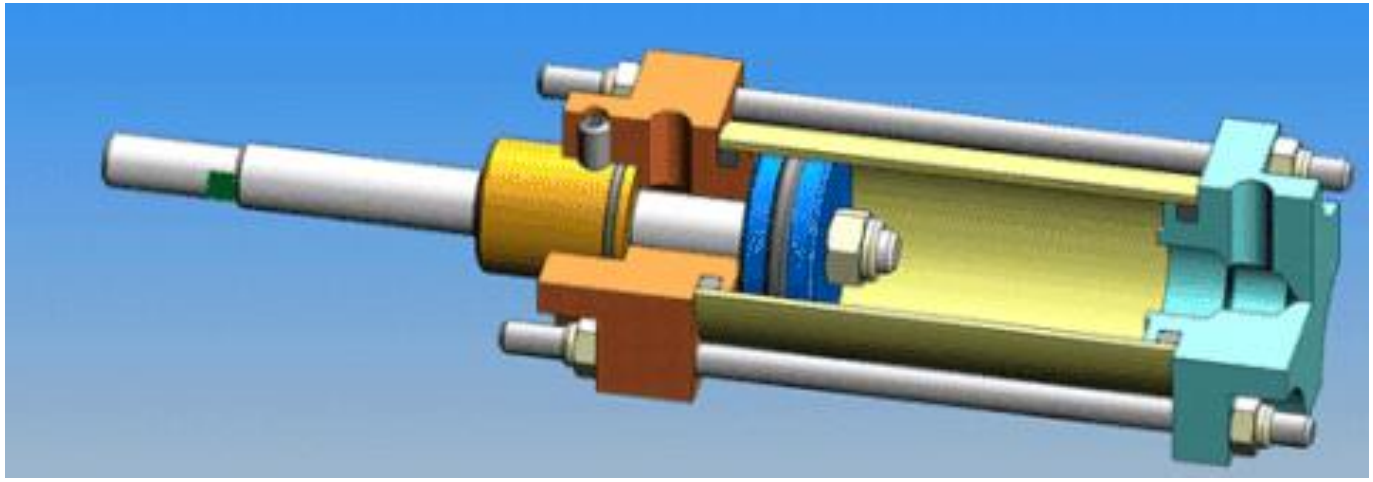


Pneumatic / Hydraulic Linear Actuator (ii)

- Double Effect



Pneumatic / Hydraulic Linear Actuator (iii)

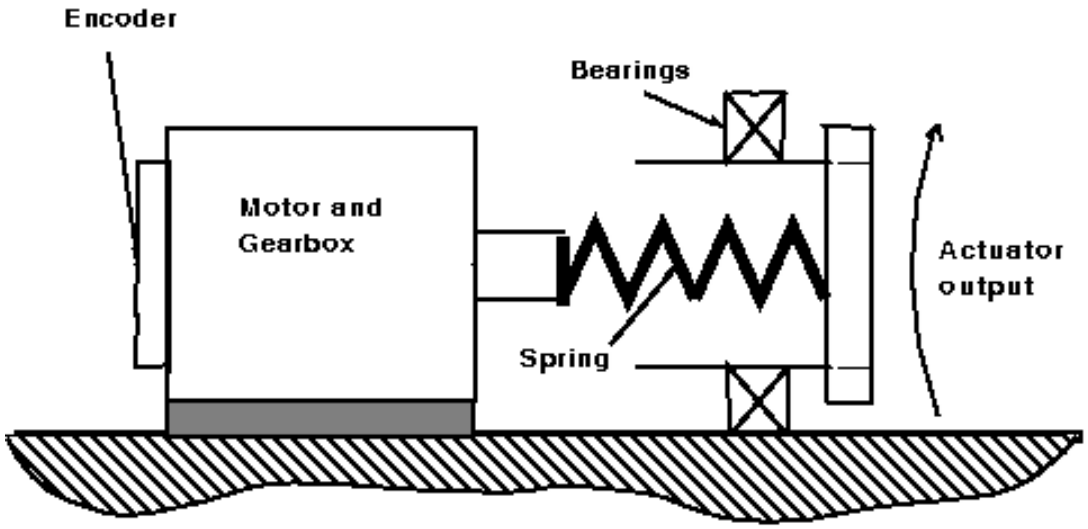


https://gifer.com/en/Ls6U

Why Pneumatic/Hidraulic ?

- Hydraulic
  - High stress (20 MPa) / High power density (600 W/Kg)
  - Moderate-high speeds (although inefficient at high speeds)
- Pneumatic
  - Moderate stress (0.7 MPa) / High power density (200 W/Kg)
  - High efficiency (~90%)
  - Fast but settling time (compressible gas, control difficulty)
- Both:
  - Bilateral actuation,
  - High instantaneous power delivery
  - Constant force advancements
  - ...

Series Elastic Actuator



Summary

- Transducers change energy types
  - Actuator “chain” (assembly, set of apparatus to change world)
  - Actuator chains change movement / forces / efficiencies
  - Efficiency, safety, etc
- Many types of actuators
  - Most Important: DC motor

Actuators

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Obs: Language: English!