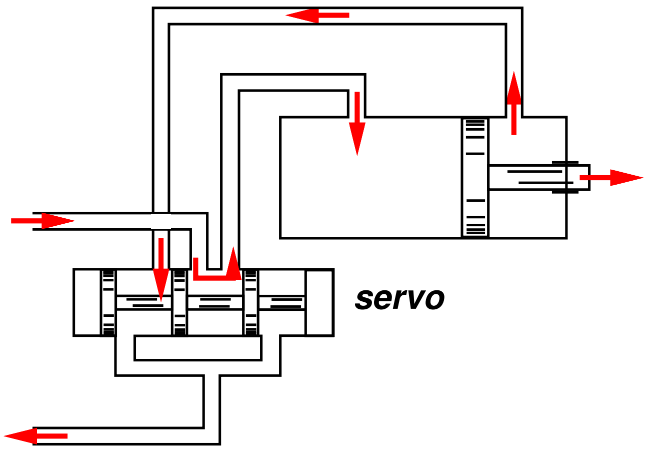
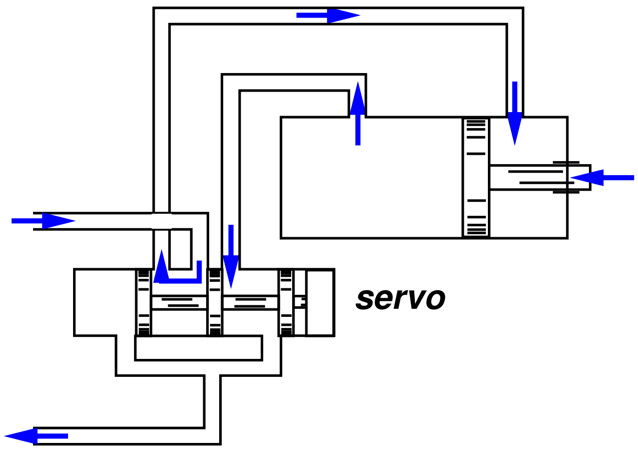
Actuators: Hydraulic





- energy is stored in the high pressure fluid reservoir (1000-3000 psi)
- open-loop control - fork lifts, back hoes
- good bandwidth (5 KHz - fluid reverses direction 5 msec)

CONS

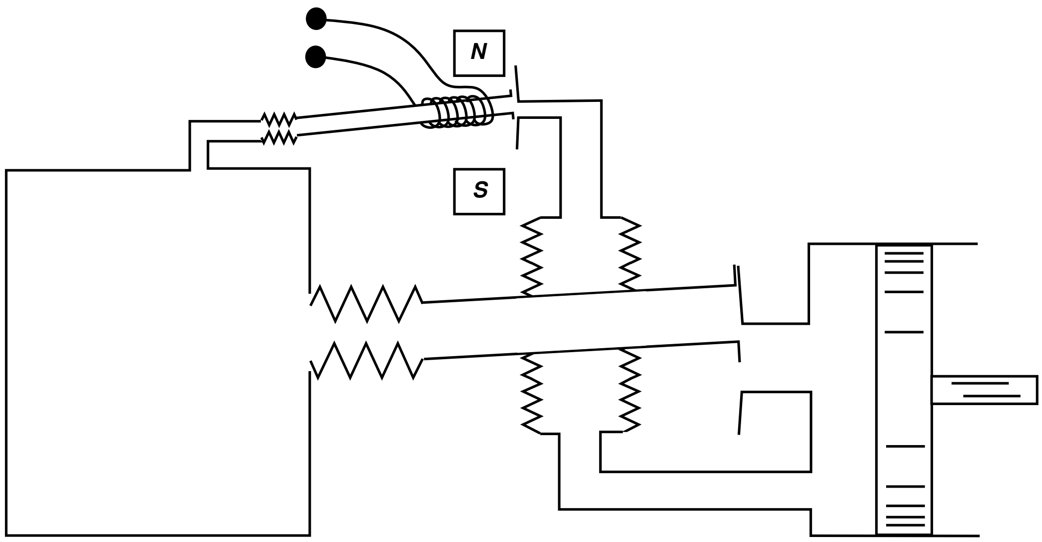
1. expensive servos
2. messy
3. high maintenance

PROS

1. good power/weight
2. safe in explosive environments

Actuators: Pneumatic

- compressible fluid (air)
- jet-pipe servo control



PROS

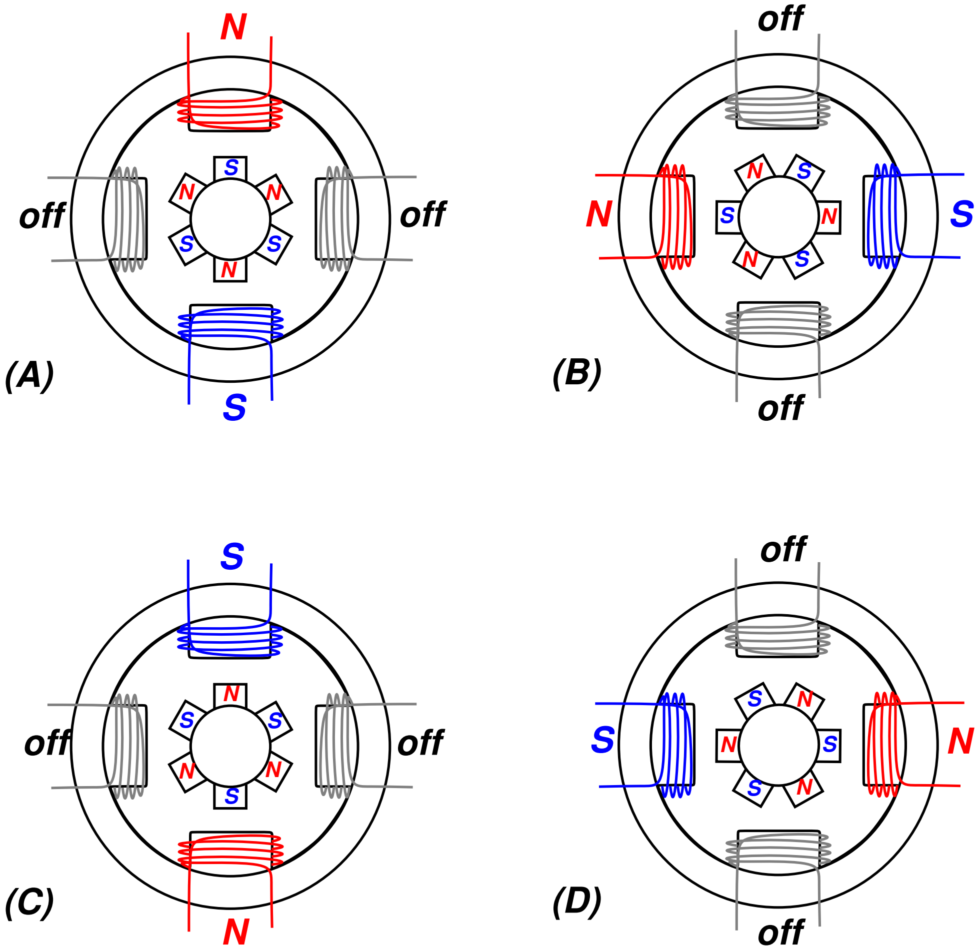
1. light and cheap
2. passively backdrivable

CONS

1. stiction
2. delicate

Actuators: Stepper Motors

- precise (low torque), open-loop position control
- *resonance* - typically between 50 and 150 *steps/sec*
- *cogging*

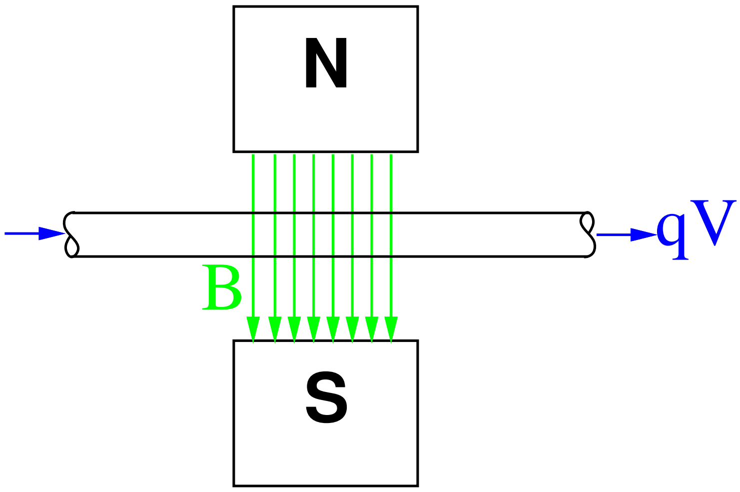


Actuators: Permanent Magnet DC Motors

- run continuously in both directions
- closed-loop servo control w/position feedback
- relaibile, good power/weight, high torques possible

Lorentz Force

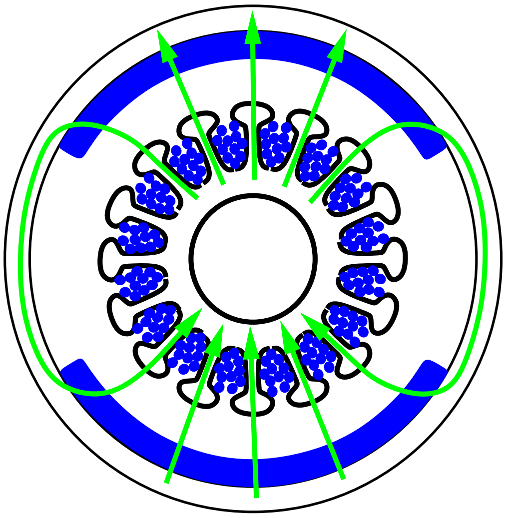
$$F = qV \times B$$

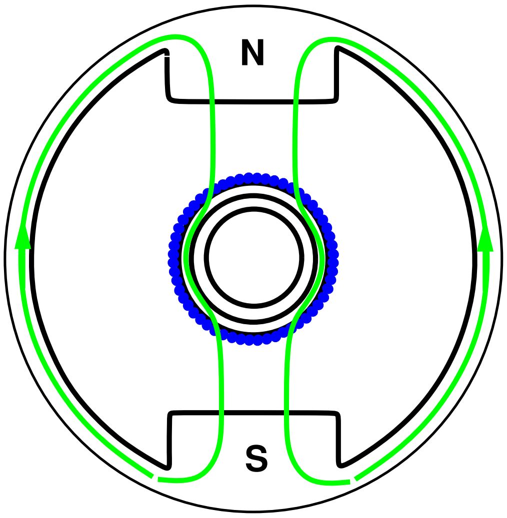


Actuators: Permanent Magnet DC Motors

Iron Core:

- high inertia, cogging
- very reliable
- cheap

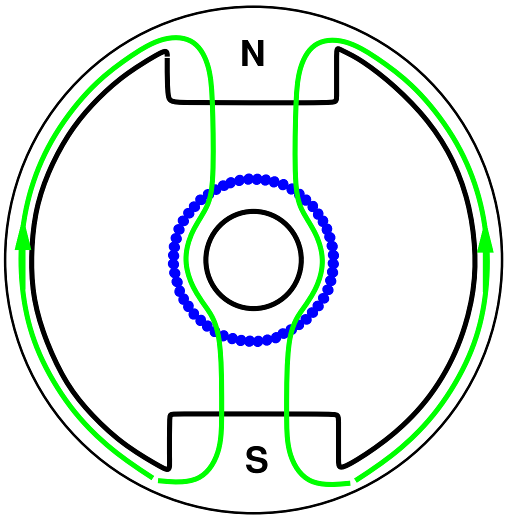




Surface Wound:

- lower inertia
- no cogging
- higher cost
- rare earth magnets

Actuators: Permanent Magnet DC Motors (cont)



Moving Coil:

- coil *is* rotor
- rotor inertia extremely low
- high performance - big torque
- thin (0.02″), large diameter (12″)
- *printed-circuit motors*
- expensive

DC Motors - Electrodynamics

force: Newton $N = kg \cdot m/sec^2$

torque: the product of a force and a moment arm

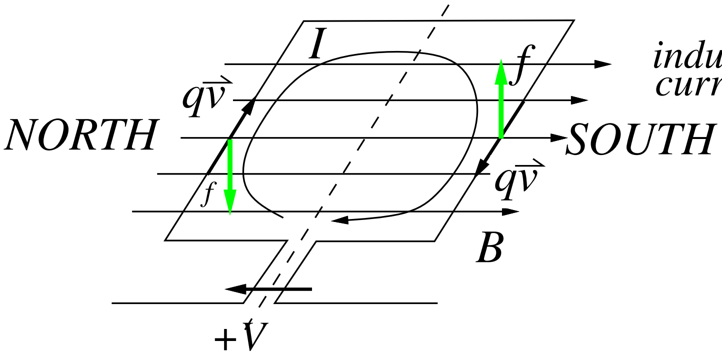
$$N \cdot m = \frac{kg \cdot m^2}{sec^2}$$

power: energy per unit time (Watts)

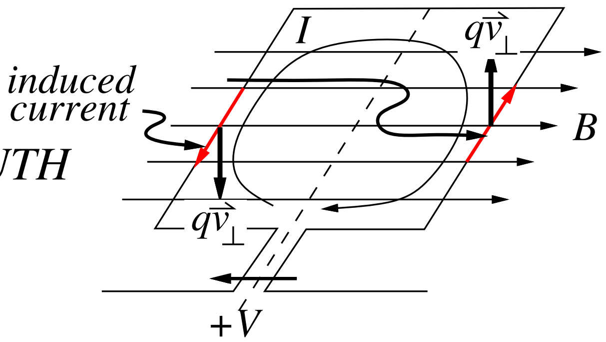
$$\begin{aligned} P &= VI(\text{electrical}) \\ &= \tau\omega(\text{mechanical}) \end{aligned}$$

$$Watt = \frac{volt \cdot coulomb}{sec} = \frac{Nm}{sec}$$

DC Motors - Electrodynamics



The Lorentz Force

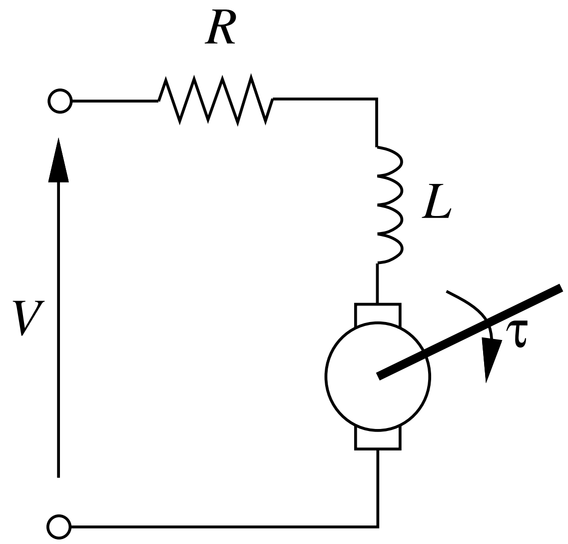


Induced Backward Electromotive Force (Back EMF)

- K_t proportional to the number of loops
- commutation - the rotor runs out of torque when the current loop is perpendicular to B, reversing the current can continue to provide torque in the same direction.
- for a commutated motor, the rotor current alternates with frequency proportional to ω

$$\text{back emf} = L\frac{dI}{dt} = K_b\omega$$

Actuators: DC Motors Electrodynamics



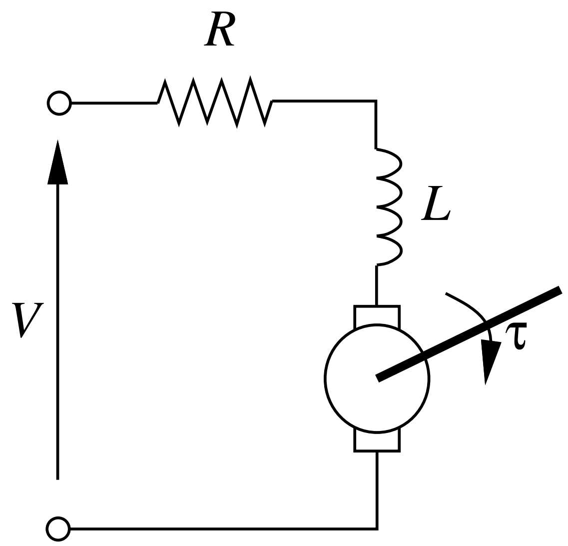
$$\tau = K_t I \qquad \textit{motor torque}$$

$$V_b = L\frac{dI}{dt} = K_b\dot{\theta} \qquad \textit{back emf}$$

$$V = IR + K_b\dot{\theta}$$

$$\begin{array}{cccc}
\begin{array}{c} mechanical \\ power \\ out \end{array} & = & \begin{array}{c} electrical \\ power \\ in \end{array} & - \; losses \\[2em]
\tau\dot{\theta} & = & VI & - \quad I^2R \\[2em]
(K_t I)\dot{\theta} & = & (IR + K_b\dot{\theta})I & - \quad I^2R \\
 & = & K_b I\dot{\theta} & \\[2em]
K_t & = & K_b &
\end{array}$$

DC Motors - Equation of Motion



$$\sum \tau = J\ddot{\theta} = KI = K\left[\frac{V}{R} - \frac{K\dot{\theta}}{R}\right]$$

$$\ddot{\theta} + \frac{K^2}{JR}\dot{\theta} + \frac{KV}{JR} = 0$$