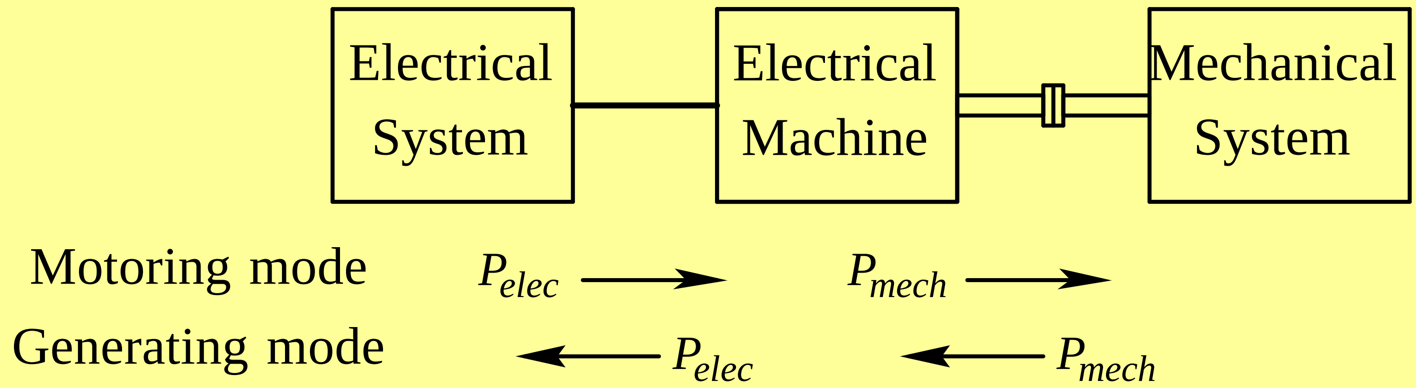
Basic Principles of Electromechanical Energy Conversion

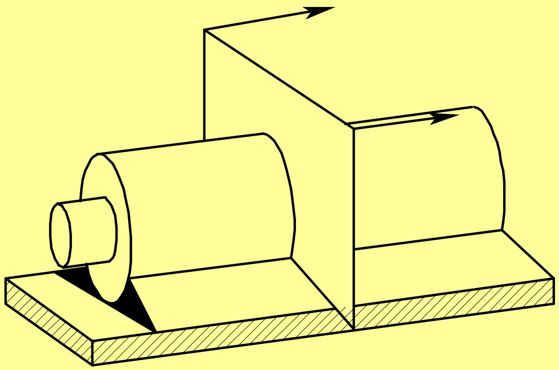
- Role
- Structure
- Production of Magnetic Field
- Basic Principles – force and induced-emf
- Motoring and Generating Modes
- Power Losses and Efficiency

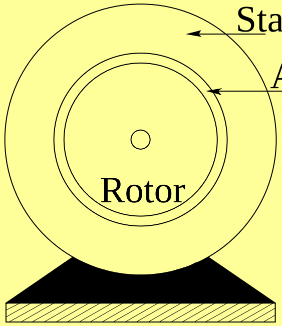
Electric Drive



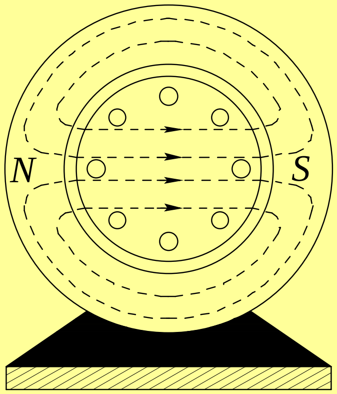
Basic Structure

- Construction

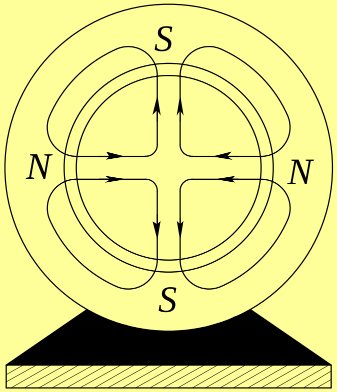




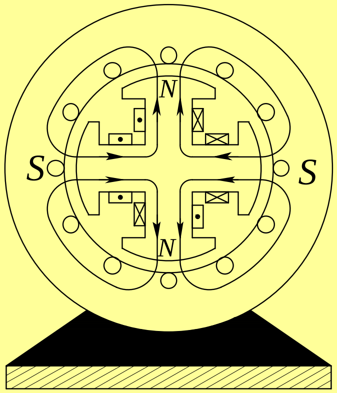
- Multi-pole structure



2 pole



4 pole



salient pole

Sufficient to consider a 2-pole machine

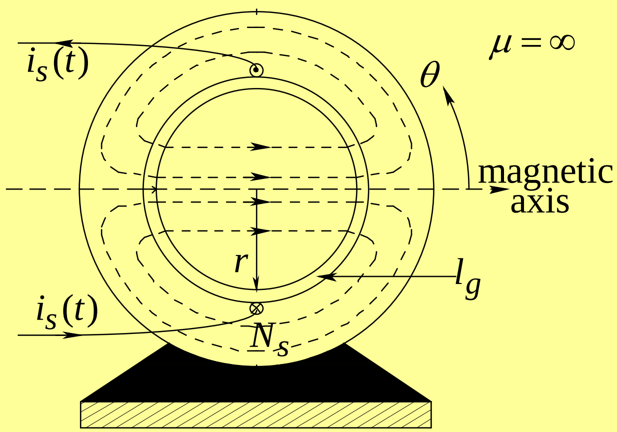
Production of Magnetic Field

- Radial field (*H,F,B*) in the air gap

  H positive if away from the center

- Using Ampere's law, field

  produced by the stator is,



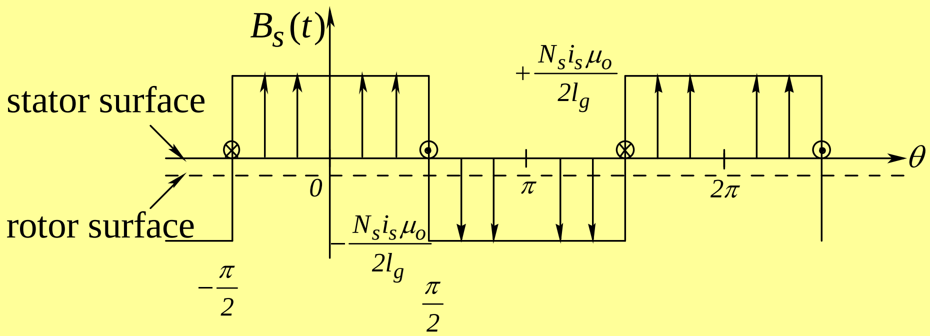
$$H_s = \frac{N_s i_s}{2\ell_g}$$

mmf acting on air gap

$$F_s = H_s \ell_g = \frac{N_s i_s}{2}$$

& Flux density in air gap

$$B_s = \mu_o H_s$$



Basic Principles of Operation

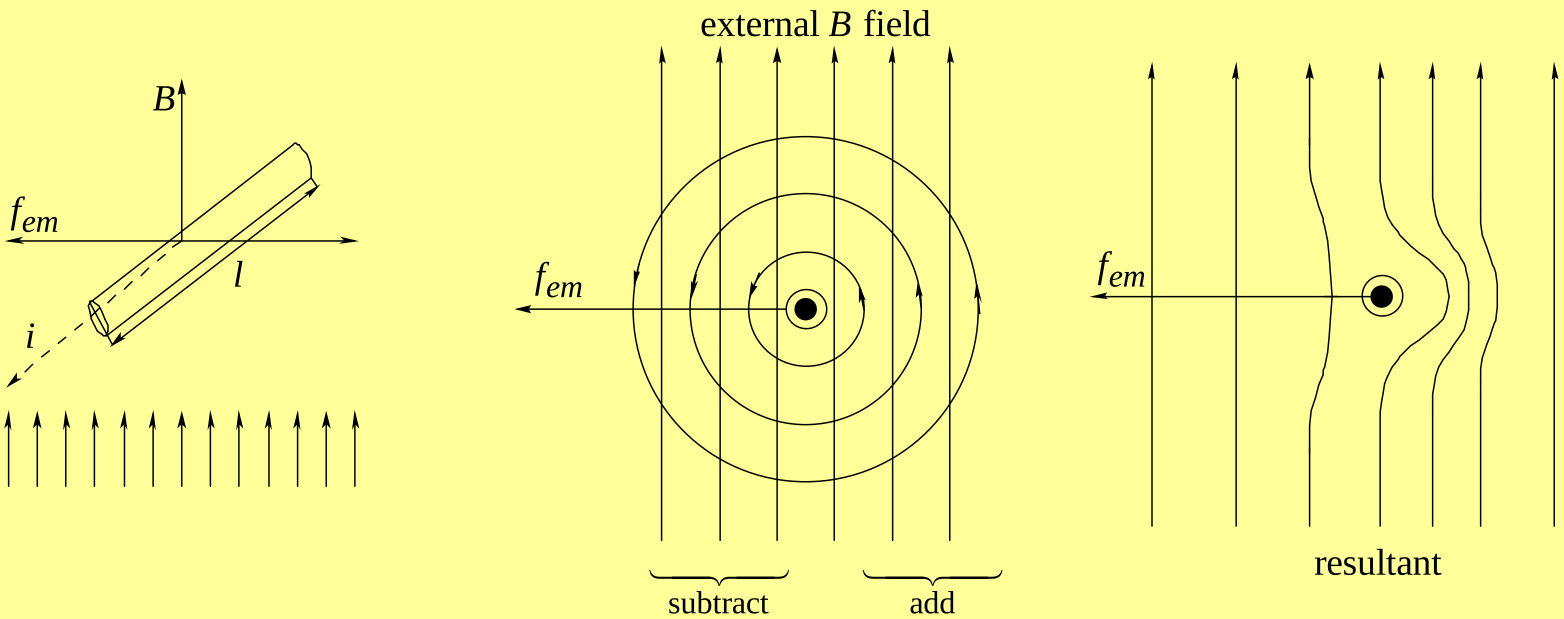
- Force on a current carrying conductor subjected to an *externally-established* magnetic field

$$f_{em} = B \ell i$$

- emf induced in a conductor moving in a magnetic field

$$e = B \ell u$$

Electromagnetic Force



$$\underbrace{f_{em}}_{[Nm]} = \underbrace{B}_{[Wb/m^2]} \underbrace{\ell}_{[m]} \underbrace{i}_{[A]}$$

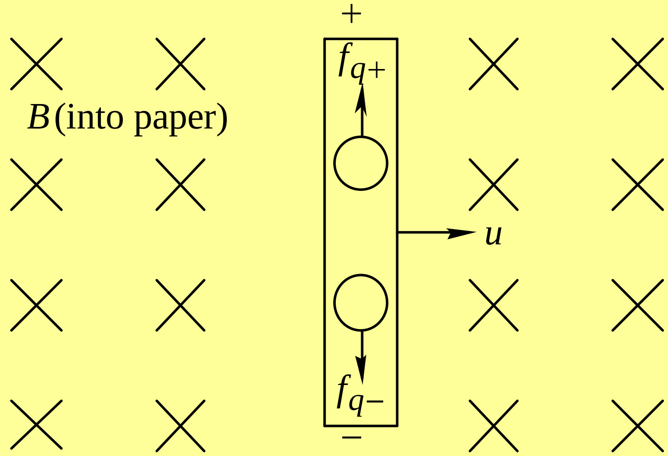
- Force Direction - Higher concentration to lower concentration

Induced EMF

Force on positive charges

$$f_q = q(\bar{u} \times \bar{B})$$

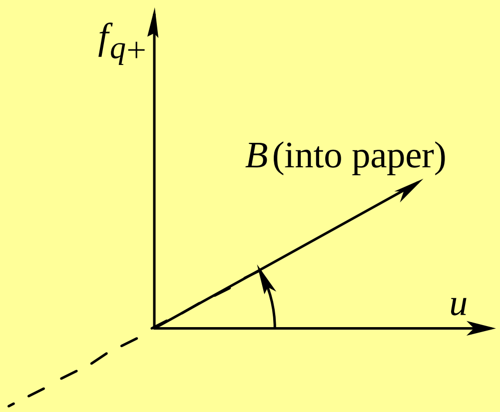
In this example a net positive charge accumulates at the top and a net negative charge accumulates at the bottom



Magnitude of induced emf

$$\underbrace{e}_{[V]} = \underbrace{B}_{[Wb/m^2]} \underbrace{l}_{[m]} \underbrace{u}_{[m/s]}$$

Polarity of induced emf is given by f_q and is independent of current flowing through the conductor



Application of Basic Principles

- Assumptions
  - Uniform B_s , radial in direction
  - Rotor current of constant magnitude but direction changes with position
  - counter-clockwise torque is positive
- Force acting on the conductor

$$f_{em} = B_s (N_r I) l$$

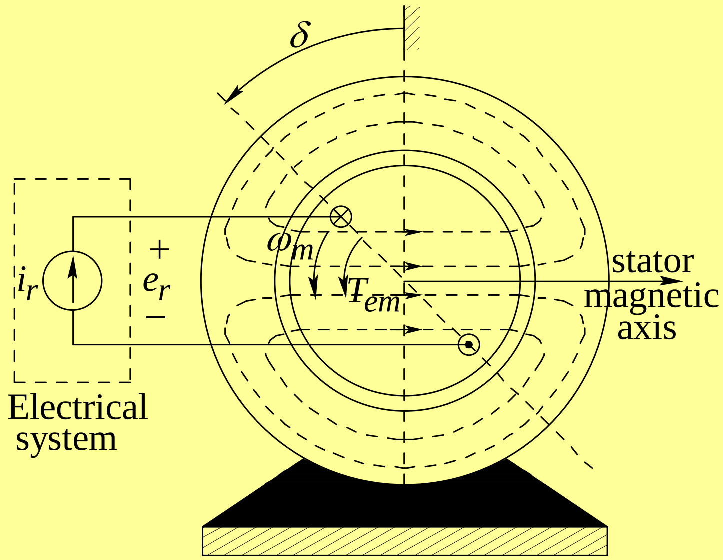
and torque on coil

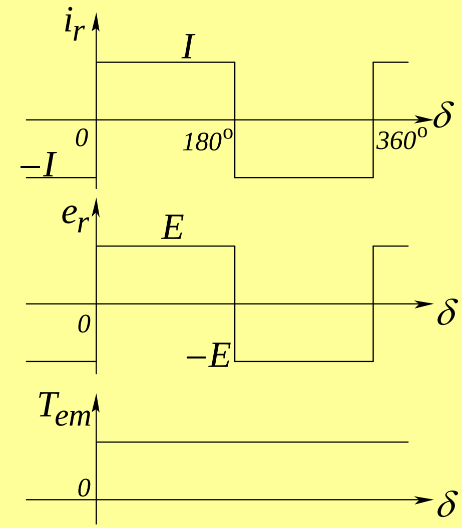
$$T_{em} = 2 f_{em} r = 2 B_s (N_r I) l r$$

torque remains constant as rotor turns

- emf induced in coil

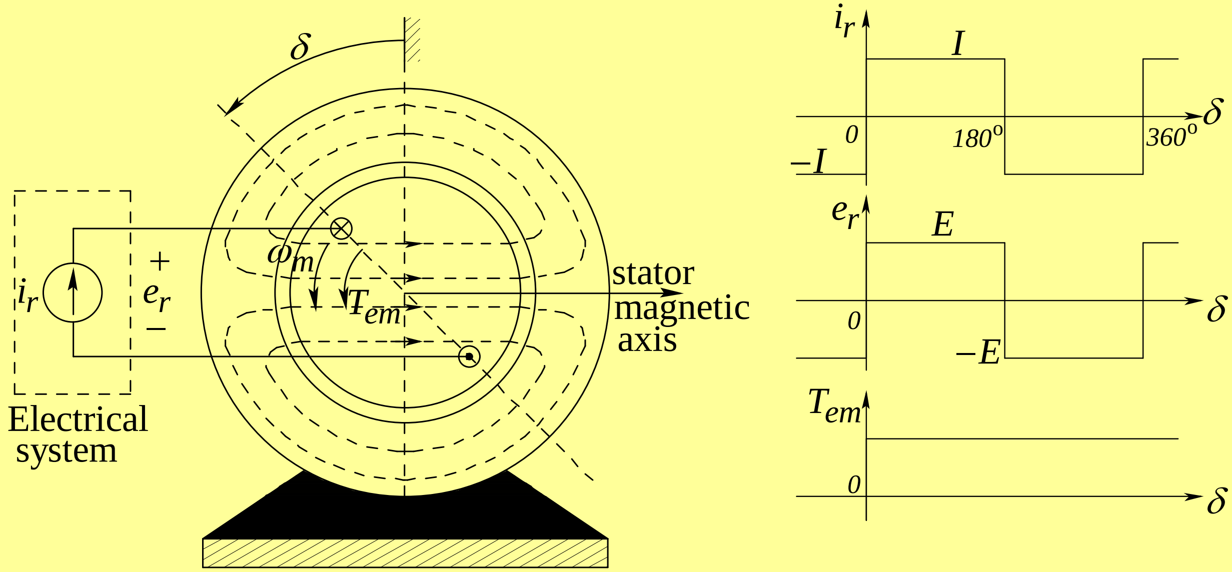
$$e_r = 2 e_{cond} = 2 N_r B_s l_r \omega_m r$$



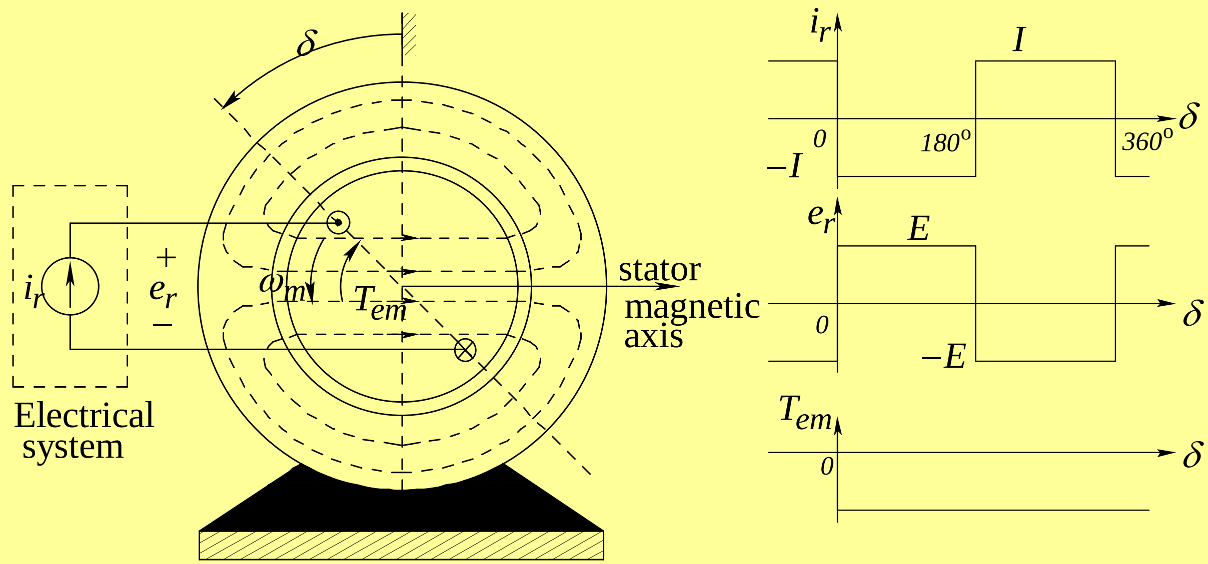


Energy conversion

Motoring Mode



Regenerative braking Mode



Power losses and Energy efficiency

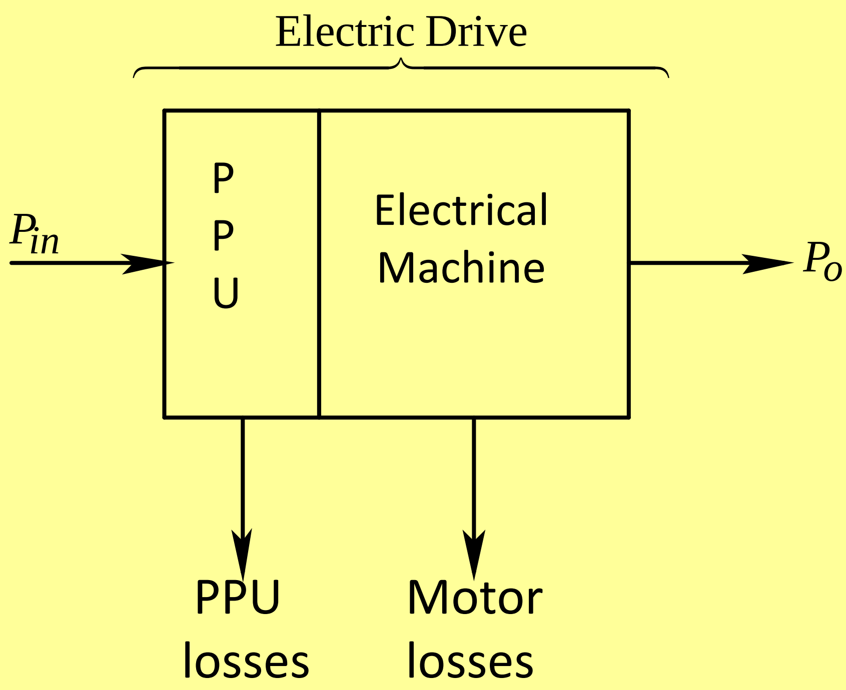
- Motor losses
  - Conduction losses, P_R
  - Iron losses, P_{he}
  - Friction and windage losses, P_{fw}
  - Switching losses, P_{sw}
  - Stray losses, P_s

$$P_{loss} = P_R + P_{he} + P_{sw} + P_{fw} + P_s$$

$$\eta_{mach} = \frac{P_o}{P_{in}} = \frac{Po}{P_o + P_{loss}}$$

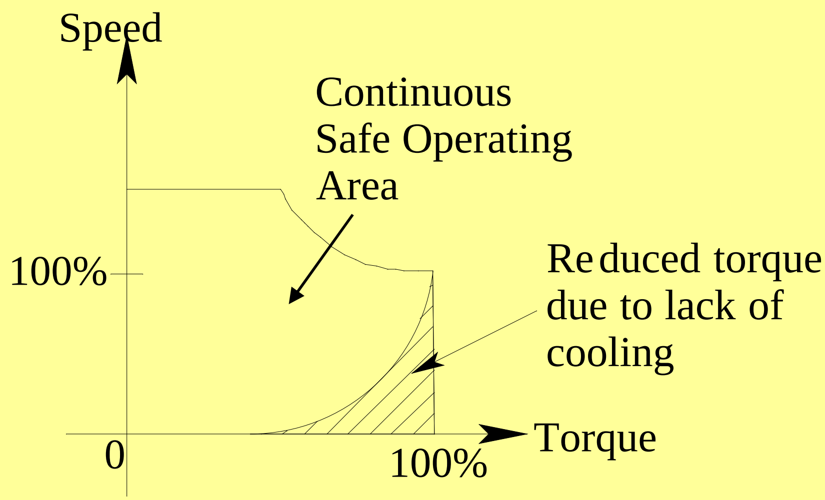
- PPU losses
  - Conduction losses
  - Switching losses

$$\eta_{drive} = \eta_{PPU} \times \eta_{motor} \qquad (80 - 90\%)$$



Motor Ratings

- Safe Operating Area



- Rated speed, torque and power $P_{rated} = \omega_{rated} T_{rated}$
- Motor temperature rise due to losses
- Expanded safe operating area during transients and for intermittent operation

Summary

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