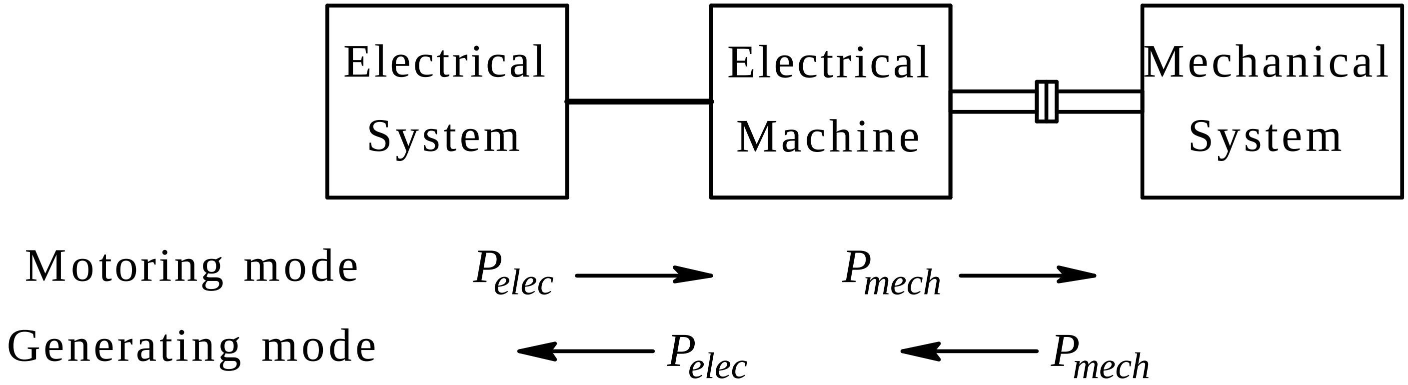
Chapter 6

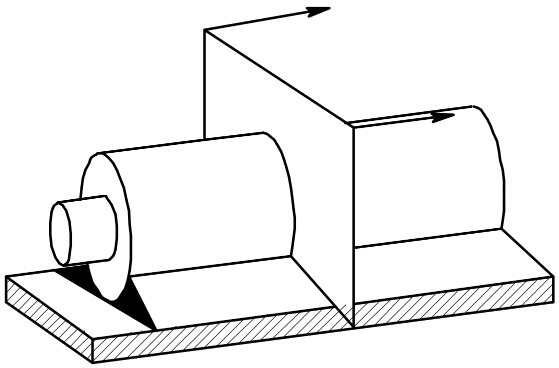
Basic Principles of Electromechanical Energy Conversion

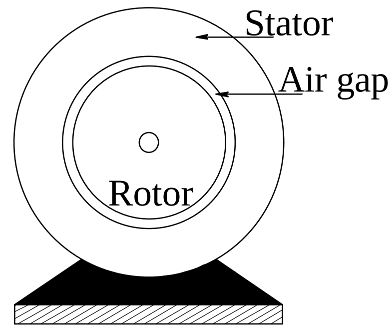
Electric Drive



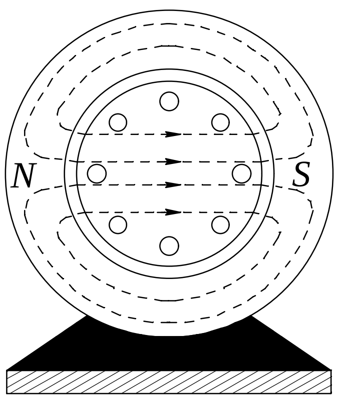
Basic Structure

- ❑ Construction

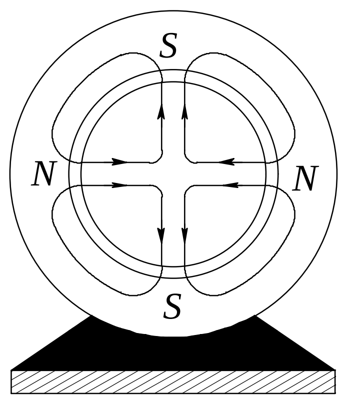




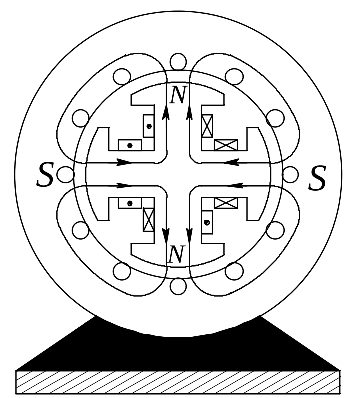
- ❑ Multi-pole structure



2pole



4pole



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,

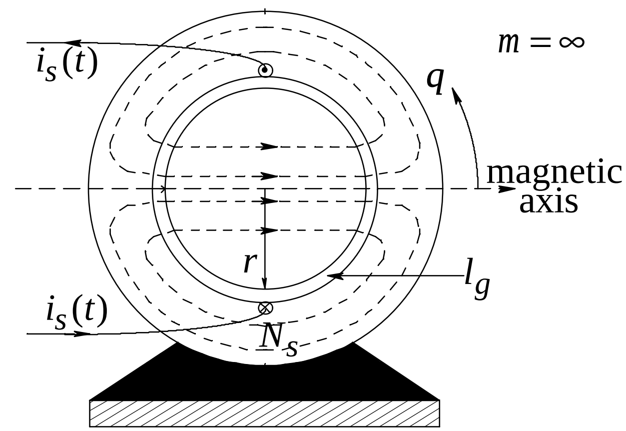
$$H_s = \frac{N_s i_s}{2\ell_g}$$

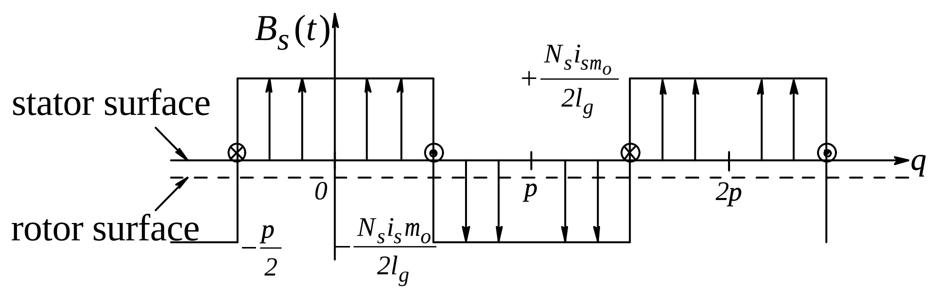
mmf acting on air gap

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

& Flux density in air gap

$$B_s = m_o H_s$$





Basic Principles of Operation

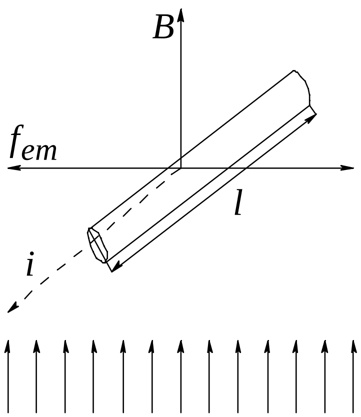
- Force on a current carrying conductor subjected to an *externally-established* magnetic field

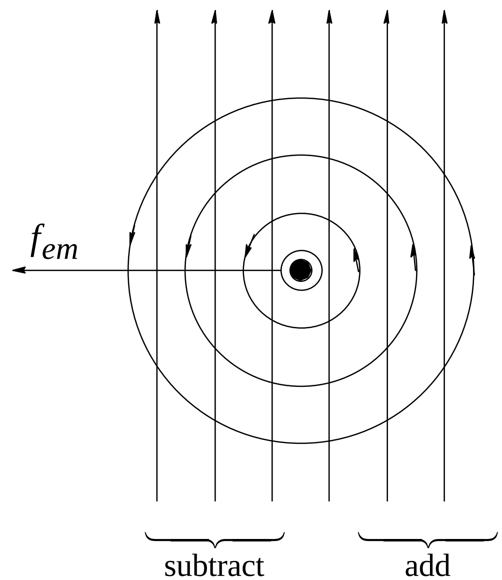
$$f_{em} = B \ell i$$

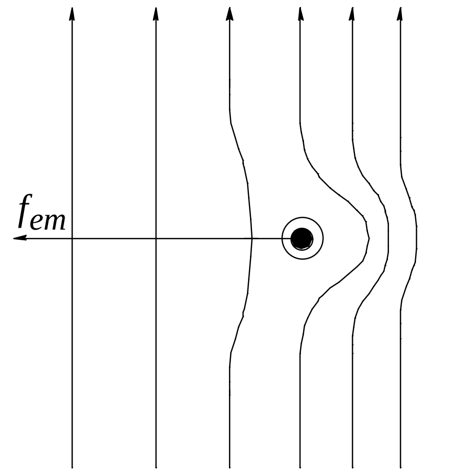
- emf induced in a conductor moving in a magnetic field

$$e = B \ell u$$

Electromagnetic Force







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

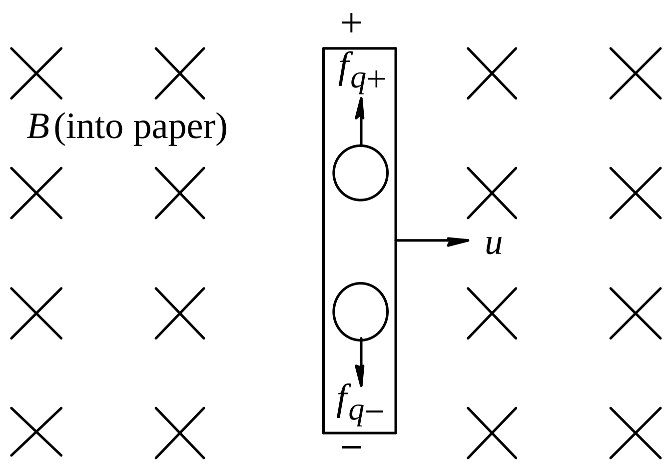
- Force Direction -
  Higher concentration to lower concentration

Induced EMF

Force on positve charges

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

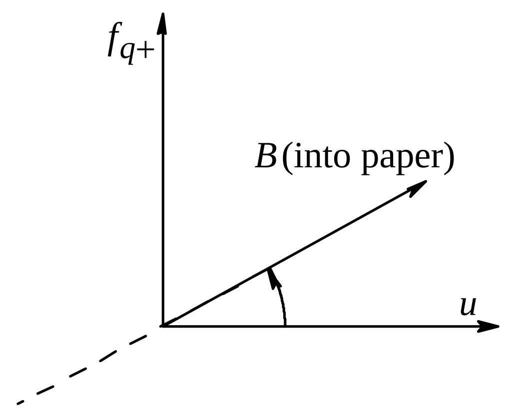
In this example a net positive charge accumulates at the top and a net negative charge accumulates at the bottom



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 polarity changes with position
  - counter-clockwise torque is positive
- Force acting on the conductor

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

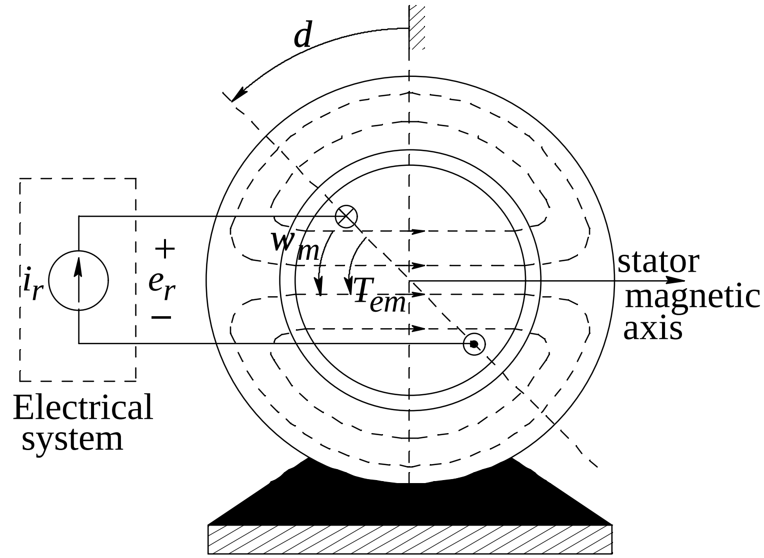
and torque on coil

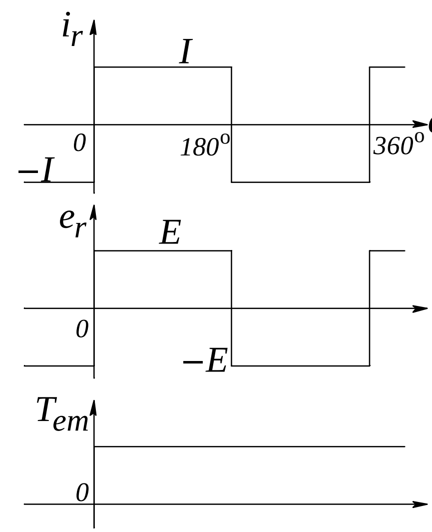
$$T_{em} = 2 f_{em} r = 2 B_s (N_r I) l r$$

torque remains constant as rotor turns

- emf induced in coil

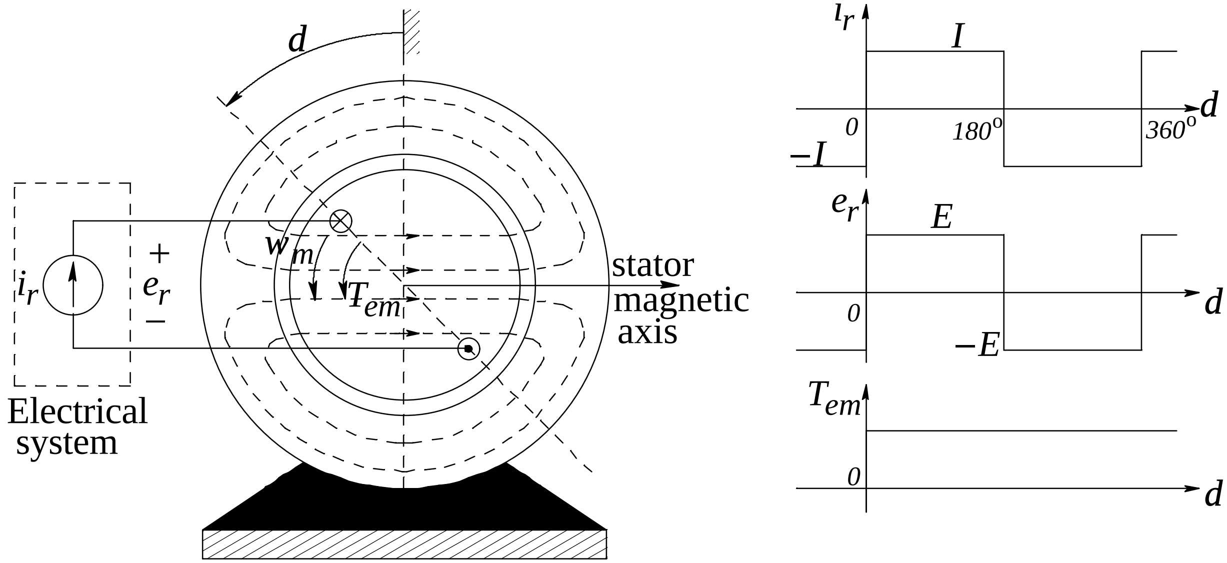
$$e_r = 2 e_{cond} = 2 N_r B_s l_r w_m r$$



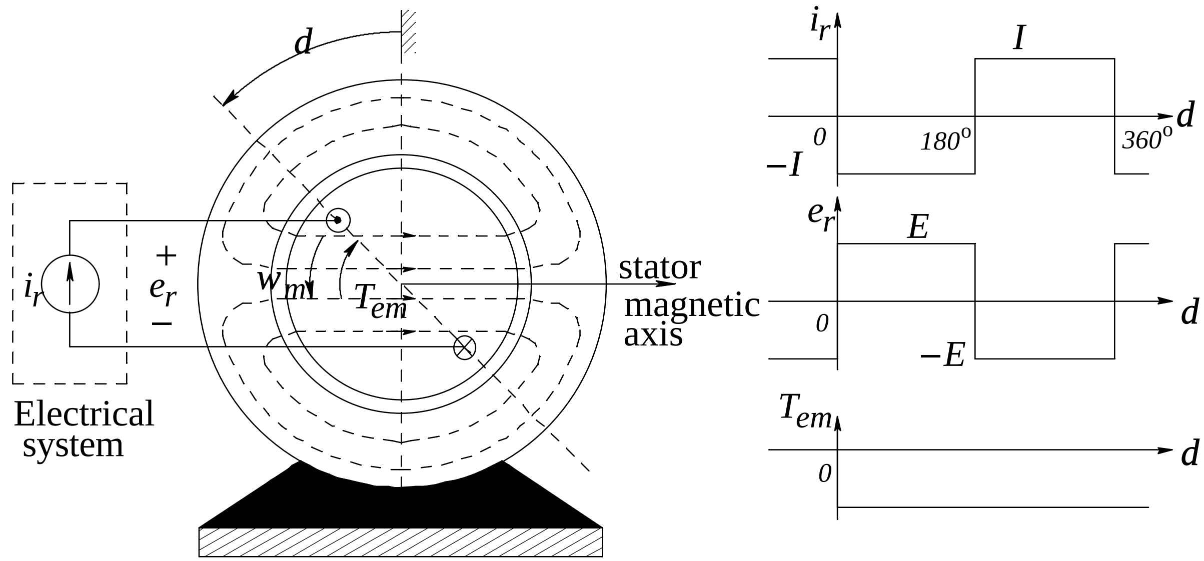


Energy conversion

Motoring Mode



Regenerative braking Mode

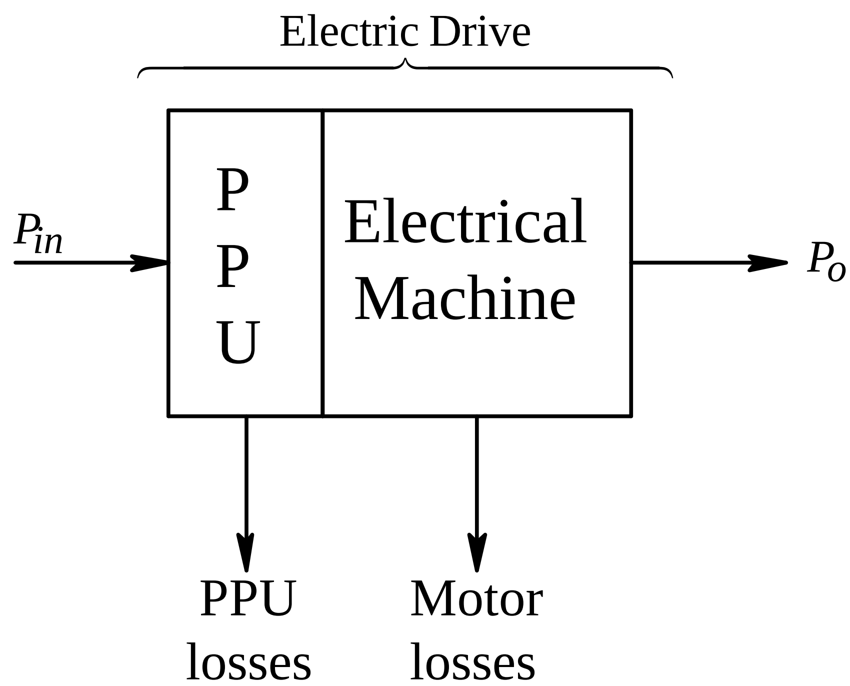


Power losses and Energy efficiency

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

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

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

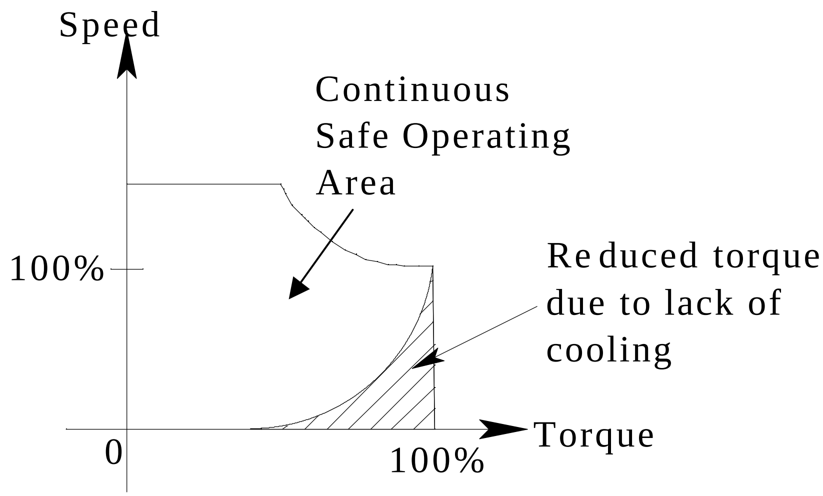


- PPU losses
  - Conduction losses
  - Switching losses

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

Motor Ratings

- Safe Operating Area



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

Summary

- What is the role of electric machines? What do the motoring-mode and the generating-mode of operations mean?
- What are the definitions of stator and rotor?
- Why do we use high permeability ferromagnetic materials for stators and rotors in electric machines? Why are these constructed by stacking laminations together, rather than as a solid structure?
- What is the approximate air gap length in machines with less than 10 kW ratings?
- What are multi-pole machines? Why can such machines be analyzed by considering only one pair of poles?

Summary

- Assuming the permeability of iron to be infinite, where is the mmf produced by machine coils "consumed"? What law is used to calculate the field quantities, such as flux density, for a given current through a coil? Why is it important to have a small air gap length?
- What are the two basic principles of operation for electric machines?
- What is the expression for force acting on a current-carrying conductor in an externally established B-field? What is its direction?
- What is slot shielding and why can we choose to ignore it?
- How do we express the induced emf in a conductor "cutting" an externally established B-field? How do we determine the polarity of the induced emf?

Summary

- How do electrical machines convert energy from one form to another?
- What are various loss mechanisms in electric machines?
- How is electrical efficiency defined and what are typical values of efficiencies for the machines, the power-processing units, and the overall drives?
- What is the end-result of power losses in electric machines?
- What is meant by the various ratings on the name-plates of machines?