Synchronous Motors

- Synchronous generators can operate either as generators or as motors
- Synchronous motors run in synchronism with the revolving field:
  - When the frequency is fixed, the motor speed stays constant irrespective of the load or voltage of the 3-phase line.

$$n_s = 120f/p$$

- Most synchronous motors used in industry are rated between 150 kW (200 hp) and 15 MW (20,000 hp), and run at speeds from 150 to 1800 r/min.

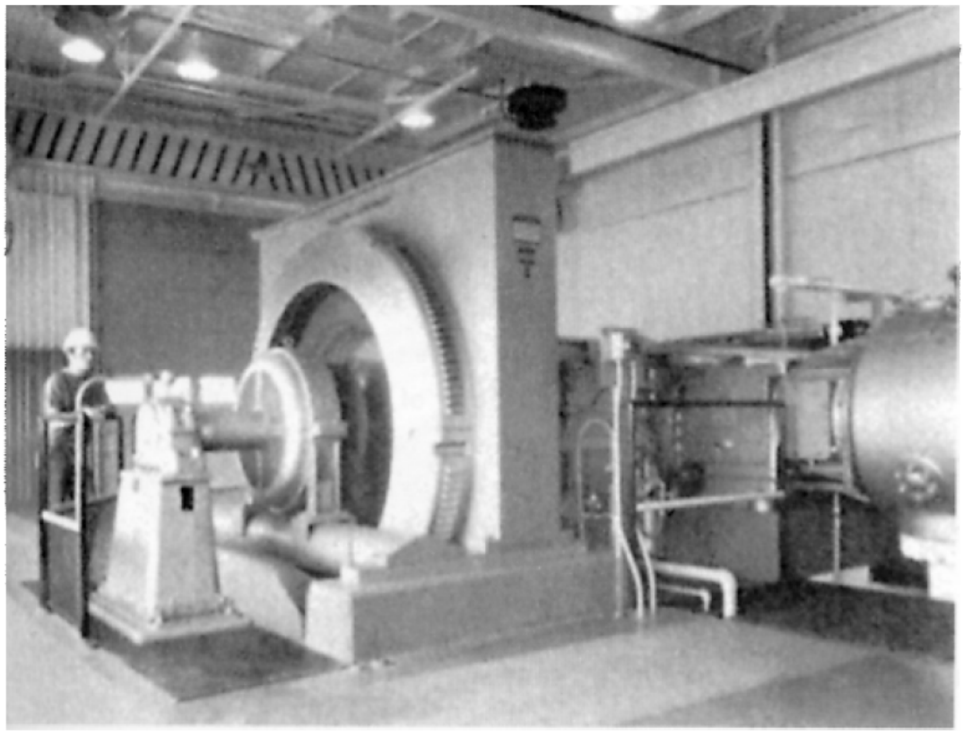


Figure 17.1
Three-phase, unity power factor synchronous motor rated 3000 hp (2200 kW), 327 r/min, 4000 V, 60 Hz driving a compressor used in a pumping station on the Trans-Canada pipeline. Brushless excitation is provided by a 21 kW, 250 V alternator/rectifier, which is mounted on the shaft between the bearing pedestal and the main rotor. (*Courtesy of General Electric*)

Motor under load

$$E_x = E - E_o = jIX_s \quad I = -j(E - E_o)/X_s$$

- At no-load,
  - The rotor and stator poles are lined up (E_o and E are in phase)
  - If E_o=E, the motor "floats" on the line (I=0)
- When a mechanical load is applied to the shaft,
  - The rotor poles fall behind the stator poles by mechanical angle α
  - E_o reaches its maximum later than E by electrical torque angle $\delta = p\alpha/2$
  - Complex power from the source $S=P+jQ$

$$P = \frac{|E_o|\cdot|E|}{X_S}\sin\delta \le P_{max} = \frac{|E_o|\cdot|E|}{X_S} \qquad Q = \frac{|E|^2}{X_s} - \frac{|E_o||E|}{X_s}\cos\delta$$

  - Mechanical torque $T=9.55P/n_s$
  - Pull-out (max.) torque $T_{max}=9.55P_{max}/n_s$
  - $|E_o|$ is adjusted to be greater or less than $|E|$ depending on the desired power factor

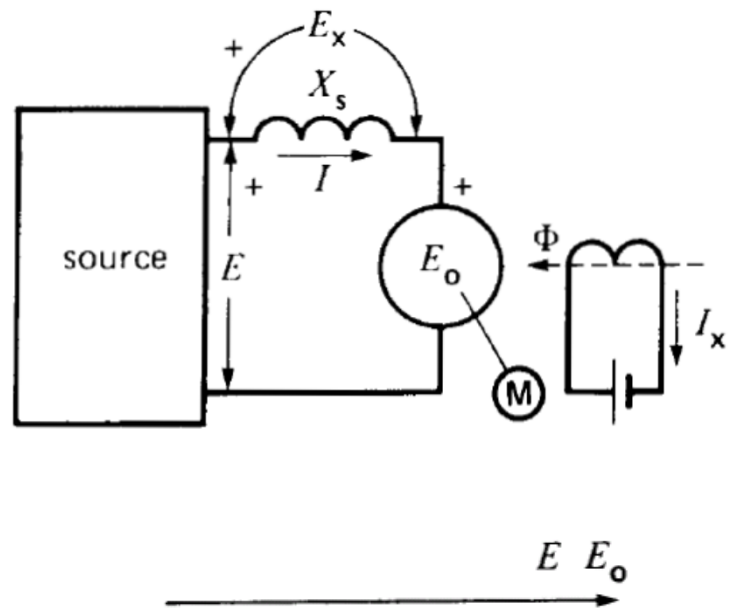


Figure 17.7b
Motor at no-load, with E_o adjusted to equal E.

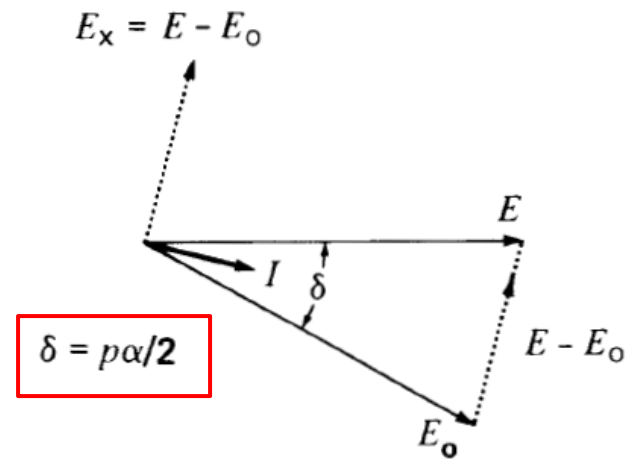


Figure 17.7c
Motor under load E_o has the same value as in Fig. 17.7b, but it lags behind E.

Power factor rating

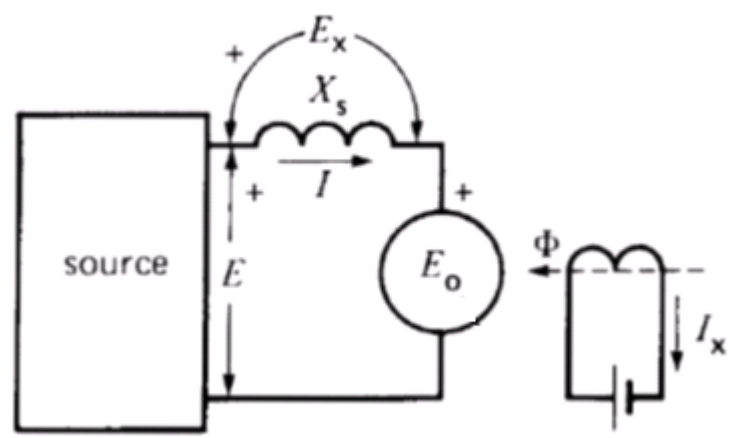
- Most synchronous motors are designed to operate at unity power factor
- However, if they also have to deliver reactive power, they are usually designed to operate at a full-load power factor of 0.8 (leading)
  - Delivering reactive power equal to 75% of its rated mechanical load

    If $|S|$=1 pu, P=0.8 pu and Q=0.6 pu = 75%×P
  - Bigger and most costly than motors operating at unity power factor

    $|I|=|S|/|E|=1.25|P|/|E|=125\%\times|I_{PF=1}|$
- **Synchronous condenser (synchronous capacitor):** Example 17-7
  - A synchronous motor running at no-load and its only purpose is to absorb or deliver reactive power on a 3-phase system by changing its excitation (I_x)
  - Rated from 20 Mvar to 200 Mvar

$$Q=\frac{|E|^2}{X_s}-\frac{|E_o||E|}{X_s}\cos(0^\circ)=\frac{|E|^2}{X_s}-\frac{|E_o||E|}{X_s}$$

$$|E_o|=|E|-QX_s/|E|$$



Induction motors vs. Synchronous motors

- SMs are more complex to build but have less weight and cost than the IMs of the same rating
- SMs have a higher efficiency and a higher starting torque

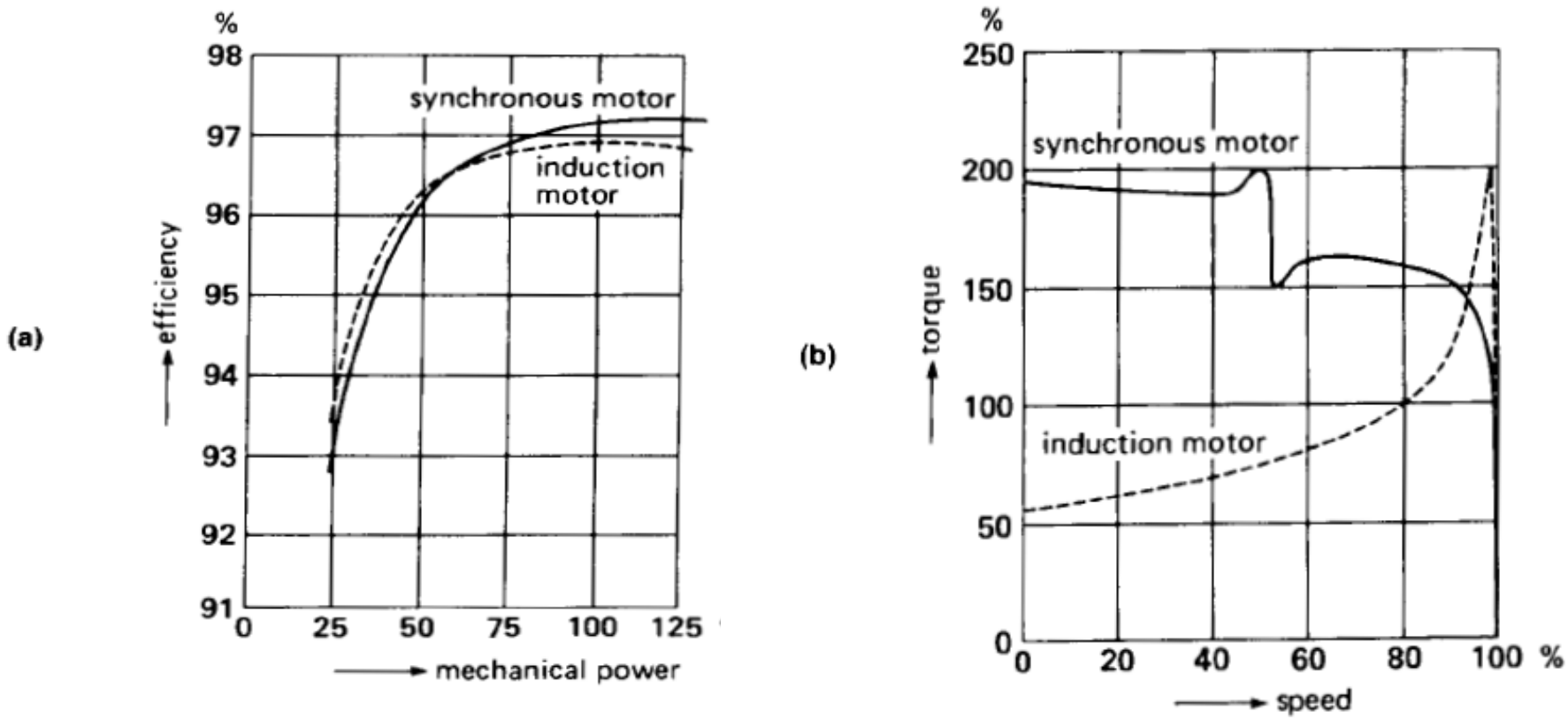


Figure 17.23
Comparison between the efficiency (a) and starting torque (b) of a squirrel-cage induction motor and a synchronous motor, both rated at 4000 hp, 1800 r/min, 6.9 kV, 60 Hz.

Examples 17-2a-b, 17-3, 17-4

Homework Assignment #7

- Read Chapters 16 and 17
- Problems:
  - 16-8, 16-16, 16-19, 16-22, 16-23, 16-24, 17-13, 17-14, 17-15, 17-19
- Due date: 11/16 (Wednesday)
  - hand in or email your homework directly to GTA