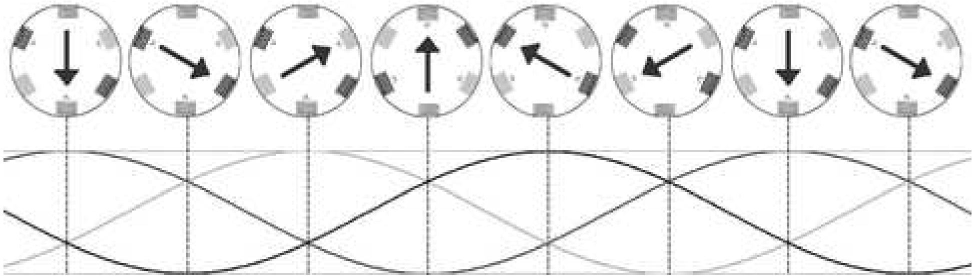
Induction Motors

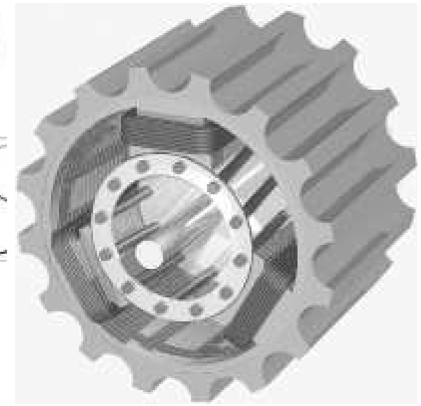
A Stolp 1/26/10

Three-phase

The magnetic flux inside the motor rotates at the "synchronous" speed. $n_{sync} = \frac{120 \cdot f}{N_{poles}}$ f = electrical frequency; n denotes rpm



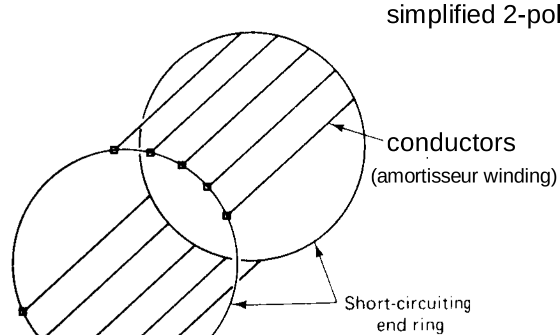
2-pole, 3-phase stator winding and the rotating flux



simplified 2-pole

If you place a rotor with a magnet or electromagnet inside this rotating magnetic flux, it would rotate at the synchronous speed.
This is the way a synchronous motor works.

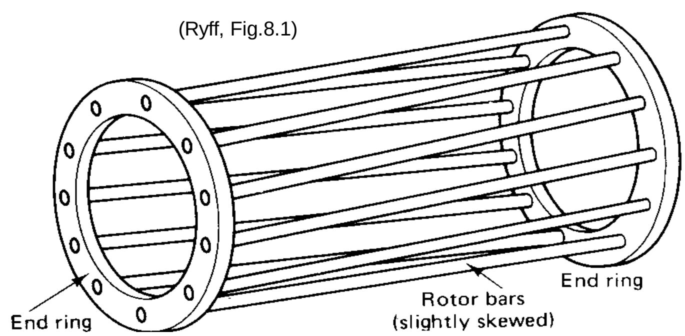
If you place a rotor with wire loops (typically a squirrel-cage winding) inside this rotating magnetic flux, currents would be induced in these windings as in the secondary of a transformer. These currents would, in turn, create a magnetic field which would tend to follow the rotating magnetic field and cause the rotor to turn. It would NOT rotate at the synchronous speed because the closer it gets, the smaller the induced currents in the rotor windings. (If the rotor ever did turn at the synchronous speed, the induced currents and torque would be zero.)
This is the way an induction motor works.



(Ryff, Fig.10.3)

A typical rotor of an induction motor includes a number of thick conductors called "rotor bars". Current is induced in these bars because the rotor normally turns at speed which is slower than the synchronous speed (the speed of the rotating flux caused by the stator windings). By Lenz's law, those currents will be induced in a direction to oppose the change that caused them. Thus the interaction between the induced current and the rotating flux provides the motor torque.

(Ryff, Fig.8.1)



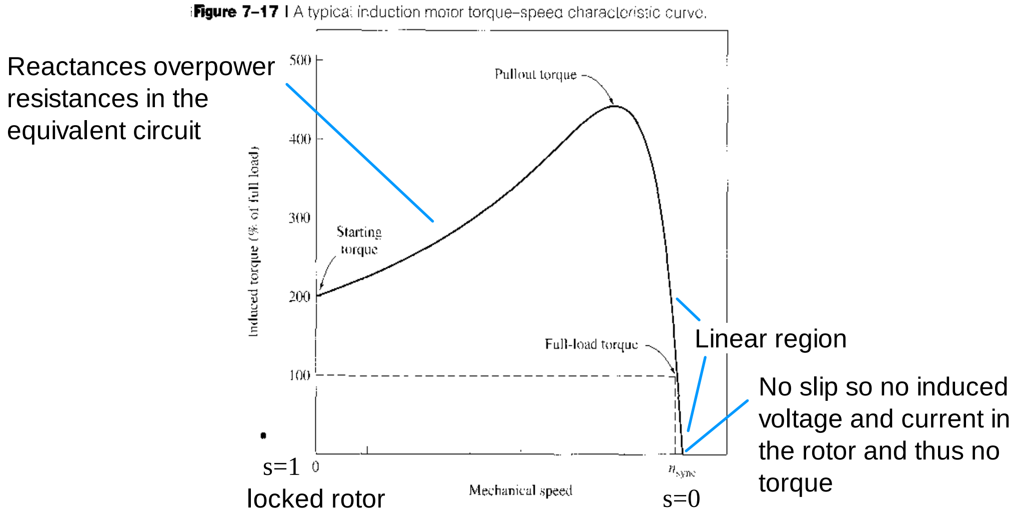
$n_{slip} = n_{sync} - n_m = s \cdot n_{sync}$

n_m = the mechanical speed of the rotor $= (1 - s) \cdot n_m$

slip $s = \frac{n_{slip}}{n_{sync}} = \frac{n_{sync} - n_m}{n_{sync}}$

Figure 7–17 | A typical induction motor torque–speed characteristic curve.

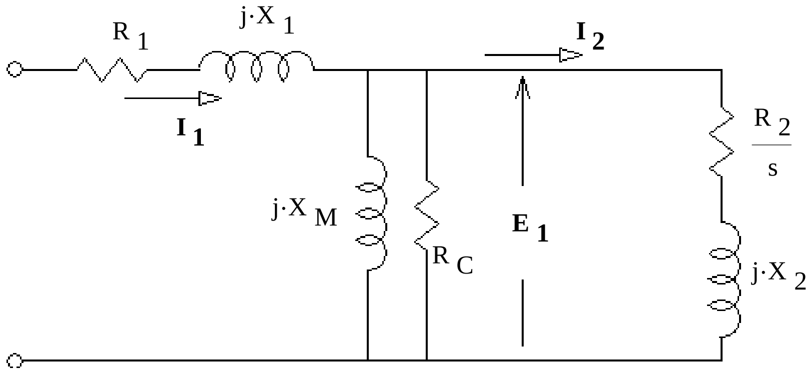
A typical torque-speed curve:



$\omega = n \cdot \left(2 \cdot \pi \cdot \frac{rad}{rev}\right) \cdot \left(\frac{min}{60 \cdot sec}\right)$

$\frac{rad}{sec}$ rpm

Model of an Induction Motor



$3 \cdot \left(I_2^{\,2} \cdot \frac{R_2}{s} \right) = P_{AG}$

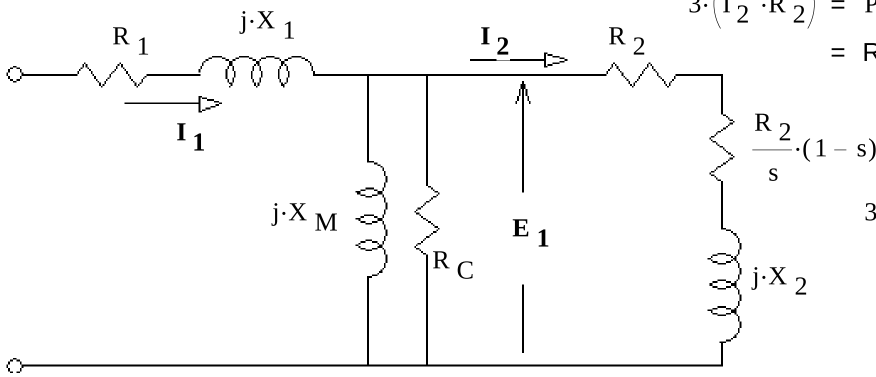
= Power that crosses the Air Gap

= Stator Copper Losses

$3 \cdot \left(I_1^{\,2} \cdot R_1 \right) = P_{SCL}$

$3 \cdot \left(I_2^{\,2} \cdot R_2 \right) = P_{RCL}$

= Rotor Copper Losses



$3 \cdot \left[I_2^{\,2} \cdot \frac{R_2}{s} \cdot (1 - s) \right] = P_{conv}$

$= (1 - s) \cdot P_{AG}$

= power converted to mechanical

$3 \cdot \frac{E_1^{\,2}}{R_C} = P_{core}$

= core loss

$P_{out} = P_{conv} - P_{mech} - P_{misc}$

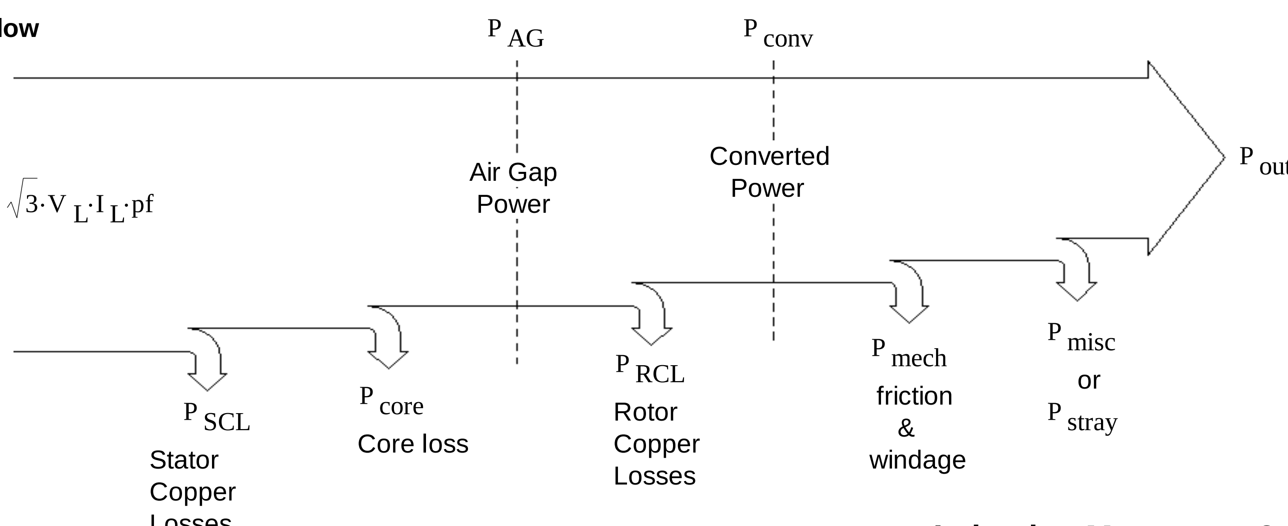
mechanical losses

induced torque = $\tau_{ind} = \frac{P_{conv}}{\omega_m}$ OR: $\tau_{ind} = \frac{P_{AG}}{\omega_{sync}}$ $(N \cdot m)$

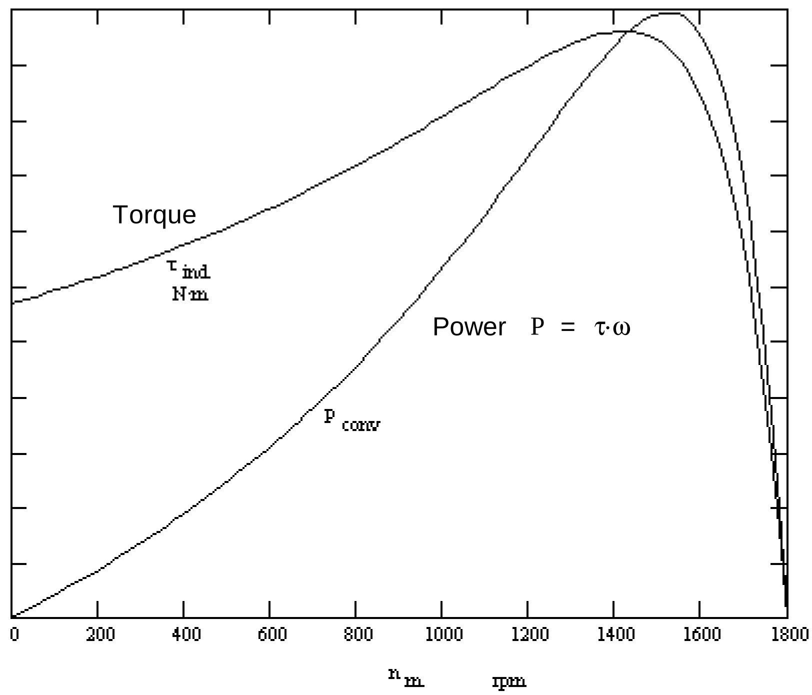
load torque = $\tau_{load} = \frac{P_{out}}{\omega_m}$

Power Flow

$P_{in} = \sqrt{3} \cdot V_L \cdot I_L \cdot pf$

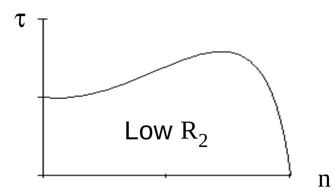


Typical torque-speed and power-speed curves for a 4-pole Induction motor

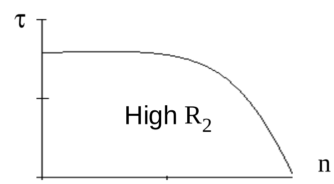


These curves are greatly affected by the rotor resistance (R_2 in our model).

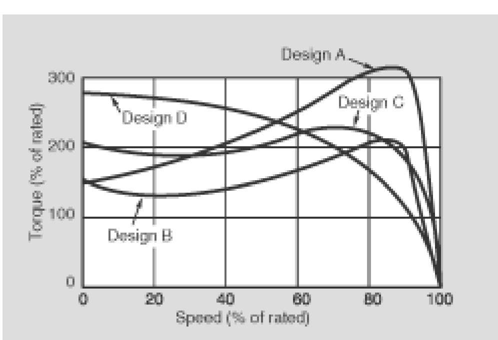
Low R_2: Higher efficiency at normal running
Lower startup torque
Higher startup current



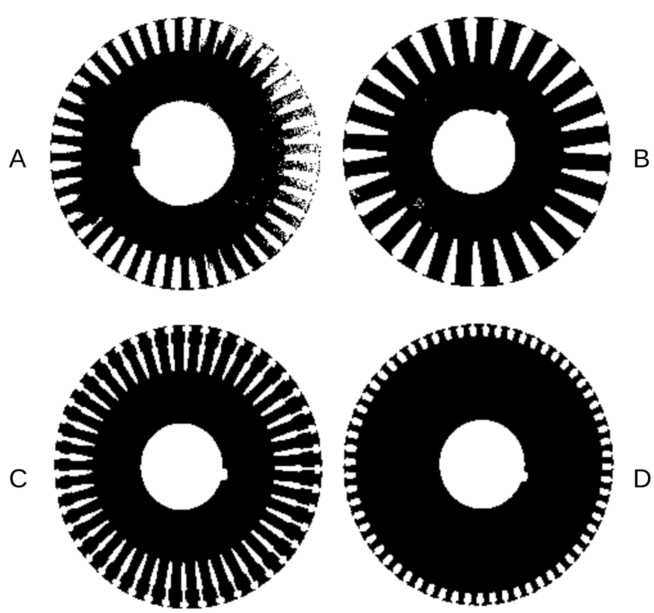
High R_2: Lower efficiency at normal running
Higher startup torque
Lower startup current



By manipulating the design of the rotor cage, you can mix some of the benefits of both.



NEMA Designs



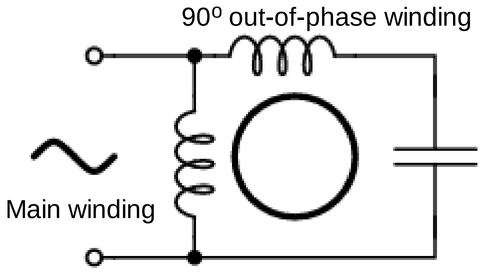
Rotor cross-sections

Induction Motors p3

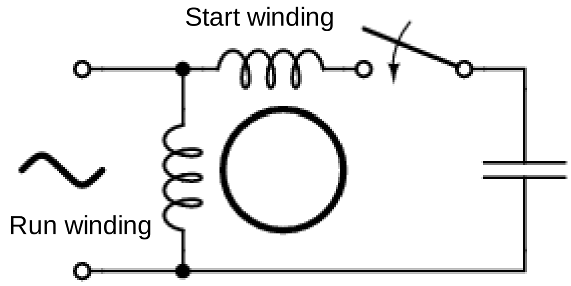
Single-Phase Induction Motors

No Starting Torque without a Start winding

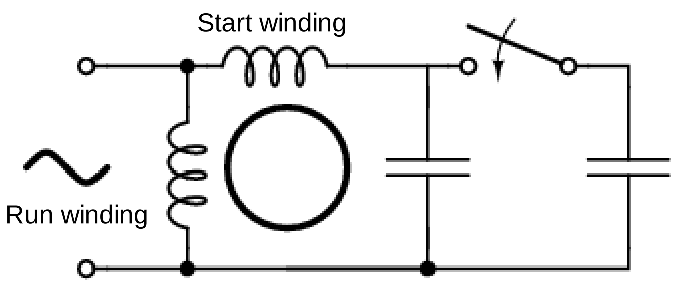
Capacitor-run

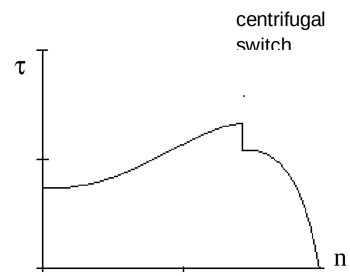


Capacitor-start



An ideal capacitor value would cause the current in the start winding to be 90º out-of-phase with the current in the run winding. That value turns out to be more for a stalled (or not-yet started) motor than one that is running at rated speed and output.

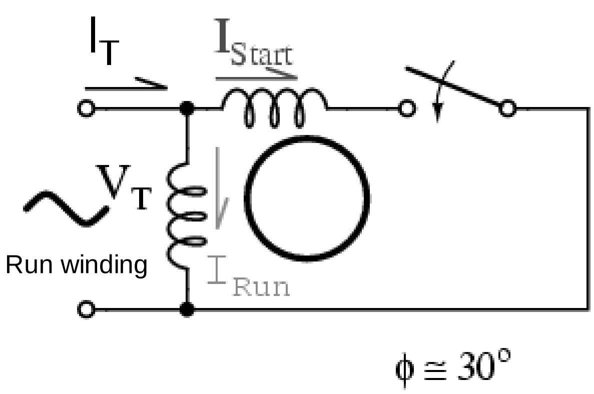


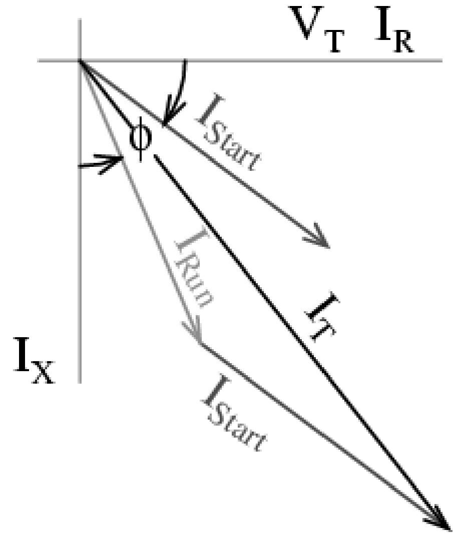


Split-Phase

The run winding has a large inductance and little resistance.

The start winding has little inductance and lots of resistance.





Start Direction: Reverse the leads to either of the windings to get the motor to start in the opposite direction.