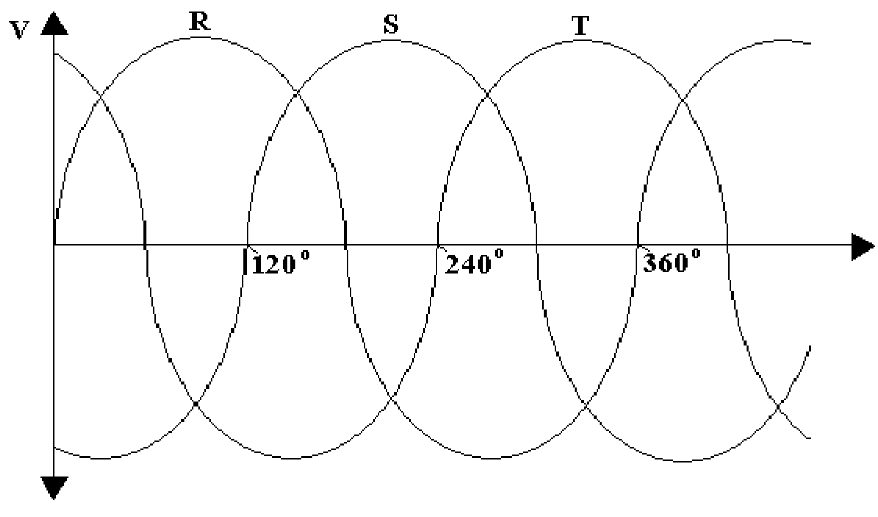
Induction Machines

Notes from Jane Courtney

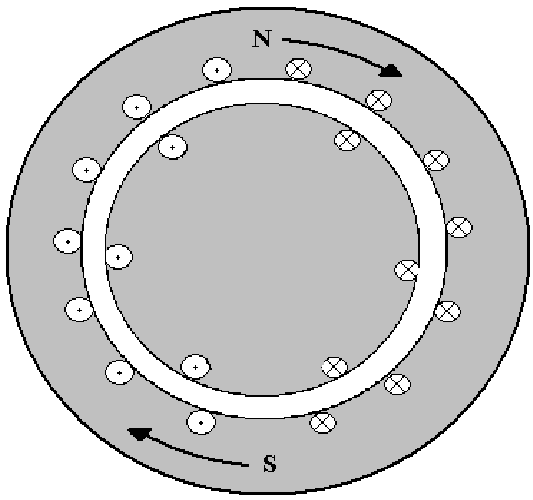
Operation

- The induction machine behaves like a transformer, transferring electrical energy from the stator to the rotor.
- A rotating magnetic field is set up on the stator by using distributed windings and a 3-phase AC supply.
- The rotor windings are generally short-circuited.
- The rotor spins *almost* in synch with stator's rotating field.
- The amount by which the rotor falls behind the stator is called the *slip*.

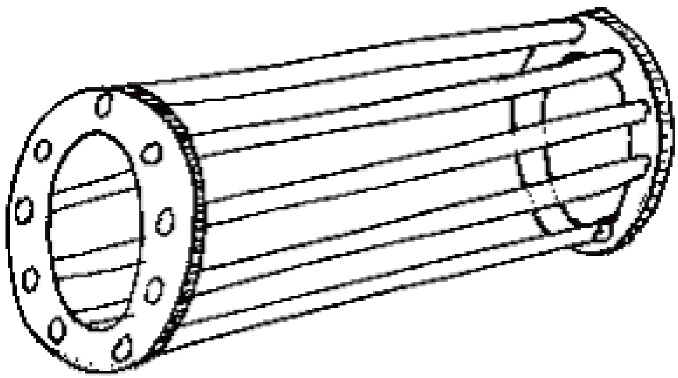
3-phase input



<u>Construction</u>



- The stator windings are sinusoidally distributed to ensure smooth motion instead of winding on salient poles.
- The rotor can be wound or ‘squirrel cage’:



Multiple Poles

If the stator has more than two magnetic poles, the magnetic field will rotate at a slower speed. The magnetic field of a *p* pole machine will rotate at a speed of:

$$\omega_S = \frac{2}{p} \cdot 2\pi . f_e \quad [rad/s] \qquad \text{or} \qquad N_S = \frac{2}{p} \cdot 60 . f_e \quad [rpm]$$

where f_e is the frequency of the electrical supply (f_e = 50Hz in Europe).
e.g. an 8-pole machine connected to the Irish supply has a rotating magnetic field turning at 25π rad/s or 750 rpm.

Slip

The slip is the amount by which the rotor movement lags behind the stator's rotating field:

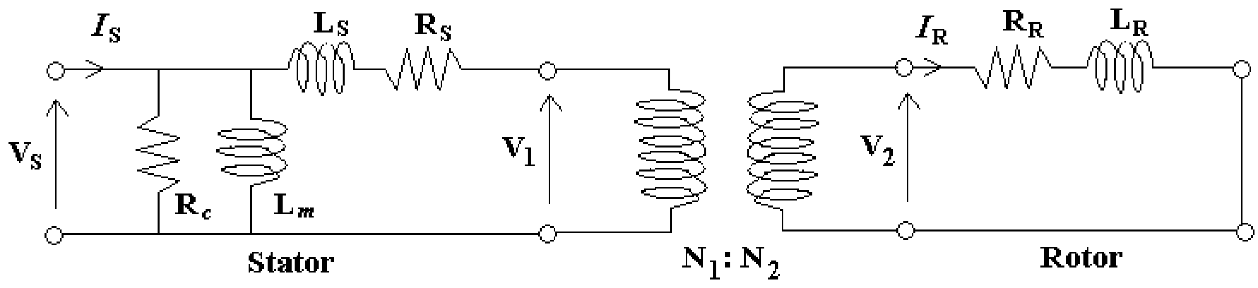
$$s = \frac{\omega_S - \omega_R}{\omega_S} \qquad \text{or} \qquad s = \frac{N_S - N_R}{N_S}$$

ω_S or N_S is the speed of the stator's magnetic field;
ω_R or N_R is the speed at which the rotor is rotating;
$\omega_S - \omega_R$ or $N_S - N_R$ is the frequency of the induced rotor current.

The slip is 1 when the machine is stationary and 0 when perfectly synchronised with the rotating field, i.e. running at *synchronous speed*.

Per-Phase Equivalent Circuit

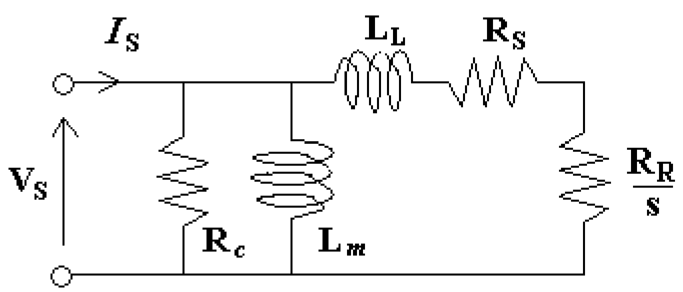
The equivalent circuit models the machine losses per phase of the stator windings. These are similar to those associated with a transformer. In this case the secondary (the rotor) is short-circuited:



The voltage ratio is slightly different from the ideal transformer ratio because the frequency is not the same on both sides:

$$\frac{V_2}{V_1} = s \cdot \frac{N_1}{N_2}$$

Generally, induction machines are built so that $N_1 = N_2$, so $V_2 = s.V_1$ and the circuit can be simplified:



L_L is the total leakage inductance in both the stator and rotor.

<u>Power Transfer</u>

- Gross Rotor Input (GRI) is the total real power passed to the rotor:

$$P_R = 3|I_R|^2 \cdot \left(\frac{R_R}{s}\right)$$

- The real power lost in the rotor is a result of copper losses:

$$P_{loss} = 3|\, I_R\,|^2.R_R$$

- The output power (seen as mechanical movement) is the input power to the rotor minus the losses in the rotor:

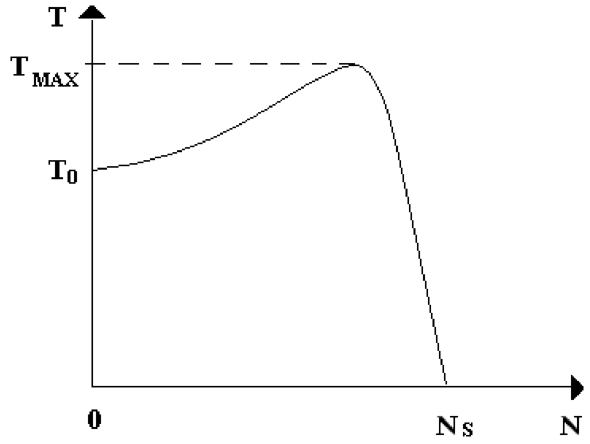
$$P_{out} = P_R - P_{loss} = 3(1-s)|\, I_R\,|^2.\frac{R_R}{s}$$

- The torque can be calculated from this since $P_{out} = P_{mech} = \omega T$.

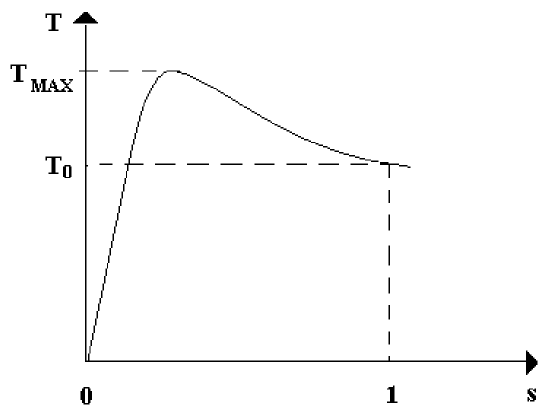
- The overall *machine efficiency* is calculated with the supply on the stator supplying the real input power and the output power being the mechanical movement:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{mech}}{\mathrm{Re}\{P_S\}} = \frac{\omega T}{3 \times \mathrm{Re}\{V_S I_S\}}$$

Torque-speed characteristic

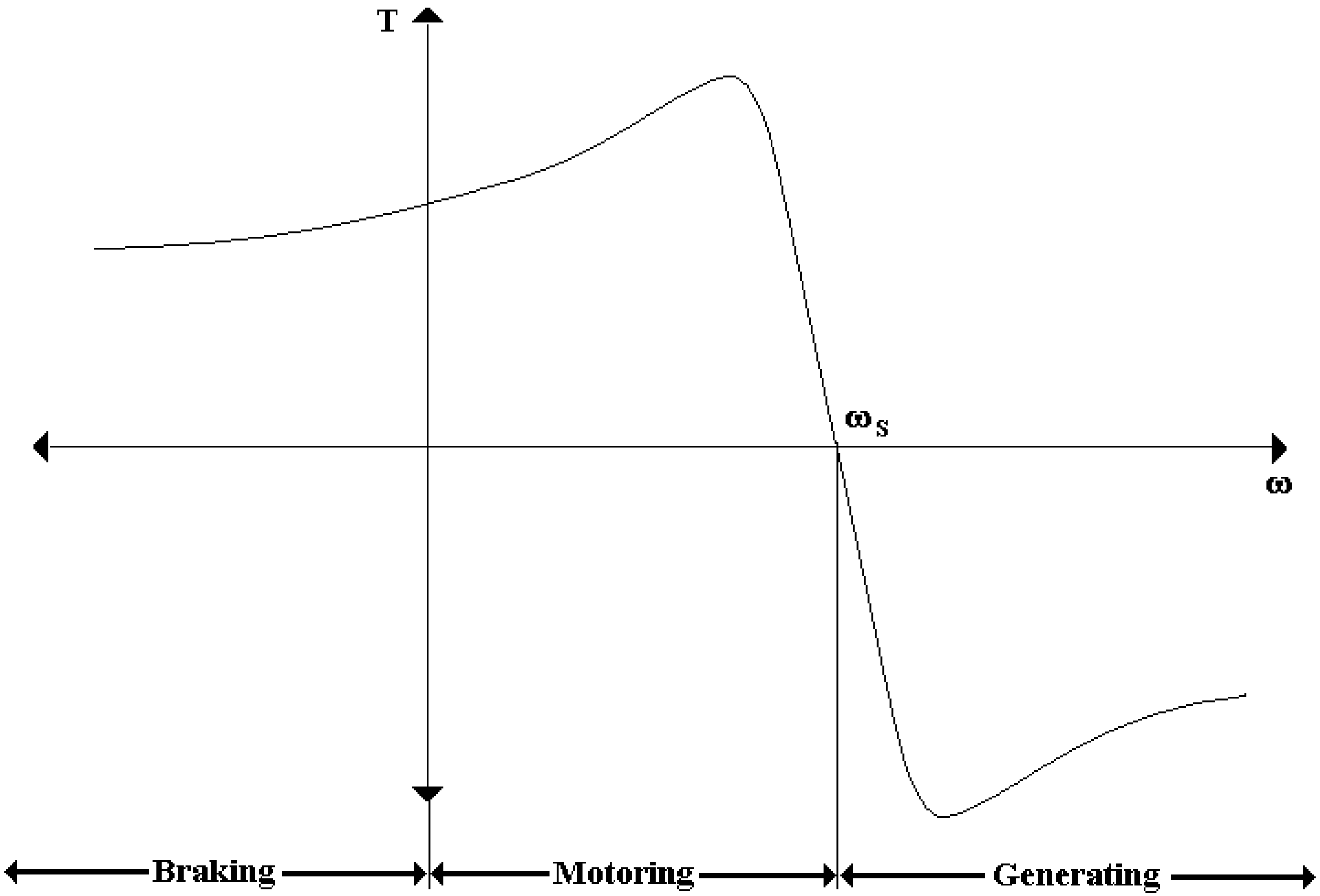


- This shows the motoring region where the speed ranges between stationary and synchronous speed.
- The starting torque T_0 is also known as the *stall torque*.
- The maximum torque T_{MAX} is called the *pull-out torque* or *breakover torque*.
- This can be compared to the slip characteristic for motoring, i.e. where the slip ranges between 0 and 1:

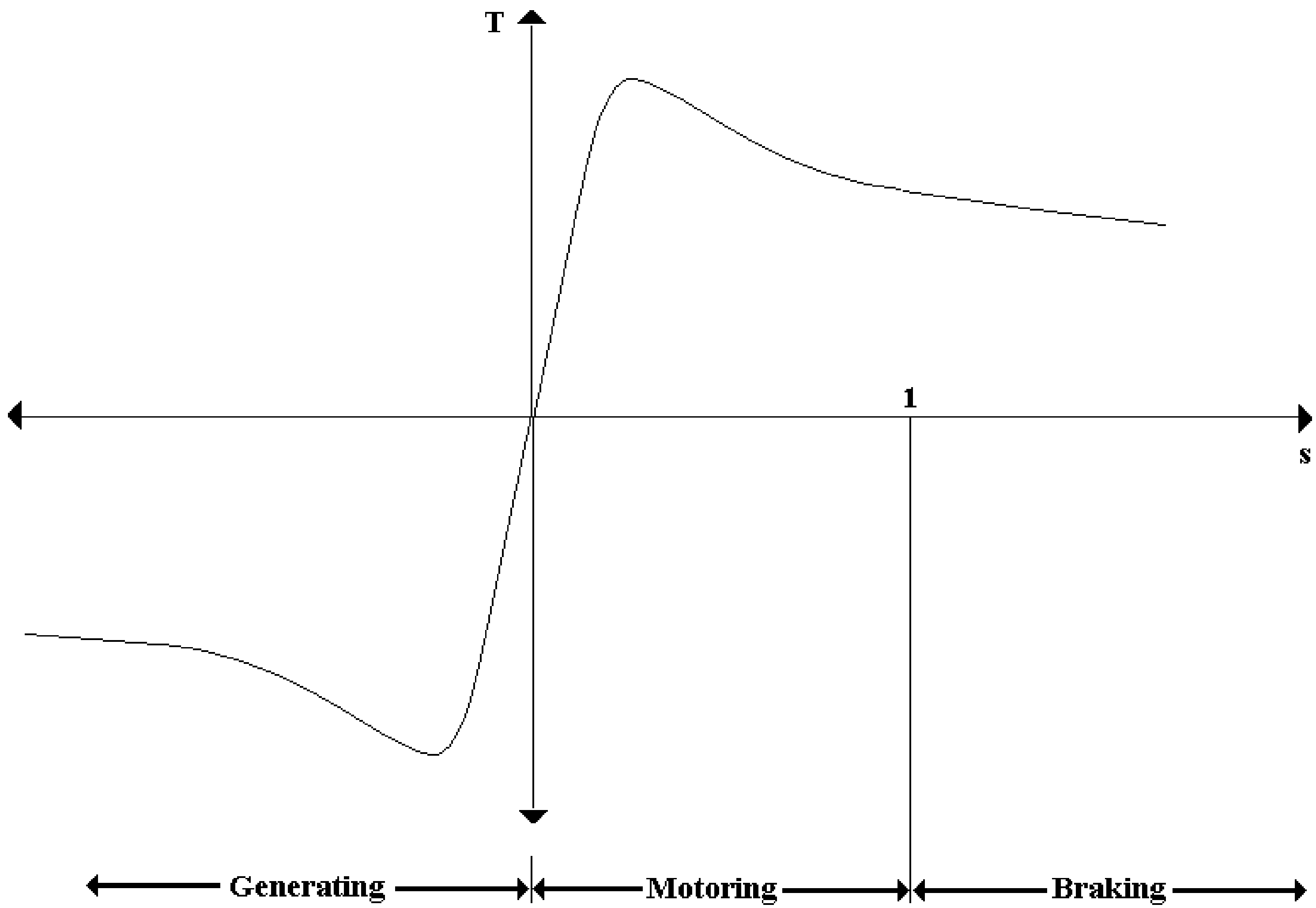


These characteristics can be extended beyond these ranges to observe the other modes of operation (See attached).

Torque vs. Speed



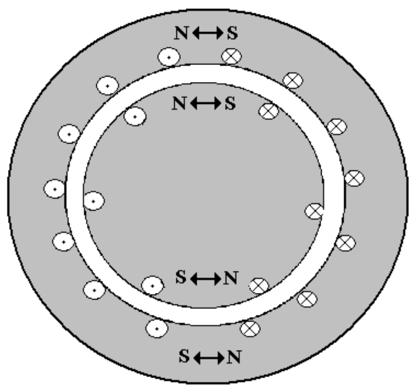
Torque vs. Slip



Single-Phase Induction Motors

Operation

- The single-phase induction motor does not have a rotating magnetic field on the stator.
- The single AC supply creates an alternating polarity field which causes the rotor to vibrate instead of rotate.
- By turning the rotor with an external force (even just by hand), the equilibrium is unbalanced and the rotor begins to rotate.
- The rotor continues to turn once started since its poles never line up with the stator's alternating poles.



Motor Starting

- Single-phase motors are classified by their starting methods.
- *Shaded-pole*: used on salient-pole machines. They are cheap to build but inefficient to run.
- *Split-phase*: the phase winding is divided to create a starting winding which simulates a two-phase field.

Split-phase Motor

- The stator winding is split to include a starting winding.
- The starting winding is physically perpendicular to the main winding and electrically parallel.
- The currents in the starting winding are forced 90^o out of phase with the main winding currents by adjusting its impedance.
- This acts like a 2-phase supply causing a pseudo-rotating field.
- Examples of split-pole machines include capacitive start and resistive start machines.