ELEC0431 : Exercise session 7

Asynchronous machine

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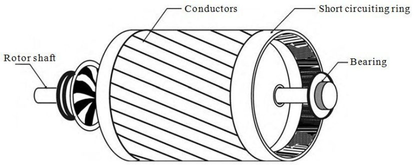
Asynchronous AC machines - Working Principle

The stator generates a rotating magnetic field rotating at $\frac{f}{p}$ rpm. In the rotor, made of short-circuited conductors, induced currents appear (due to the stator rotating field) and a torque is created on the rotor bars. The rotor is then put into motion at a speed slightly slower than the stator magnetic flux's speed. Since a short-circuited loop does not want to see its flux change

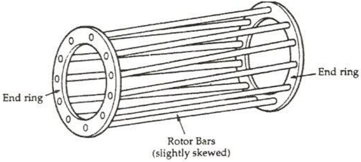


Rotor of Squirrel Cage Induction Motor

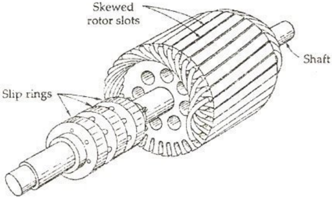
it will create a magnetic induction via eddy currents in order to try to keep the flux constant. By doing so the rotor will create poles that are attracted by the rotating stator resultant flux : a torque appears

Types of rotor

The two main types of rotor found on asynchronous machines



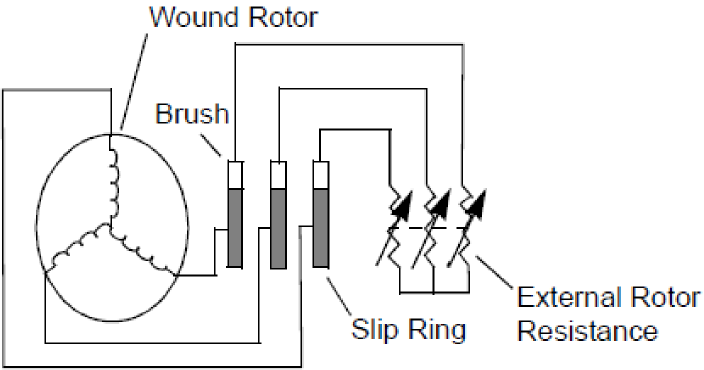
The squirrel cage rotor, made of solid conducting bars.



The wound rotor, made of three-phase windings that can be connected to an external rotor resistance.

The squirrel cage and the rotor slots are a little bit twisted to smoothen the torque by averaging it all over the bar.

Illustration of the wound rotor



Speed of rotation

Synchronous speed

The synchronous speed corresponds to the speed at which the stator magnetic flux varies over time.

$$\boxed{\dot{\theta}_s = \frac{f}{p}} \tag{1}$$

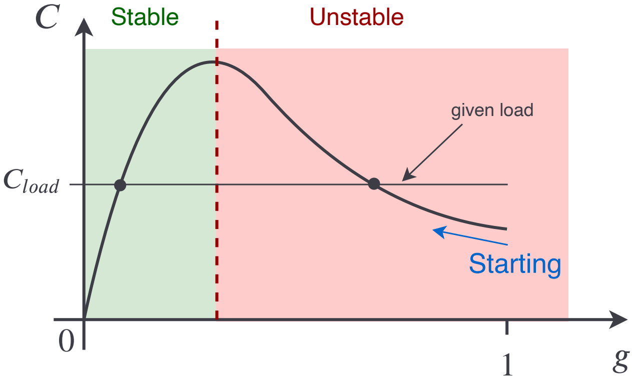
The practical speed of the rotor $\dot{\theta}$ is different than the synchronous speed and is computed from it, based on the slip g.

$$\boxed{g = \frac{\dot{\theta}_s - \dot{\theta}}{\dot{\theta}_s}} \tag{2}$$

Remark that the torque is zero at the synchronous speed thus the synchronous speed is not reachable due to at least a friction torque.

Torque depending on the slip

The relationship between the torque and the slip leads to the stable and unstable behaviours of the asynchronous machine.



Stator

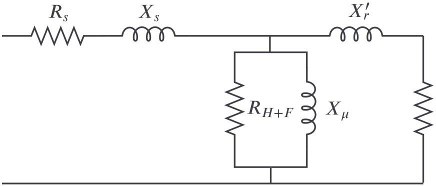
The stator of the asynchronous machine is the same as described for the synchronous machine.

Rotor

The rotor is either a squirrel cage rotor or a wound rotor.

Equivalent circuit of the asynchronous machine

The equivalent circuit of the asynchronous machine is close to the circuit of the transformer.



$$\frac{R'_r}{g} = \underbrace{R'_r}_{\text{rotor copper losses}} + \underbrace{\frac{1-g}{g} R'_r}_{\substack{\text{power transmitted}\\ \text{the rotor shaft}}}$$

Indeed, the induction machine behaves as a transformer with its secondary short-circuited. The important difference is that the rotor, as it is a moving part of the machine, sees a frequency $g \cdot f$ different than the stator nominal frequency f.

Equivalent circuit of the asynchronous machine

The different components represent physical phenomenon such as

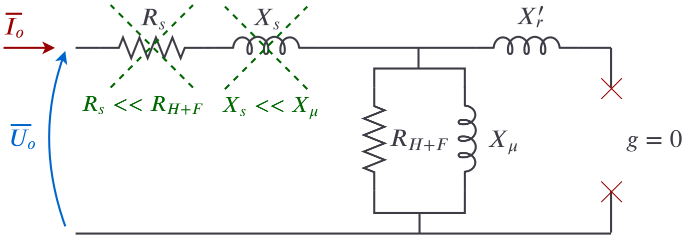
R_s : the joule losses in the stator winding
X_s : the leakage flux of the stator
R'_r : the joule losses in the rotor , seen from the stator
X'_r : the leakage flux of the rotor, seen from the stator
R_{H+F} : the magnetic losses in the core such as hysteresis ($\propto f$) and eddy current ($\propto f^2$)
X_μ : the magnetizing reactance

In practice, the machines are build in order to minimize the losses and the undesired effects, which leads to

$$R_s << R_{H+F} \quad ; \quad R'_r << R_{H+F} \quad ; \quad X_s << X_\mu \quad ; \quad X'_r << X_\mu$$

Remark that a quite large air gap is required between the rotor and the stator (for a frictionless motion) which leads to a decrease of the magnetizing reactance.

Synchronous speed test (= open circuit)

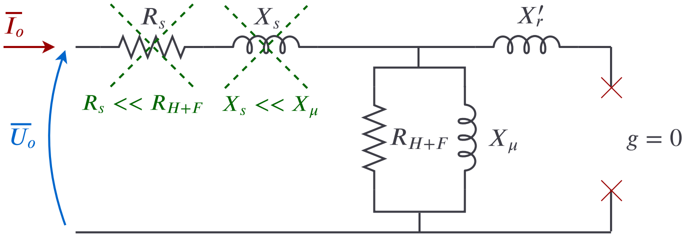


For this test, the asynchronous machine is brought to the synchronous speed by another machine in order to obtain a zero slip

$$\boxed{g = 0} \tag{3}$$

which ensures that no induced current flows in the rotor. This is equivalent to the open circuit test of the transformer.

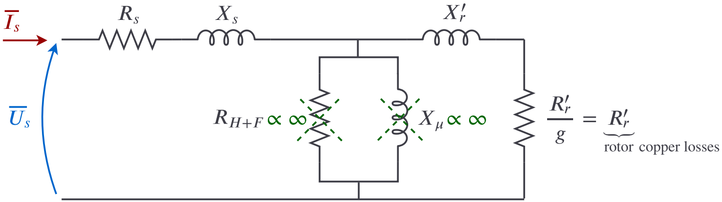
Synchronous speed test (= open circuit)



$$\boxed{\begin{aligned} R_{H+F} &= \frac{U_o^2}{P_o} \quad (4) \\ X_\mu &= \frac{U_o^2}{Q_o} \quad (5) \end{aligned}}$$

where P_{1o} and Q_{1o} are the active and reactive powers consumed during the test at synchronous speed.

Stalled rotor test (= short circuit)

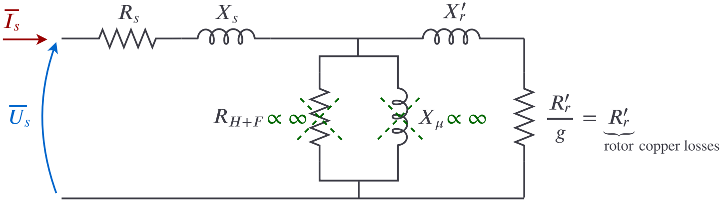


For this test, the rotor of the asynchronous machine is blocked (the machine is stalled) in order to obtain a unitary slip

$$\boxed{g = 1} \tag{6}$$

which ensures that all the active power transmitted to the rotor only corresponds to its Joule losses. This is equivalent to the short circuit test of the transformer.

Stalled rotor test (= short circuit)



$$R_s + R'_r = \frac{P_s}{I_s^2} \quad (7)$$

$$X_s + X'_r = \frac{Q_s}{I_s^2} \quad (8)$$

where P_s and Q_s are the active and reactive powers consumed during the stalled rotor test.

Exercises