Electric machines

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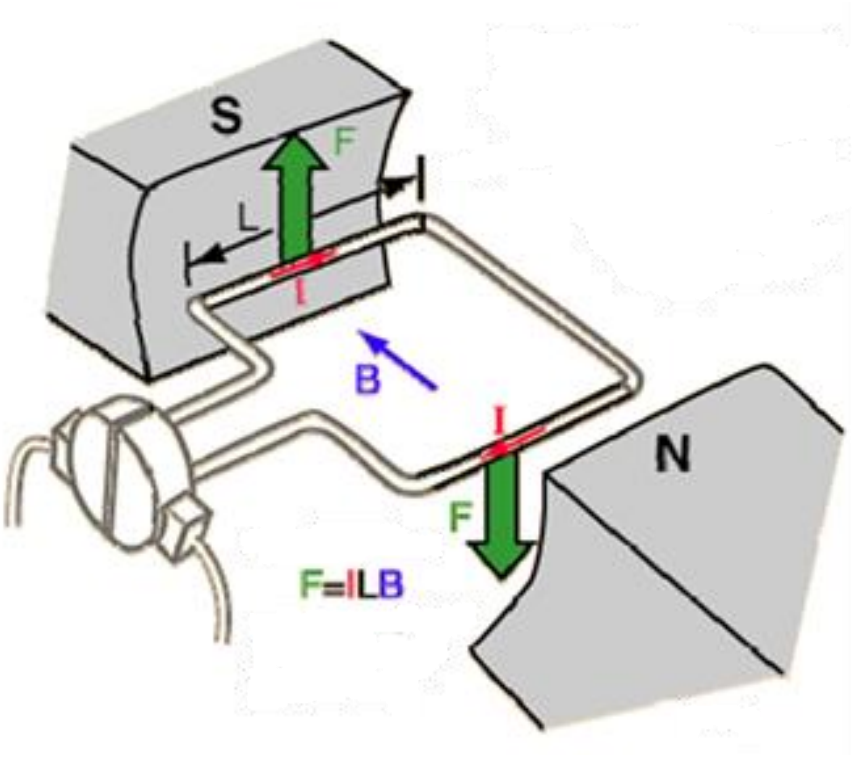
How does a rotating machine spin?



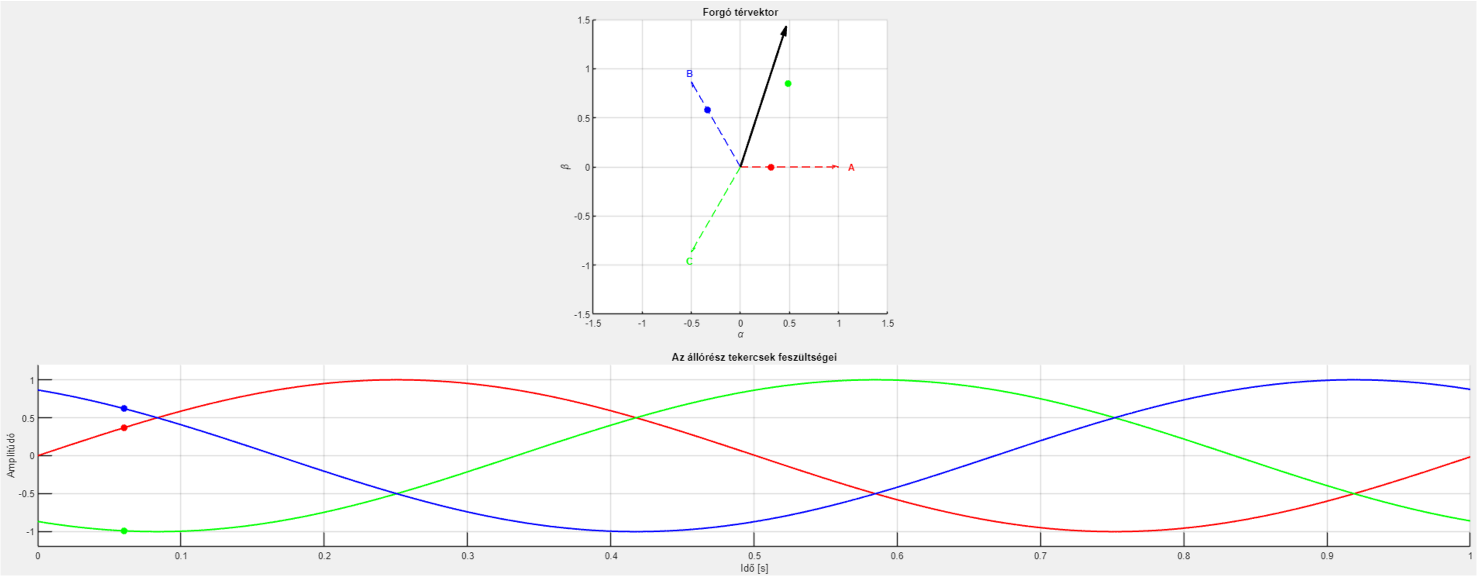
The force generated on each side of the frame:

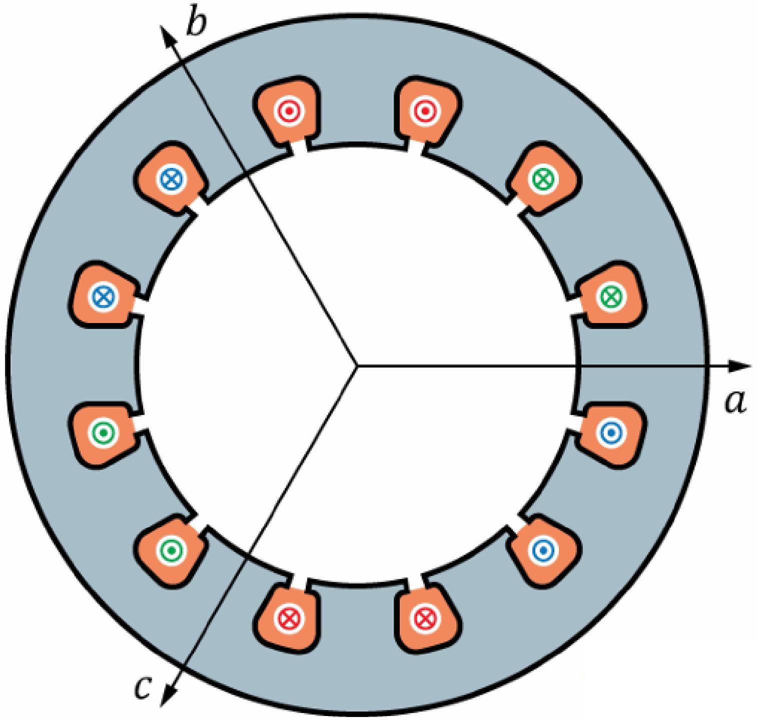
$$\vec{F} = I\overrightarrow{dl} \times \vec{B}$$

The torque generated on the frame:

$$M = IABsin(\alpha)$$

Creating a rotating magnetic field

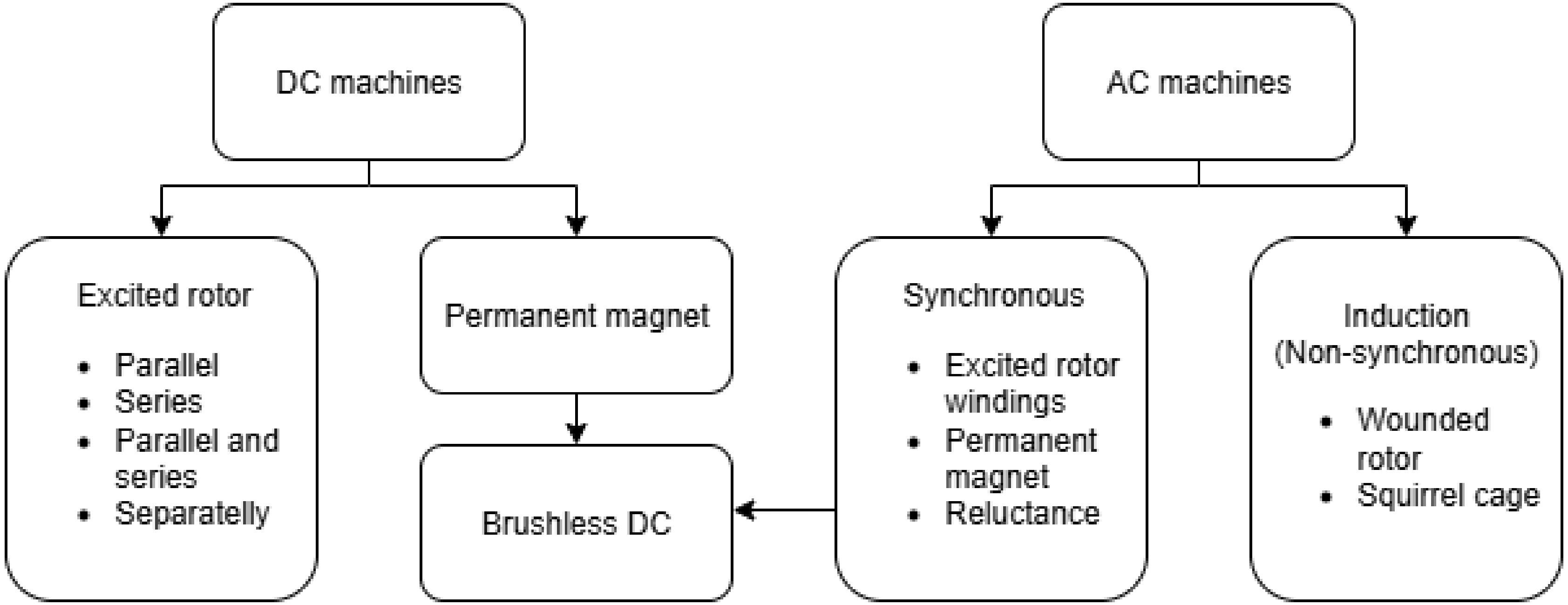




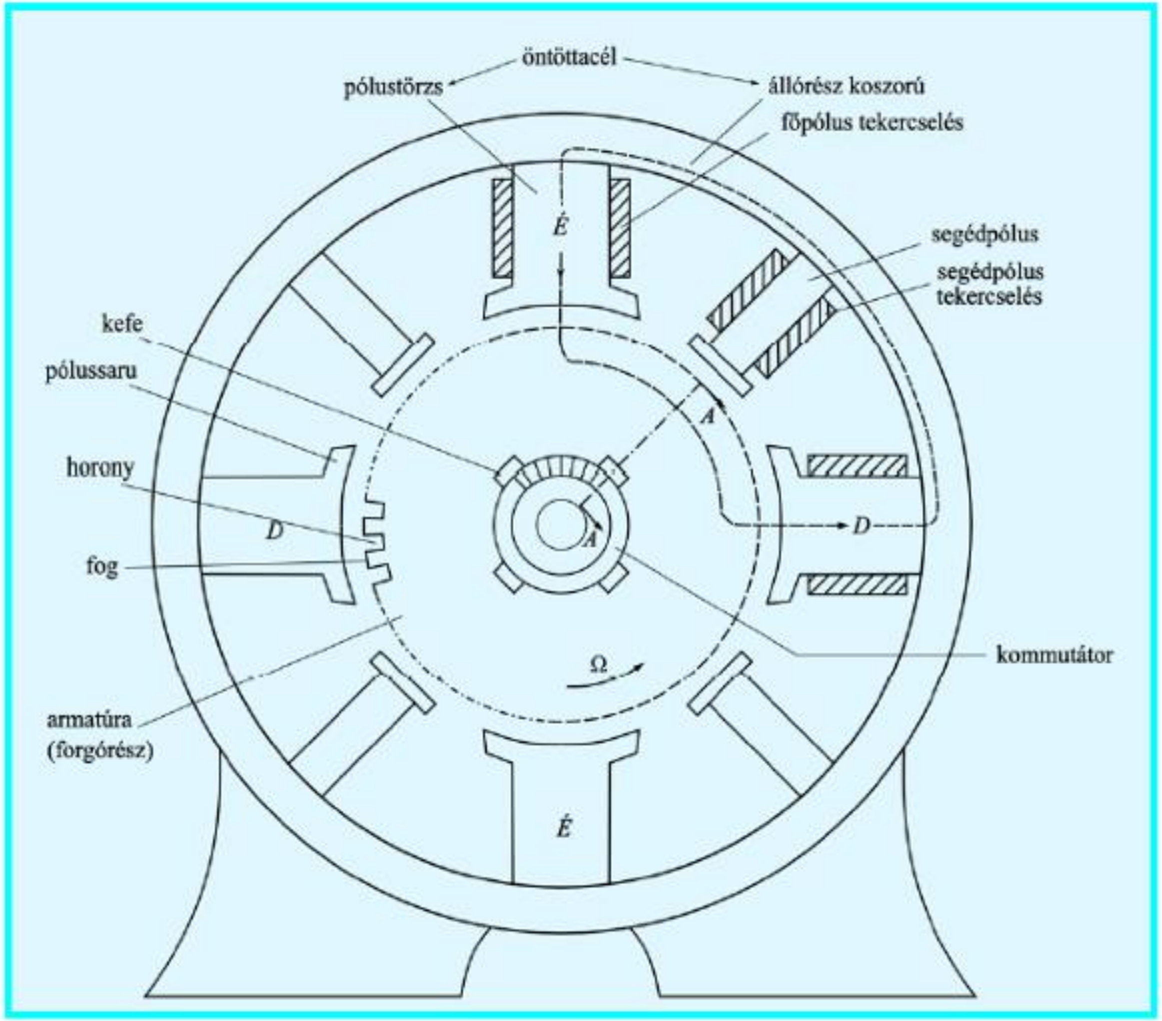
$$\omega_e = 2\pi f \ [rad/s]$$

$$n = \frac{f}{N} \ [RPM]$$

Electric machine types

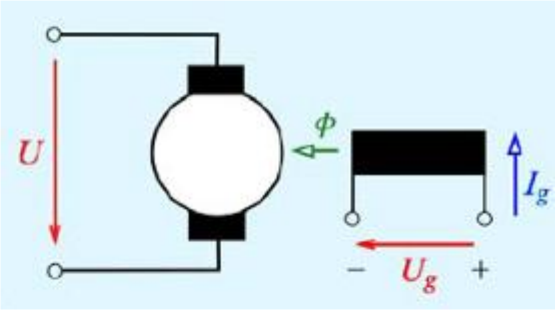


Structure of a DC machine

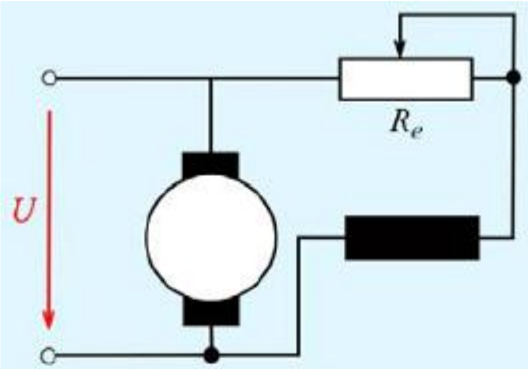


DC machine excitation types

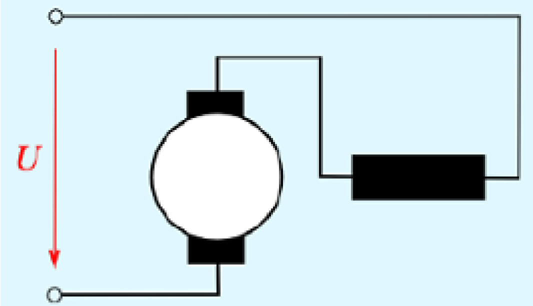
Separatelly excited DC machine



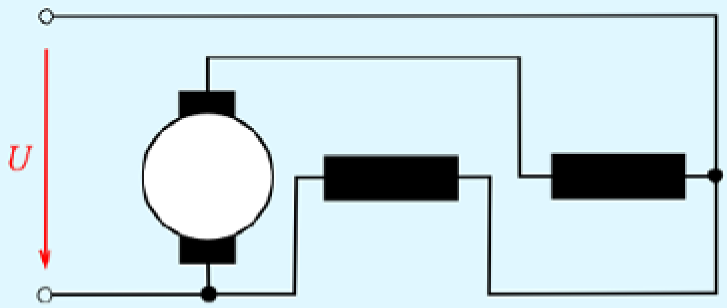
Parallel excited DC machine



Series excited DC machine



Series and parallel excited DC machine



Controlling DC machines

Main control tasks:

- Changing the speed and rotating direction of the machine
- Torque control of the machine
- Starting the machine (soft starting)
- Braking the machine

Main equations of (separatelly excited and permanent magnet) DC machine:

- Induced voltage: $U_i = k\Phi\omega_\mathrm{m}$
- Internal power: $P_b = U_i I_a = T\omega_m$
- Toreue equation: $\mathrm{T} = \frac{P_b}{\omega_m} = \frac{U_i I_a}{\omega_m} = k\Phi\mathrm{I_a}$
- Terminal voltage equation: $U = U_i + I_a R$

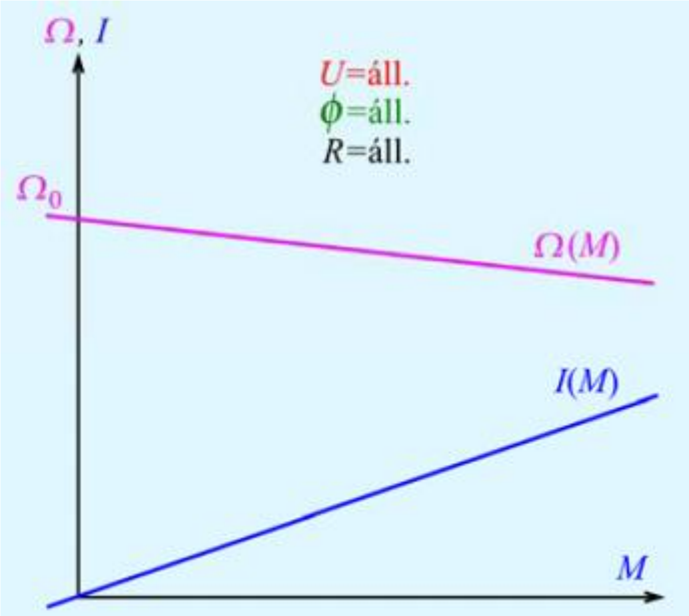
$$\omega_m = \frac{U}{k\Phi} - \frac{TR}{(k\Phi)^2}$$

	Symbol	Unit
Induced voltage	U_i	V
Terminal voltage	U	V
Armature current	I_a	A
Machine flux	Φ	Wb

	Symbol	Unit
Torque	T, M	Nm
Mechanical rotational speed	ω_m, Ω	rad/s
Machine constant	k	-
Winding resistance	R	Ω

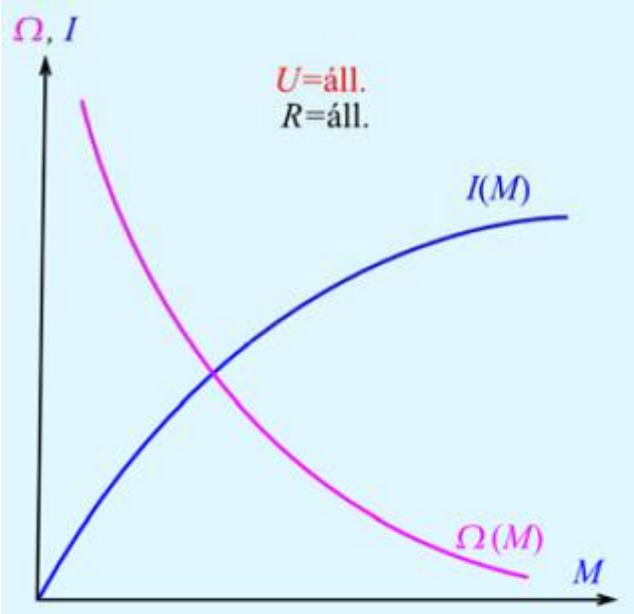
Torque-speed characteristics

Separatelly excited or PM DC machine



$$\omega_m = \frac{U}{k\Phi} - \frac{TR}{(k\Phi)^2}$$

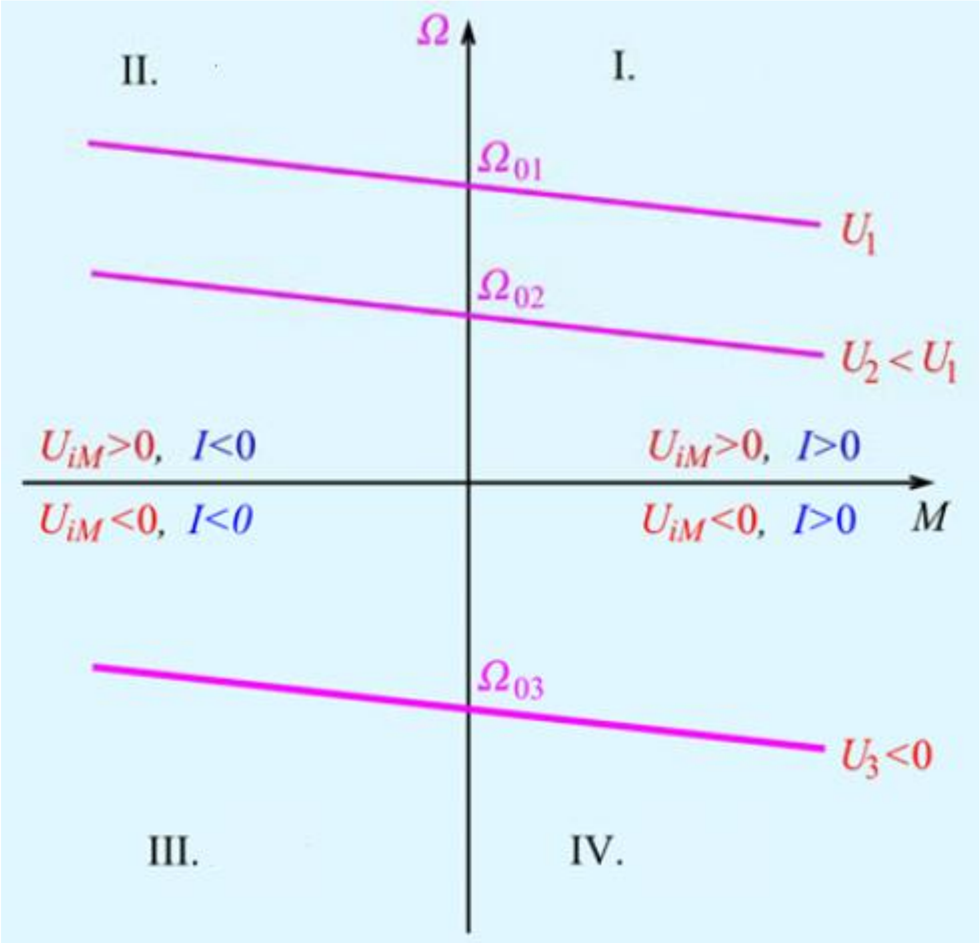
Series excited DC machine



$$\omega_m = \frac{U}{\sqrt{kc}\sqrt{T}} - \frac{R}{kc}$$

$$\Phi = \mathrm{cI_a}$$

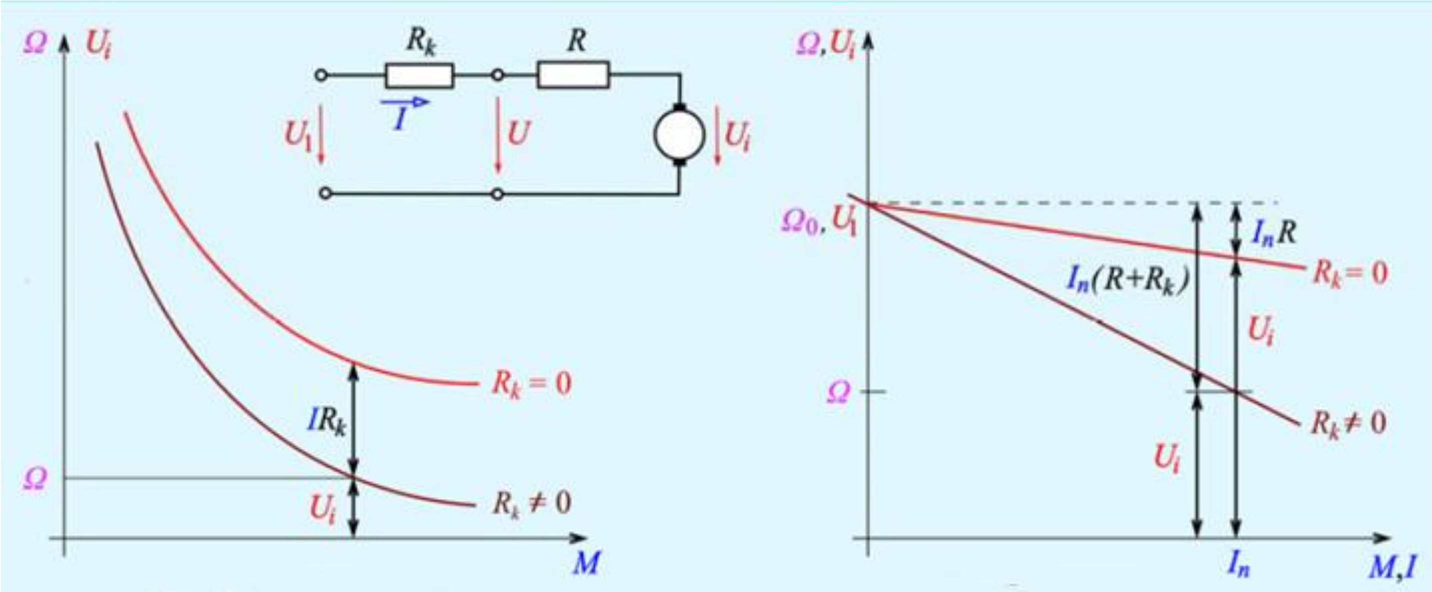
The four operating quadrant of DC machines



I. Motor
II. Generator
III. Motor
IV. Generator

Changing speed with stator resistance

Series excited DC machine	Separatelly excited or PM DC machine



$$\omega_m = \frac{U}{\sqrt{kc}\sqrt{T}} - \frac{R}{kc}$$

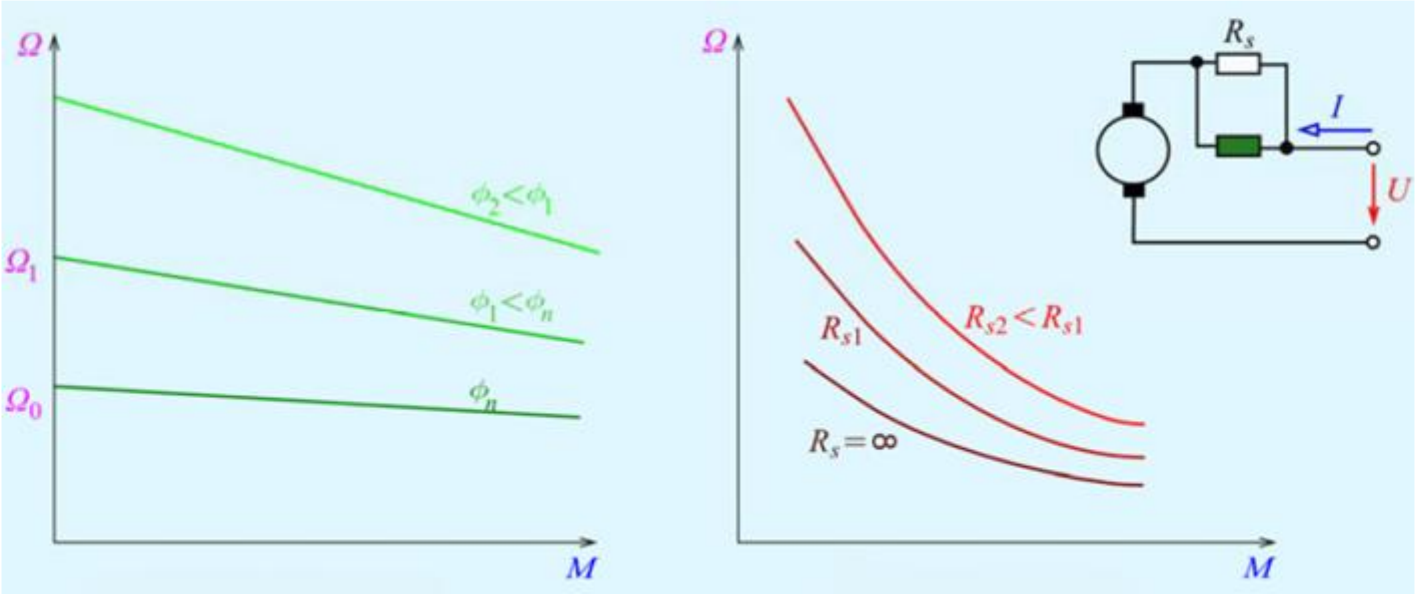
$$\omega_m = \frac{U}{k\Phi} - \frac{TR}{(k\Phi)^2}$$

$$\Phi = \mathrm{c}\mathrm{I}_\mathrm{a}$$

Changing speed with flux

Separatelly excited or PM DC machine

Series excited DC machine

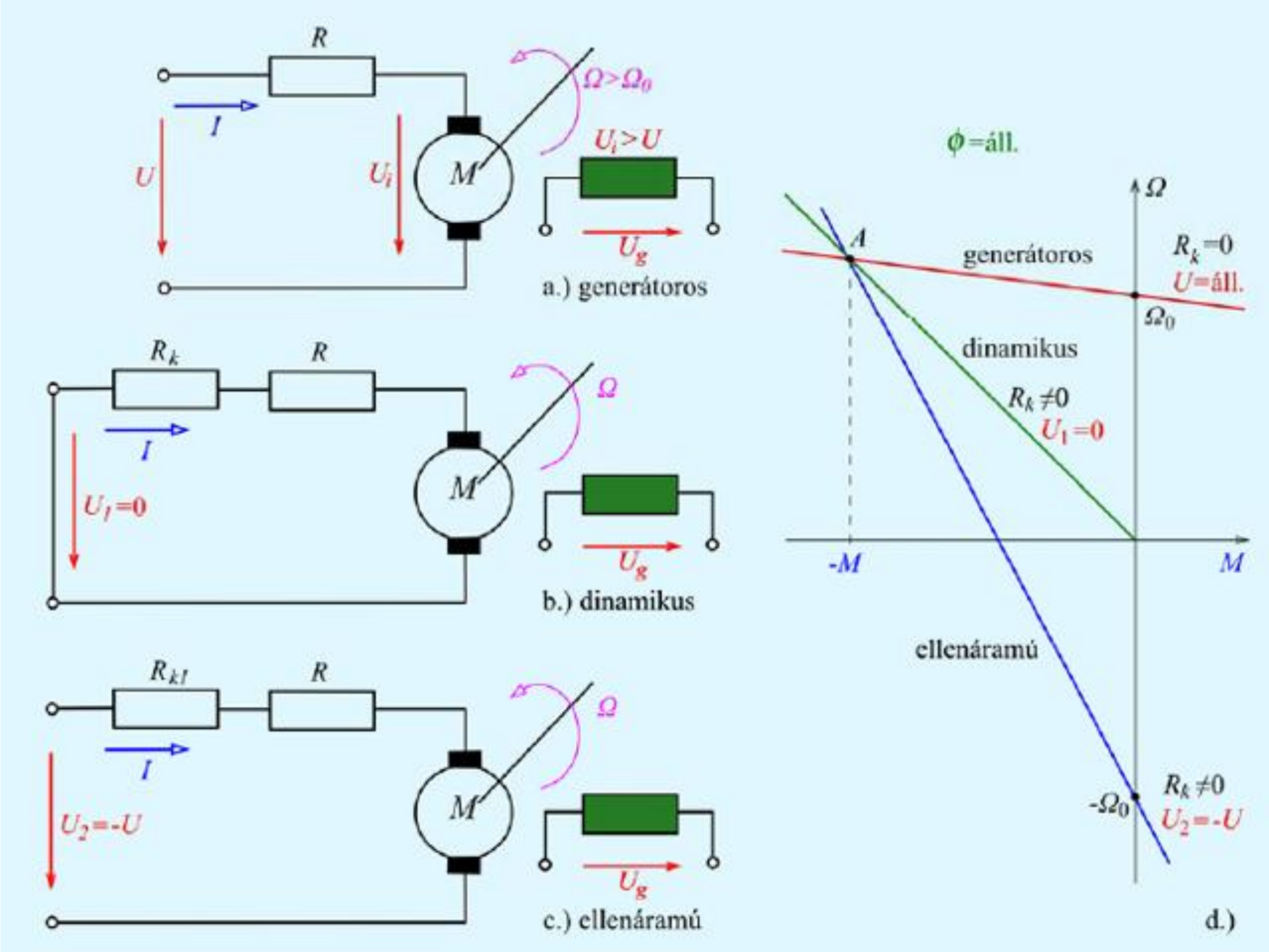


$$\omega_m = \frac{U}{k\Phi} - \frac{TR}{(k\Phi)^2}$$

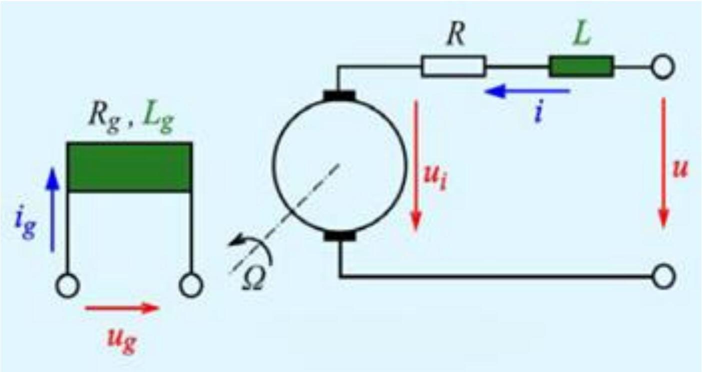
$$\omega_m = \frac{U}{\sqrt{kc}\sqrt{T}} - \frac{R}{kc}$$

$$\Phi = \mathrm{cI_a}$$

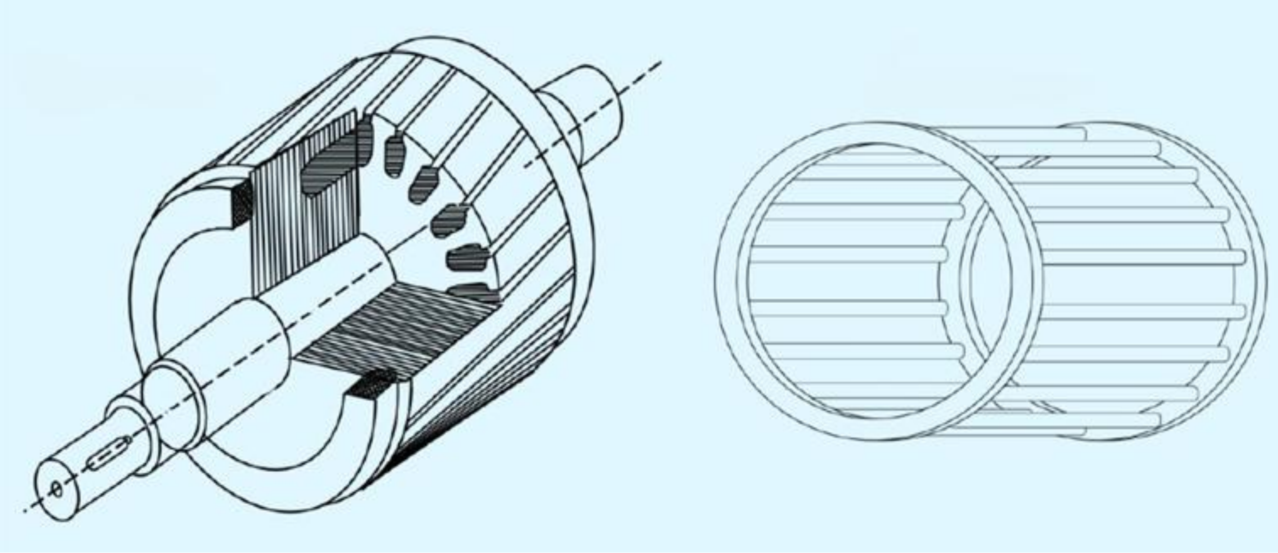
Braking of DC machines

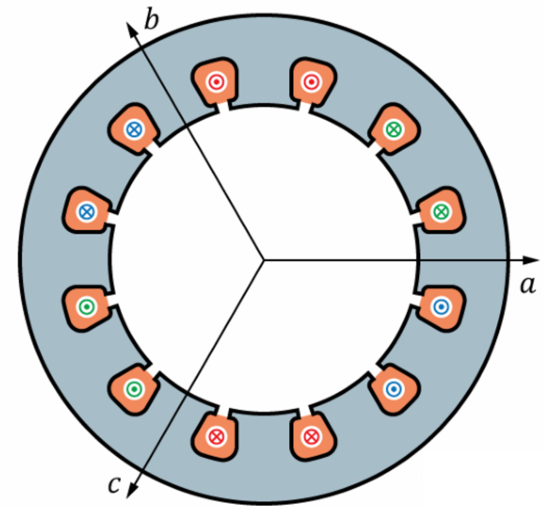


Dynamic model of separatelly excited DC machines

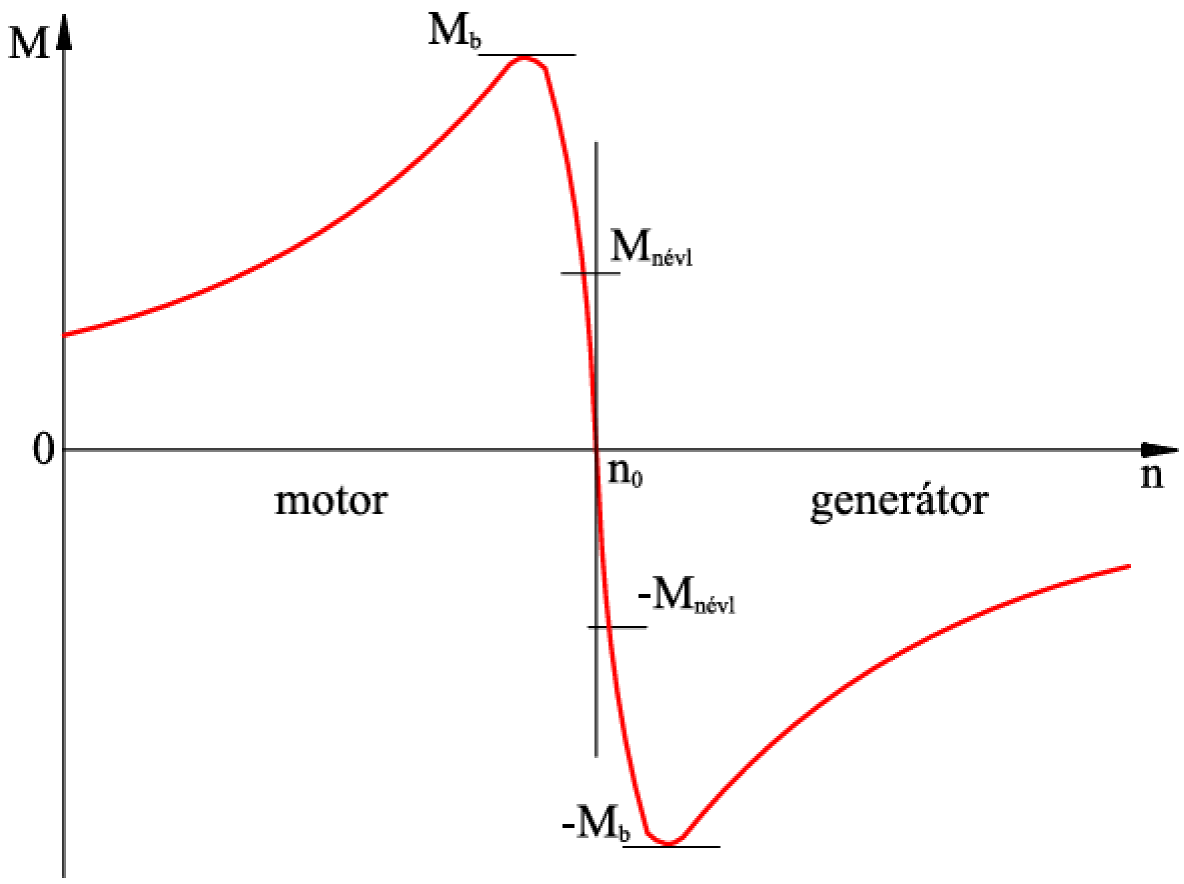


Induction machine





Torque-speed characteristic of the machine



Synchronous rotating speed:

$$n_0 = 60\frac{f}{N}[RPM]$$

Slip of the machine:

$$s = \frac{n_0 - n}{n_0}$$

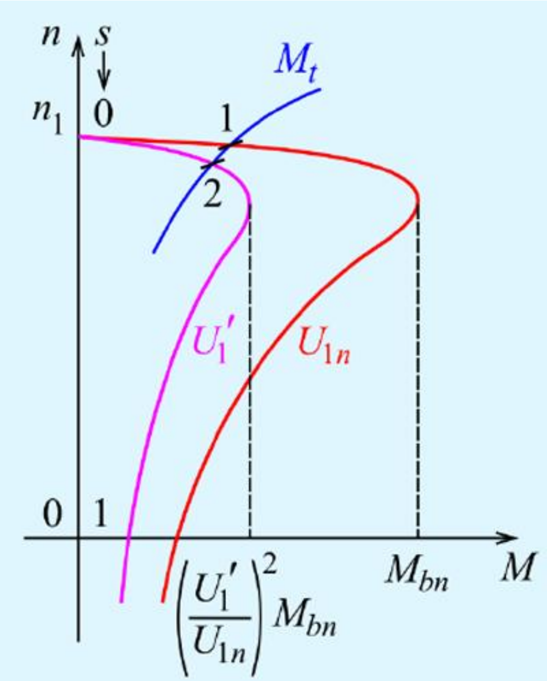
Changing the rotational speed of the machine

$$s = \frac{n_0 - n}{n_0}$$

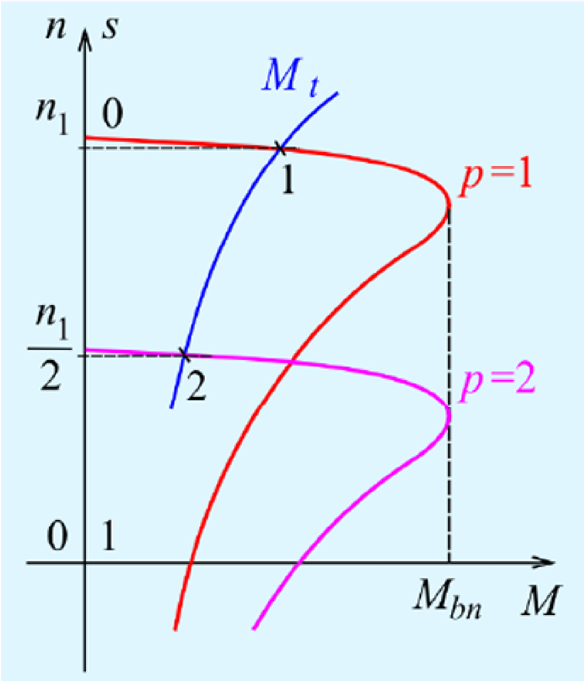
$$n_0 = 60\frac{f}{N}$$

$$n = n_0(1-s) = \frac{f}{p}(1-s)$$

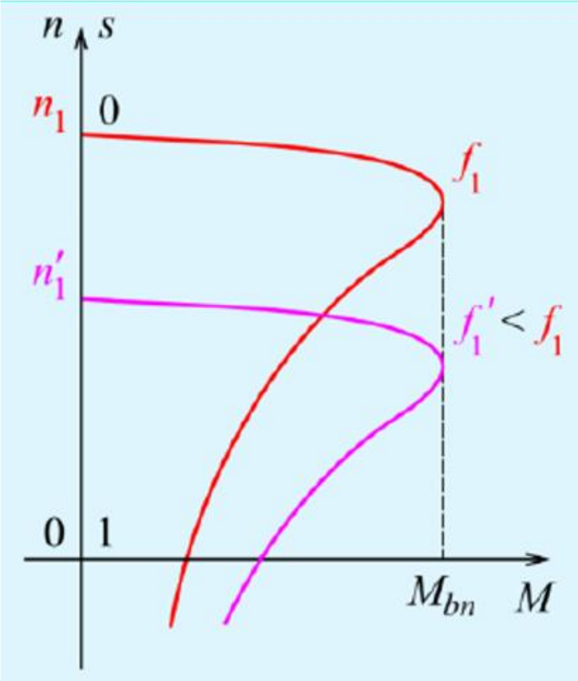
Changing terminal voltage



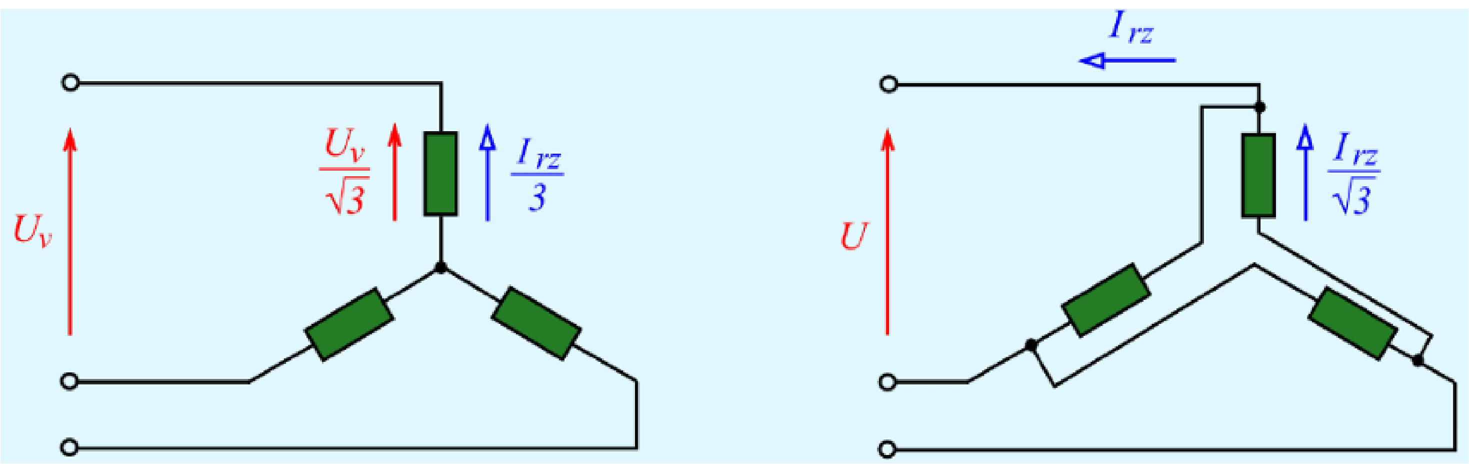
Changing pole pairs

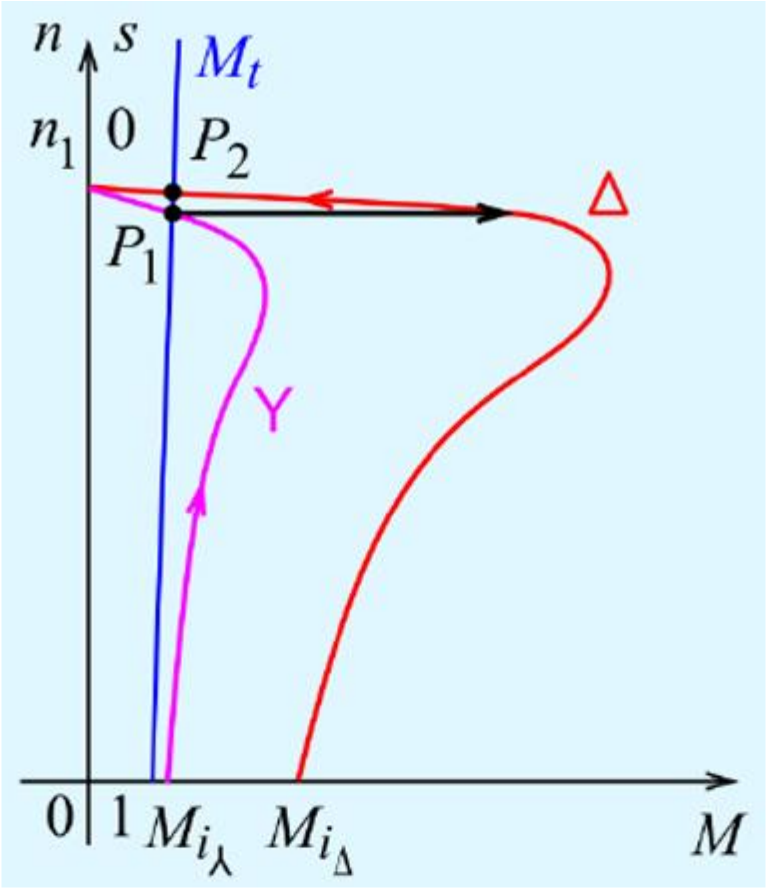


Changing frequency



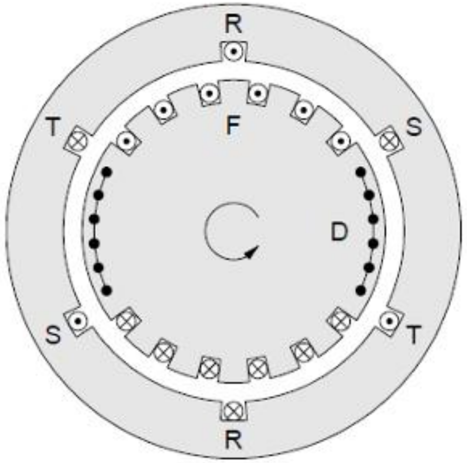
Starting the induction machine



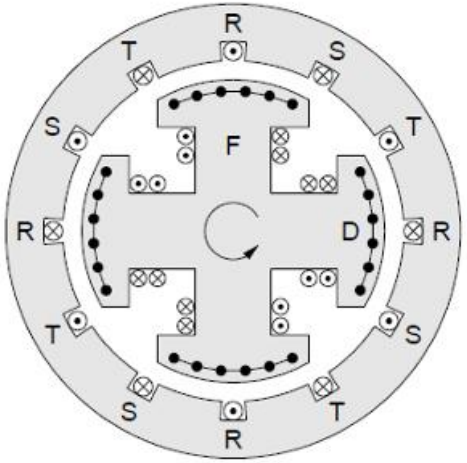


Synchronous machine

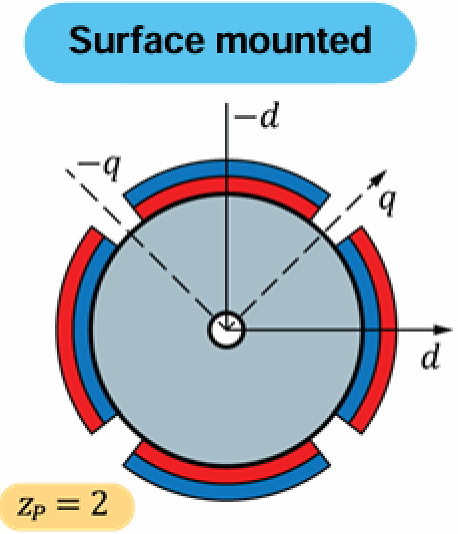
Excited rotor winding	Permanent magnet	Reluctance

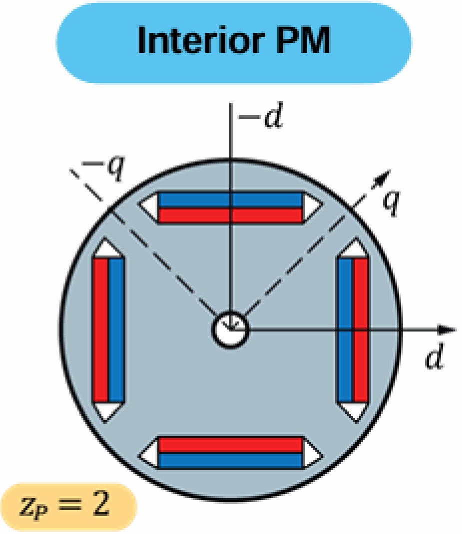


Round rotor
$p = 2,\ n = 3000\,\mathrm{min}^{-1}$ for $f = 50\,\mathrm{Hz}$

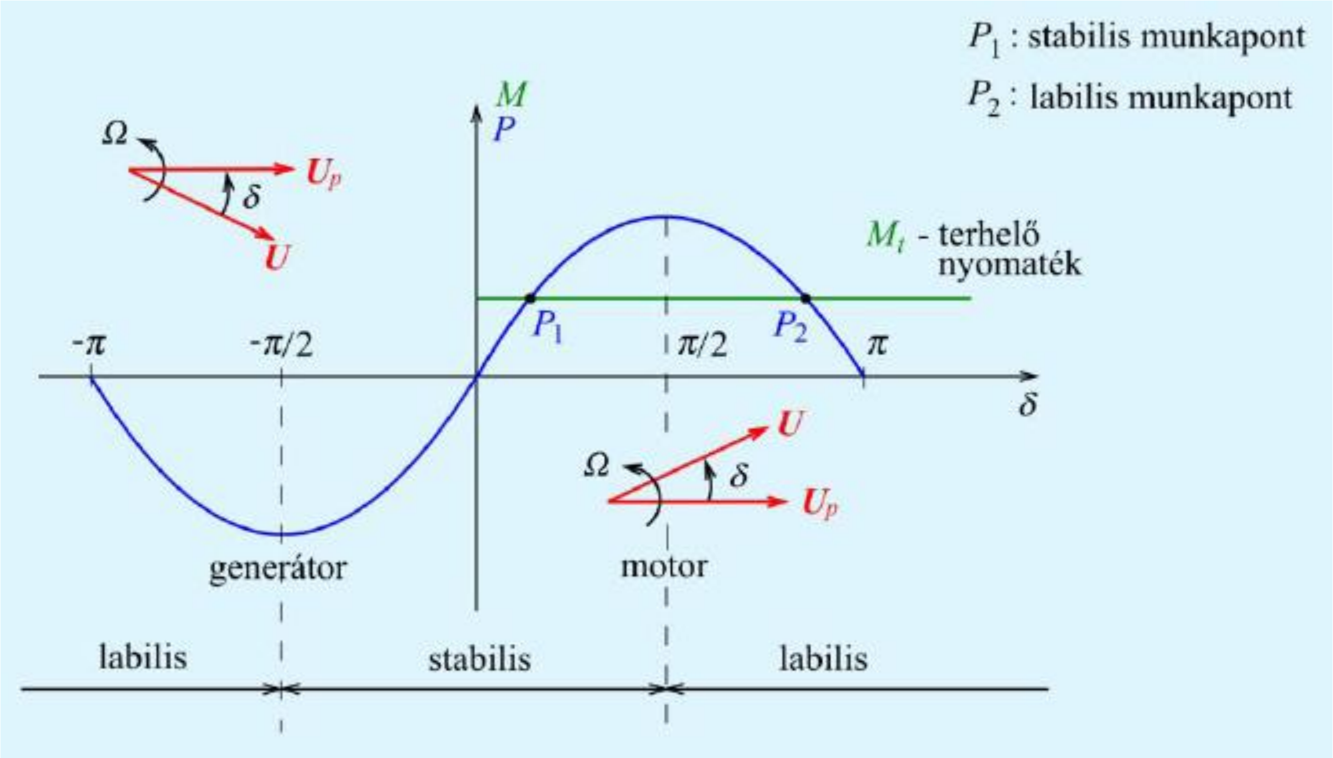


Salient pole rotor
$p = 4,\ n = 1500\,\mathrm{min}^{-1}$ for $f = 50\,\mathrm{Hz}$





Szinkron gép üzemtana



Changing the rotational speed:

$$s = 0$$

$$n = \frac{f}{N}$$

- frequency
- polepair