Power Plants
A1M15ENY

Lecture No. 3

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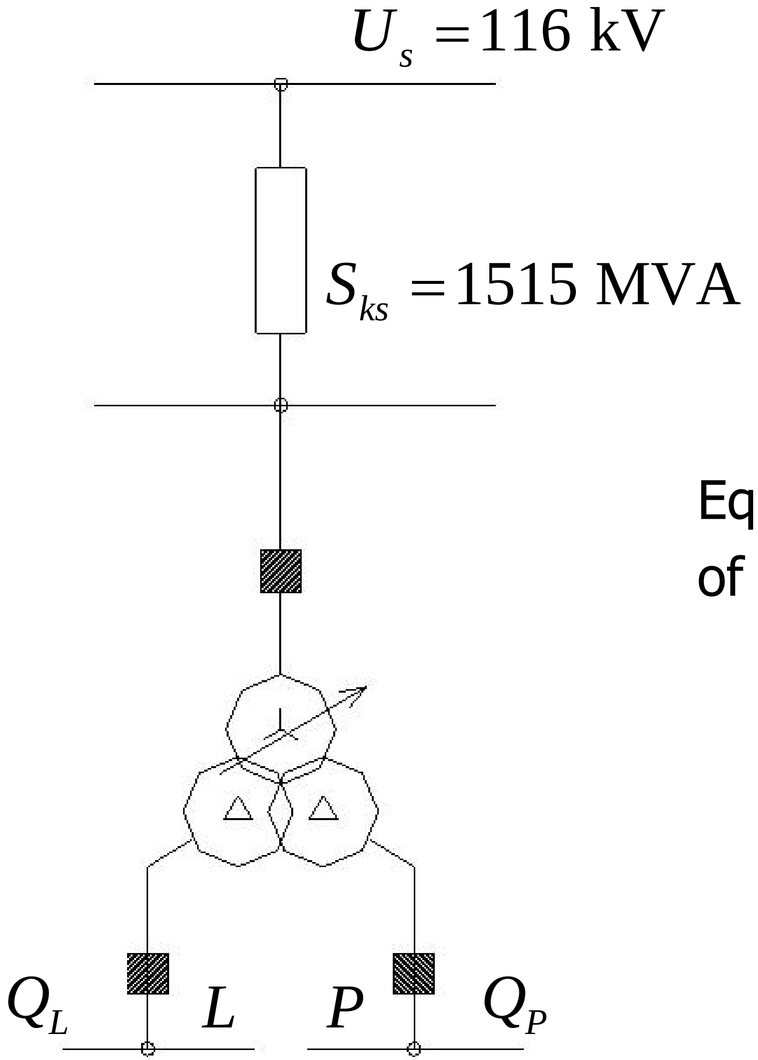
Determination of three winding transformer ratio:



$$S_{nT} = 63/31{,}5/31{,}5 \text{ MVA}$$

$$110 \pm 8x2\%/6{,}3/6{,}3 \text{ kV}$$

$$u_{k12} = 9\%,\ u_{k13} = 9\%,\ u_{k23} = 18\%$$

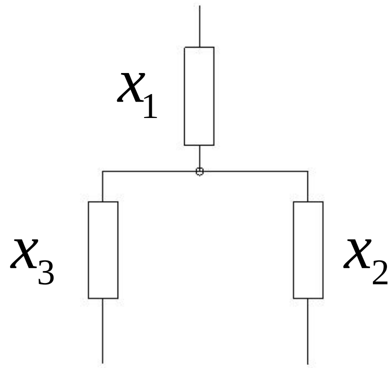
As base apparent power we choose trf. *Sn*

$$S_V = 63 \text{ MVA}$$

Base voltage= required voltage at aux. busbars:

$$U_V = 6{,}3 \text{ kV}$$

Equivalent impedance of the trf:



$$x_1 = \frac{u_{k12} + u_{k13} - u_{k23}}{2} \cdot \frac{S_V}{S_{nT}} \cdot \left(\frac{U_{nT}}{U_V}\right)^2 =$$

$$= \frac{0{,}09 + 0{,}09 - 0{,}18}{2} \cdot \frac{63}{63} \cdot \left(\frac{6{,}3}{6{,}3}\right)^2 = 0$$

$$x_2 = x_3 = \frac{0{,}18}{2} \cdot \frac{63}{63} \cdot \left(\frac{6{,}3}{6{,}3}\right)^2 = 0{,}09$$

a) Reactive component of current total / left section / right section:

$$i_j = \frac{Q_L + Q_P}{u_P.S_V} = \frac{23+23}{1.63} = 0,73$$

$$i_{jL} = \frac{Q_L}{u_P.S_V} = \frac{23}{1.63} = 0,365 \qquad i_{jP} = \frac{Q_P}{u_P.S_V} = \frac{23}{1.63} = 0,365$$

$$u_P = u_L = \frac{6,3}{6,3} = 1$$

Quadratic equation for unknown ratio:

$$0 = \left(x_1.i_j + x_2.i_{jP} + u_P\right).p^2 - p.\frac{U_S}{U_V} + \frac{S_V}{S_{ks}}.\left(\frac{U_S}{U_V}\right)^2.i_j$$

$$0 = \left(0.0,73 + 0,09.0,365 + 1\right).p^2 - p.\frac{116}{6,3} + \frac{63}{1515}.\left(\frac{116}{6,3}\right)^2.0,73$$

$$0 = 1,03285.p^2 - 18,413.p + 10,292$$

$$p_1 = 0,577 \qquad p_2 = 17,249$$

Second root is admissible:

$$p_2 = 17,249 \qquad 108,6/6,3\ \text{kV}$$

We choose tap No. – 1x2,2kV, ratio is thus

$$107,8/6,3\ \text{kV}$$

b) Equation for the second case

$$0 = \left(x_1.i_j + x_2.i_{jP} + u_P\right).p^2 - p.\frac{U_S}{U_V} + \frac{S_V}{S_{ks}}.\left(\frac{U_S}{U_V}\right)^2.i_j$$

$$0 = \left(0.0 + 0,09.0 + 1\right).p^2 - p.\frac{116}{6,3} + \frac{63}{1515}.\left(\frac{116}{6,3}\right)^2.0$$

$$p = \frac{116}{6,3}$$

We choose tap No. + 3x2,2kV, ratio is thus

$$116,6/6,3\ \text{kV}$$

Auxiliary Drives' Characteristics

Among the most important attributes of each appliance are from dimensioning point of view

- Power input (+ rated power factor)
- Start-up current
- Start-up time

Auxiliary Drives' Characteristics

According to technology:

Coal (fuel) handling system

- Belt conveyors (from the place of mining, coal depot, unloading /if transported by rail/, to operation fuel storages), coal rollers, dust collector fan

Boiler house

- Feedwater pumps, forced draught fans, flue gas fans, mechanical / elektrostatic precipitators, compressors for pressurized air generation (used for ash transportation), fuel feeders (fuel transportation from fuel storages), hammer / fan mills, slag conveyor + crusher, excavator pumps, pumping of light fuel oil (LFO) for start-up, drives for fittings

Turbine hall

- Drives for oil pumps, turbine turning gear, cooling water pumps, vacuum pump, condensing pumps, raw water pumps, demineralized (DEMI) water pumps, drives for fittings

Auxiliary Drives’ Characteristics

Desulphurization (not present in TPP with fluid boilers)

- Limestone worm conveyors, compressors for silos deaerating, absorber mixers’ drives, gypsum slurry pumps, induced draught fan, drive for gas-gas heater (GGH), limestone slurry pump (in the case of wet desulphurisation)

Electrical part and I&C + other parts

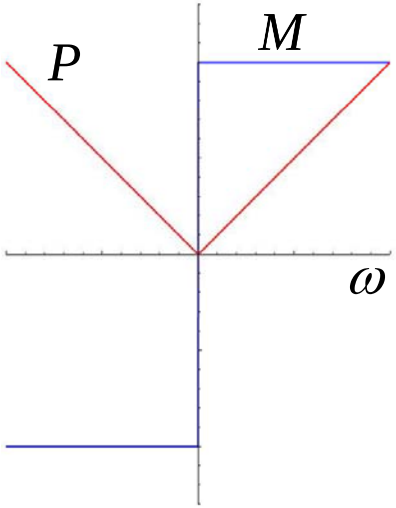
- Drives and heating of devices (disconnectors, circuit breakers), supplying of protection and control system, water treatment plant, sewage disposal plant, lighting

In the case of NPP:

- Fuel and flue gas handling and processing technology is not present, but additionally main circulation pump / turbocompressor (NPP with gas coolant), electrical heater of pressurizer, protections and fuel transportation and spent fuel system

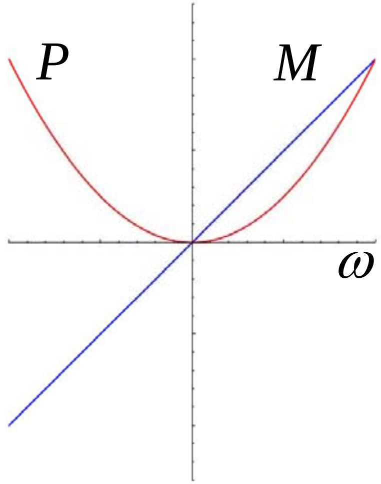
Torque - Speed Characteristics

constant (hoist)



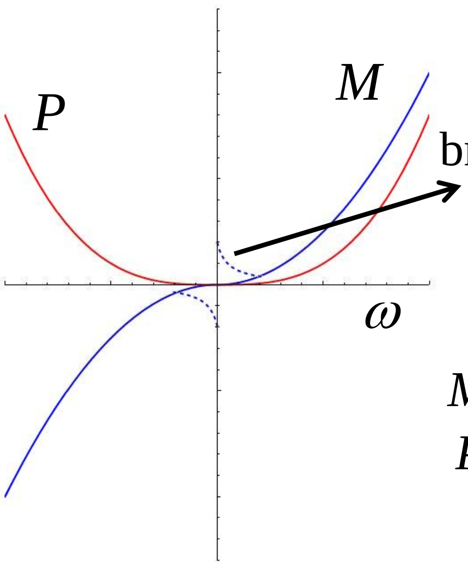
$$M = K.sign(\omega)$$
$$P = K.|\omega|$$

linear (roller)



$$M = K.\omega$$
$$P = K.\omega^2$$

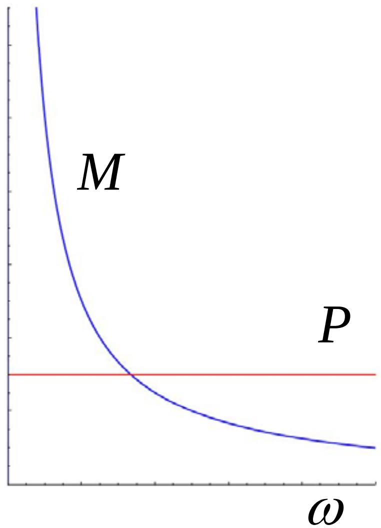
quadratic (fan)



breakaway torque

$$M = K.\omega^2.sign(\omega)$$
$$P = K.|\omega^3|$$

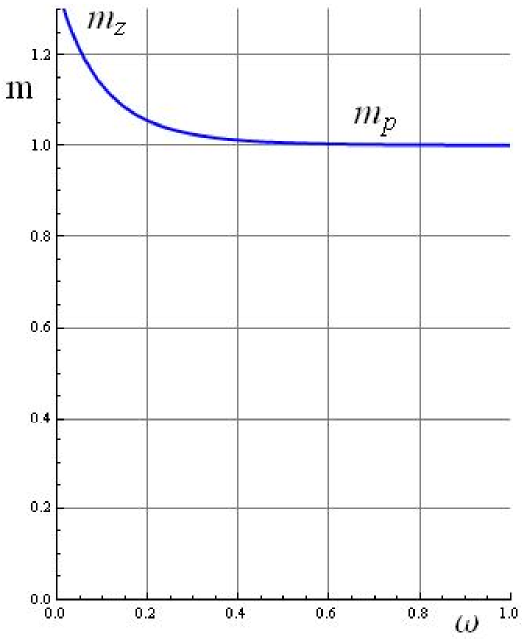
hyperbolic (winch)



$$M = \frac{K}{\omega}$$
$$P = K$$

Torque - Speed Characteristics

<u>Constant load characteristics in detail:</u>



m_z initial torque $\sim 1,3.m_p$

m_p nominal torque

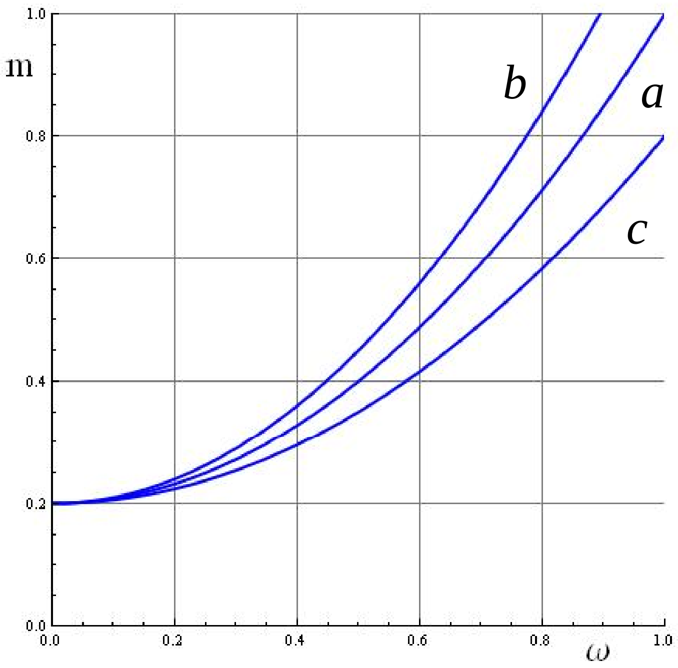
Predominantly low speed drives where air resistance is negligible and only mechanical friction is taken into consideration

<u>Typical loads:</u>

- belt conveyors
- feeders
- grates
- gear and piston pumps
- compressors
- cranes

Torque - Speed Characteristics

Variable load characteristics (quadratic) in detail:



a normal motor loading

b valve is throttled, axial pump or fan

c valve is throttled, radial pump or fan

Machines working at higher speed level

Typical loads:

- pumps
- fans
- turbocompressors

Approximated by formula:

$$m = m_0 + \left(m_p - m_0\right).\left(\frac{\omega}{\omega_p}\right)^{\alpha}$$

m_0 initial torque $\sim 0{,}1 - 0{,}2.m_p$

m_p nominal torque

α a factor dependent on load character and valve position

Motors for Auxiliary Devices

Specific requirements are connected with operation, reliability, economy and maintenance:

- To ensure necessary power supply at nominal and transient states
- To have torque characteristic enabling smooth start-up
- To be able to perform up to three heavy cold start-ups (40°C)
- To be able to perform up to two heated motor start-ups (120°C) /rem. CS typical setting: 2nd start disabled for 1 min., 3rd for 1 hr./
- Generally high reliability even if started frequently (300-400x per year)
- Device life monitoring
- If possible, initial current less than 5,5xIn
- To be able to run at reduced voltage level (~0,7 Vn)
- Torque maximum to be more than 2xMn
- Noise level up to 85 dB /rem. Dependent on circumstances i.e. blízkost industrial or residential zone, „synergy" PP noise + outer sources like communications etc. – noise studies, measurements…/

=> Squirrel cage induction machines

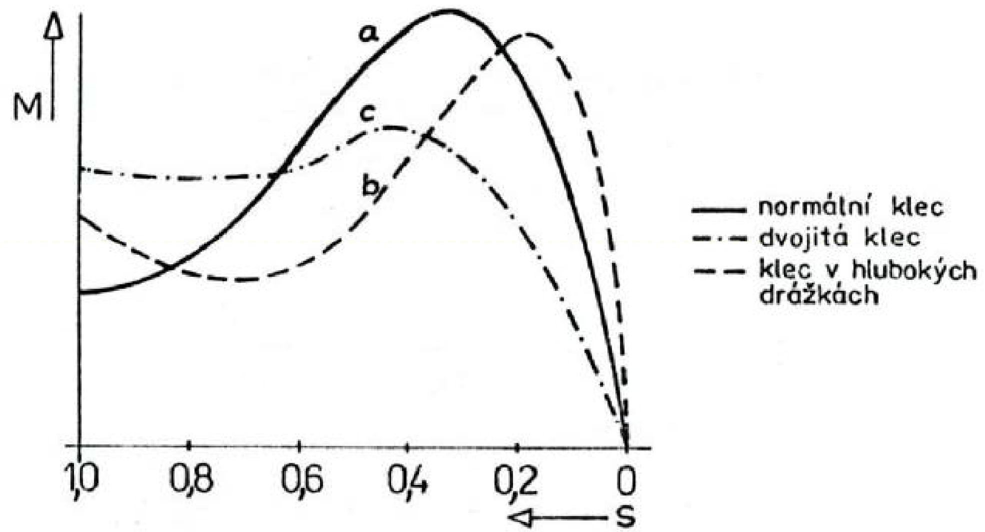
Motors for Auxiliary Devices

Voltage level determining:

- voltage level at 400V is used for drives up to 250 kW (rarely up to 350 kW voltage 500V), for greater output MV level is used (typically 6,3 kV, but nowadays other levels are used 1,5 and 3 kV). Overvoltages from switching off small inductive currents is another problem to be checked at MV level

Nominal power determining:

- At level of 1.1 – 1.15 x power input of device + respecting requirements meant hereinabove (time and smoothness of start-up). Max. power of IM is circa 10 MW, what is comfortable for example even in case of 500 MW unit feedwater pump



Induction Machine Start-up

During start-up a machine is speeded up by acceleration torque:

$$\Delta M = M_e - M_p$$

For smooth start-up has to be:

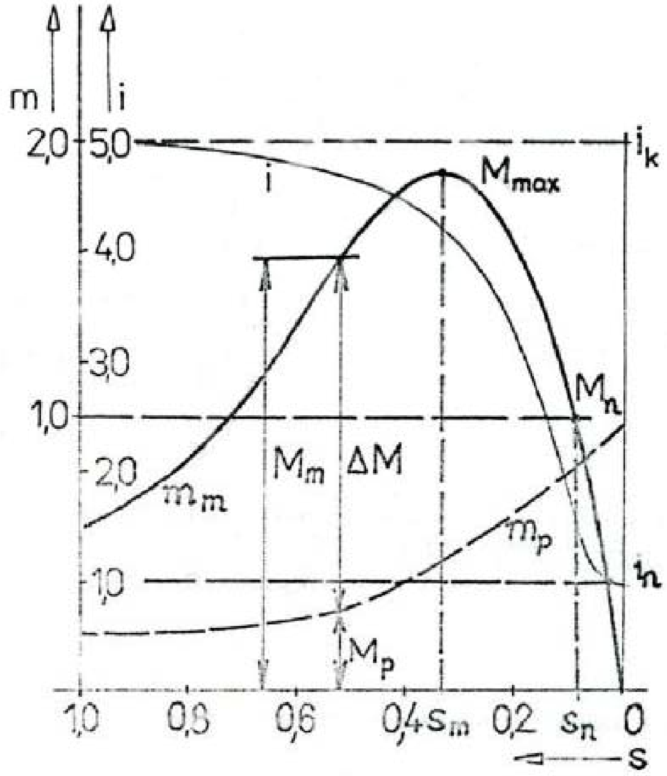
$$\Delta M \geq 0,2.M_n$$

This requirement has to be satisfied even if supply voltage is reduced:

$$u_z = \frac{U_z}{U_n}$$

Thus final condition for start-up is:

$$M_z u_z^2 - M_{p0} \geq 0,2.M_n$$



This can be met by:

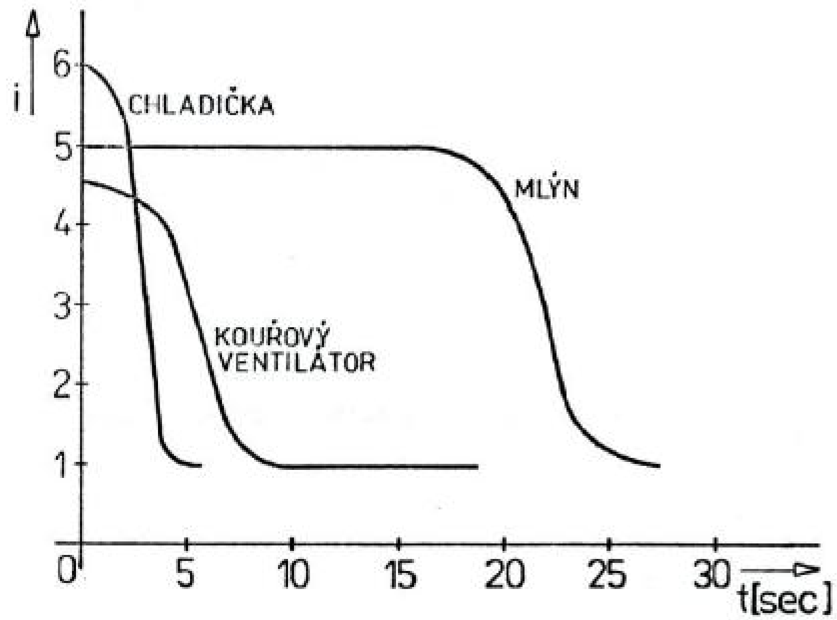
a) Correct determination of m_z (in most cases cost effective solution)

b) Overdimensioning of nominal power

Induction Machine Start-up

Typical startup times:

Mlýny paliva	30 až 35 sec.
Kouřové ventilátory	7 až 10 sec.
Napáječky	6 až 8 sec.
Vzduchové ventilátory	3 až 4 sec.
Další menší pohony	2 až 3 sec.



Induction Machine Start-up

Differential equation for startup: $\Delta M = J.\dfrac{d\Omega_M}{dt}$

In p.u.:

$$\omega_M = \frac{\Omega_M}{\Omega_{SM}} \qquad m = \frac{M}{M_n} \qquad \Delta m = \frac{J.\Omega_{SM}}{M_n}.\frac{d\omega_M}{dt}$$

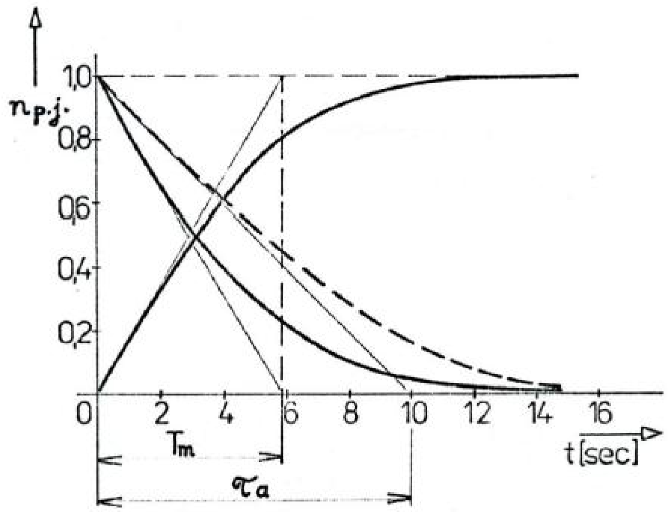
Startup time:

$$t_R = \frac{J.\Omega_{SM}}{M_n}.\int_0^{\omega_n} \frac{d\omega_M}{\Delta m} = \frac{J.\Omega_{SM}^2}{P_n}.\int_0^{\omega_n} \frac{d\omega_M}{\Delta m} = T_M.\int_0^{\omega_n} \frac{d\omega_M}{\Delta m}$$

a) If GD2 is known:

$$J = \frac{GD^2}{4}$$

b) If run down is known:



$$T_M.\int_1^0 \frac{d\omega_M}{-1} = T_M$$

If the device has not been loaded with Mn:

$$\tau_A = \frac{M_P}{M_n}.T_M = \frac{P_P}{P_n}.T_M.\eta$$

Torque Characteristics Construction

a) If known: M_{MAX}, s_n

Kloss' formula:

$$m = \frac{2.m_{MAX}}{\frac{s_{MAX}}{s} + \frac{s}{s_{MAX}}}$$

After substitution at point of nominal speed/slip/torque:

$$1 = \frac{2.m_{MAX}}{\frac{s_{MAX}}{s} + \frac{s}{s_{MAX}}} \qquad s_{MAX} = s_n\left(m_{MAX} + \sqrt{m_{MAX}^2 - 1}\right)$$

b) If known: U_k, I_k, P_k, R_s

$$X_s \cong X_r' = \frac{1}{2}.\frac{\sqrt{3.U_k^2.I_k^2 - P_k^2}}{3.I_k^2} \qquad R_r' = \frac{P_k^2}{3.I_k^2} - R_s$$

$$M = \frac{R_r'}{s.\Omega_{SM}}.\frac{U^2}{(X_s + X_r')^2 + \left(R_s + \frac{R_r'}{s}\right)^2}$$

kde: $\Omega_{SM} = \frac{\Omega_S}{p}$

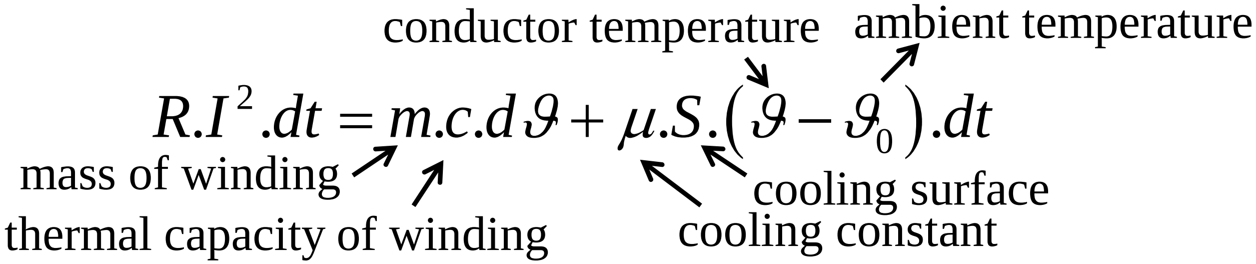
el. synchronous speed (Ω_S)

number of pole pairs (p)

Start-up Warming

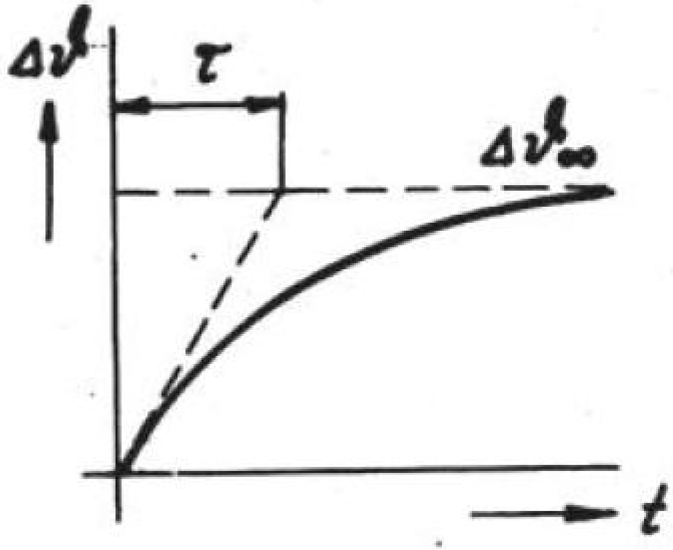
Calculation is important in case of device with a long startup

$$R.I^2.dt = m.c.d\vartheta + \mu.S.(\vartheta - \vartheta_0).dt$$



Solution:

$$\Delta\vartheta = \Delta\vartheta_\infty.\left(1-e^{-\frac{t}{\tau}}\right)$$



where:

$$\Delta\vartheta_\infty = \frac{R.I^2}{\mu.S}$$ a $$\tau = \frac{\mu.S}{m.c}$$

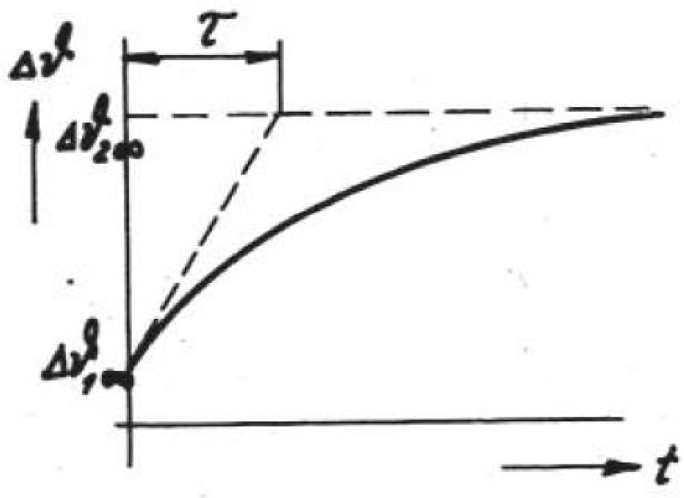
For nominal current we obtain nominal temperature rise: $\Delta\vartheta_{\infty n} = \frac{R.I_n^2}{\mu.S}$

then $$\frac{\Delta\vartheta}{\Delta\vartheta_n} = \frac{\Delta\vartheta_\infty}{\Delta\vartheta_{\infty n}}.\left(1-e^{-\frac{t}{\tau}}\right) = \frac{I^2}{I_n^2}.\left(1-e^{-\frac{t}{\tau}}\right) = i^2.\left(1-e^{-\frac{t}{\tau}}\right)$$

Start-up Warming

For temperature rise calculation during transients:

$$\frac{\Delta\vartheta}{\Delta\vartheta_n} = i_1^2 + \left(i_2^2 - i_1^2\right).\left(1 - e^{-\frac{t}{\tau}}\right)$$



With help of these formulas it is possible to solve:

- Long start-ups (initial current, nominal current)
- Short-term or periodic duty types (warming/getting cold)

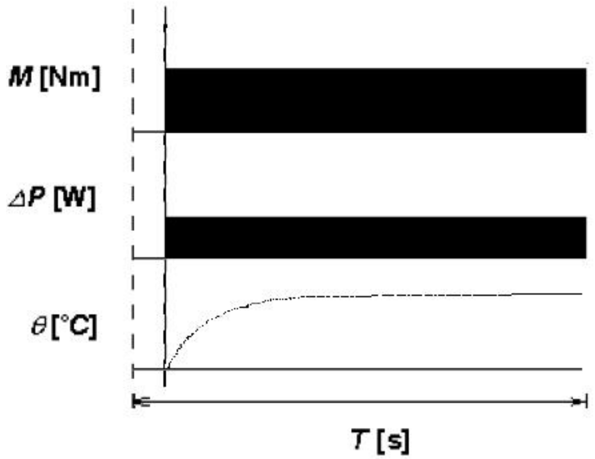
Types of Duties

Many auxiliary applications require other type of duties than continuous regime (startup, breaking, reversation etc.). Way of operation has thus significant effect on motor warming.

Acc. to EN 60034-1 are classified types of duties S1-S10

For example:

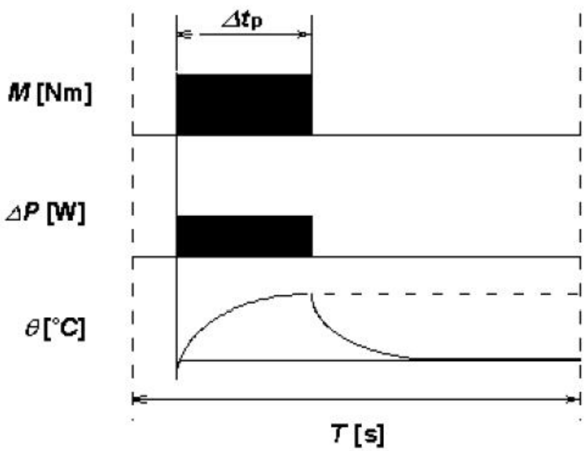
S1: Continuous running



Example:

S1

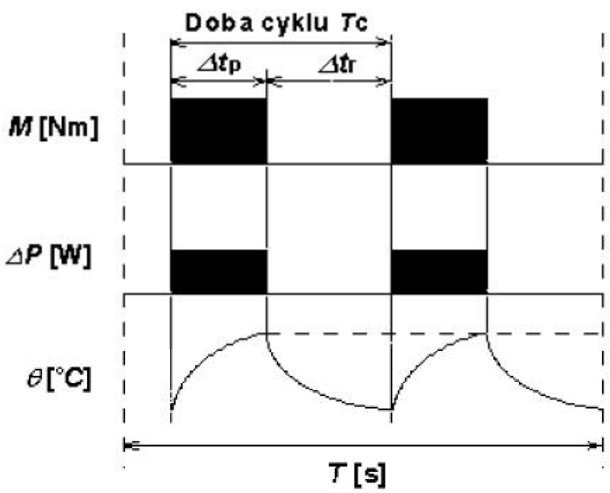
S2: Short-term



Example:

S2, Δtp

S3: Intermittent periodic



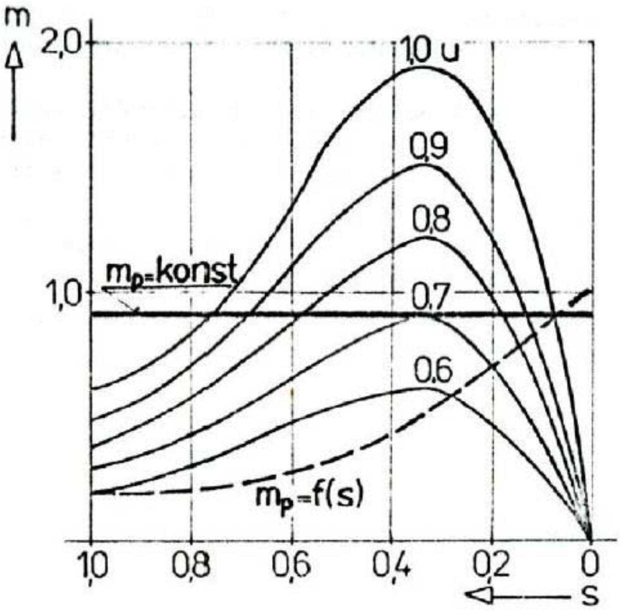
Example:

S3, Tc, Δtp (or %)

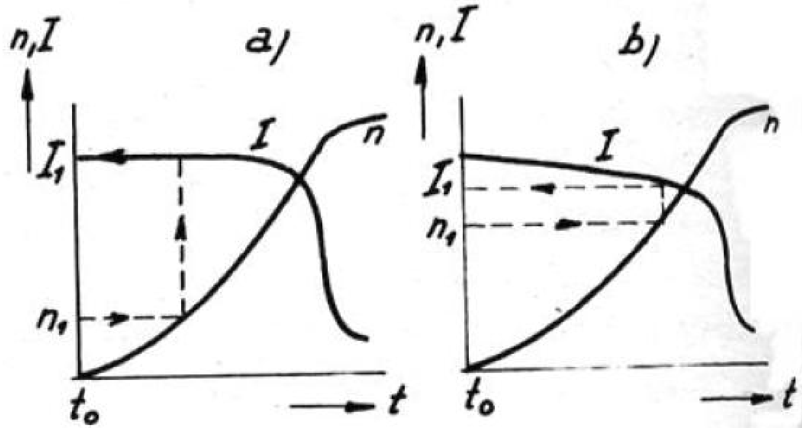
Auxiliary Start-up Critical Voltage

If the voltage on auxiliary busbars is reduced, electrical machines are slowing down and current is rising up. From a certain level of voltage decrease a torque characteristics of the machine will be completely under a torque characteristics of the load. At this point the machine will rapidly slow down and finally stop. This voltage is called critical and can be obtained as:

$$M_n = \left(\frac{U_{krit}}{U_n}\right)^2 .M_{MAX}$$ or in p.u. $$\frac{1}{m_{MAX}} = u_{krit}^2$$



Attention! After voltage recovery the machine current is very similar to its initial current.



Typical Values

For 200 MW unit

Pohon	Jmenovité provozní hodnoty				Hodnoty při rozběhu				
	P_N [kW]	U_N [kV]	I_N [A]	n_N [ot./min]	U [kV]	I [A]	t [sec]	I_{ZN} [A]	k []
Kouřový ventilátor	1000	6	116	494	5.8	585	6.3	605	5.21
Vzduchový ventilátor	1000	6	123	741	5.8	530	5.5	548	4.45
Mlýn	700	6	83.2	1480	5.85	330	41.5	338	4.06
Chladící čerp.	2000	6	245	423	5.7	1018	1.5	1070	4.37
Elektronapaječka	4250	6	490	2980	5.6	2500	3.1	2680	5.47

High initial start-up currents can be avoided by:

- Starting-up with wye-delta switching
- Softstarters (regulating terminal voltage, in order to reduce current)
- Frequency inverters (regulating frequency -> synchronous speed)

=> Start-up is smoother, but longer

Motor Protections

Small LV motors:

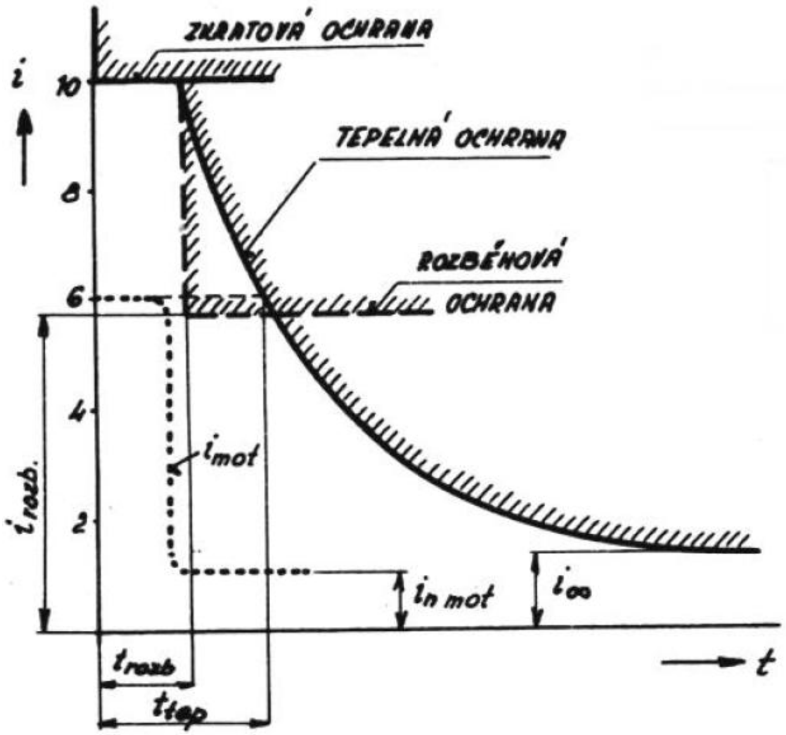
Circuit breaker or contactor with bimetal. Relay

Motors with long start-up time require overcurrent relay combined with thermal protection (thermal sensor or thermal model)

Bigger motors:

Digital multifunctional relays equipped with additional functions such as

- Unbalance
- Undervoltage/Overvoltage
- Reverse power
- Phase order



Addenum to 3rd Lecture

Calculate the constants for torque characteristics of feedwater pump

Pn [kW]	**1600**
Un [kV]	**6**
In [A]	**185**
cos fi n [-]	**0,87**

Synchronous speed
3000

	No-load	Short circuit
Voltage [V]	6000	1529
Current [A]	39,7	185
Power [kW]	27	127,5

Stator winding resistance at 20°C [Ohm]
0,1437
Operating temperature [°C]
80

Winding material: Cu