## *10. Characteristics of drives in the power plant's own consumption*

The appliances in the V.S. have the following characteristics:

- Power input
- Shot Momentum
- Start-up time

The main consumer circuits of a conventional thermal power plant are:

1. Charring
   Belt conveyors directly from the mining operation (unless transport is by rail or ship) plus from the fuel storage yard and basket unloaders and loaders. All equipped with braking device in case of loss of power.
2. Boiler drives
   Water supply by feeders, support of combustion and gasification of fuel by air fans, support of chimney draft by smoke fans, removal of ash by electrostatic precipitators. The feed pumps equipped with hydraulic coupling also have oil pumps and cooling devices.
   Fuel transport by raw coal feeders to the mills, slag removal by slag extractors and slag crushers plus hydraulic transport together with the ash to the pits and to the stockpiles. Pumping of fuel oils for running the block to the operating tanks and then to the heaters. Drives in the fuel desulphurisation system.
3. Drives in the engine room
   Drive of oil pumps and rotation of turbo-machines during starting and stopping of the block (otherwise ensured by mechanical pumps), - lifting pumps and rotation drives for uniform heating of the machine.
   Valve drives, main circuit cooling pumps, oil cooling, alternator cooling, condensate pumps, raw water pumping in cooling and feed water treatment.
4. Other appliancesMeasuring
   , control, security and information technology, lifts, cranes, lighting.

The main circuits of nuclear power plant appliances are similar to those of conventional power plants, with the exception that higher demands are usually placed on reliability. Higher power requirements for the same block power also result from the poorer steam parameters of NPPs. In addition, there are the following major appliances:

Main circulation pumps for circulating the coolant of pressurized water reactors

- Strokeless pumps (hydraulic and drive part in one unit with low inertia and small V.S. power failures, thus it is necessary to ensure the inertia of the main turbomachine)
- Sealed pumps (they have a flywheel on the rotor shaft increasing safety, they are also more efficient, the drive is out of contact with the refrigerant and therefore easier to inspect or replace)
- Centrifugal pumps for liquid metal cooled NPPs

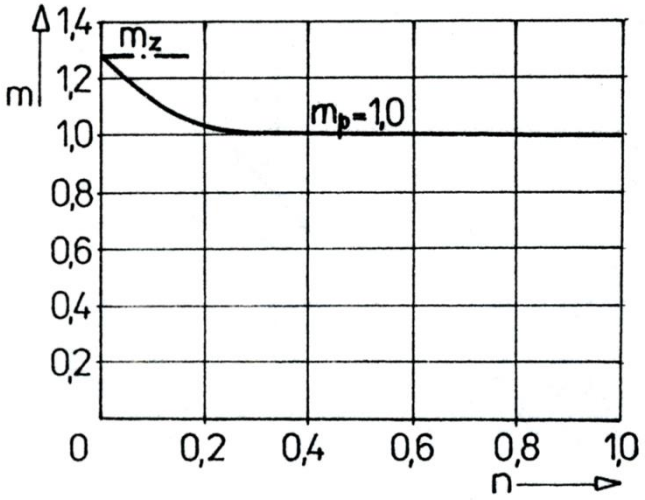
Turbocompressors in the main circuit of NPPs with gaseous coolant driven by electricity. synchronous machines.

Volume compensator electric heaters to maintain constant refrigerant pressure and prevent possible boiling. Relatively large appliance (VVER 440 at start-up about 1.5 MW). For metal cooled NPPs, heating is wherever solidification of the medium is potentially possible.
Protection system equipment, transport systems and reactor control systems for control of nuclear and thermal parameters (control and accident rods), measurement of radioactivity, neutron flux, reactor poisoning, spent fuel transport, fuel cell leak check, high power ventilation systems, etc.

**Torque characteristics of V.S. drives**

Torque characteristics of constant torque drives

The characteristic is valid for low speed devices where air resistance is negligible and only mechanical friction is considered. This applies to horizontal conveyors, feeders, grates, gear and piston pumps, compressors, etc. A small increase in load torque is only present when the equipment is started from rest.




$m_P$ -nominal load moment
$m_Z \sim 1.3\ m_P$ -moment of load at start-up (when starting in relief is $m_Z \sim (0.2 \text{ to } 0.5)\ m_P$

Torque characteristics of variable torque drives

This applies to relatively higher speed equipment such as conventional pumps, fans, turbochargers. The characteristics of these drives vary according to the speed and the amount of medium supplied:

Amount of media:

$$Q_2 = \frac{n_2}{n_1} Q_1$$

Media pressure:

$$p_2 = \left(\frac{n_2}{n_1}\right)^2 p_1$$

Drive power input:

$$P_2 = \left(\frac{n_2}{n_1}\right)^3 P_1$$

Torque of mechanical load:

$$M_2 = \left(\frac{n_2}{n_1}\right)^{\alpha} M_1$$

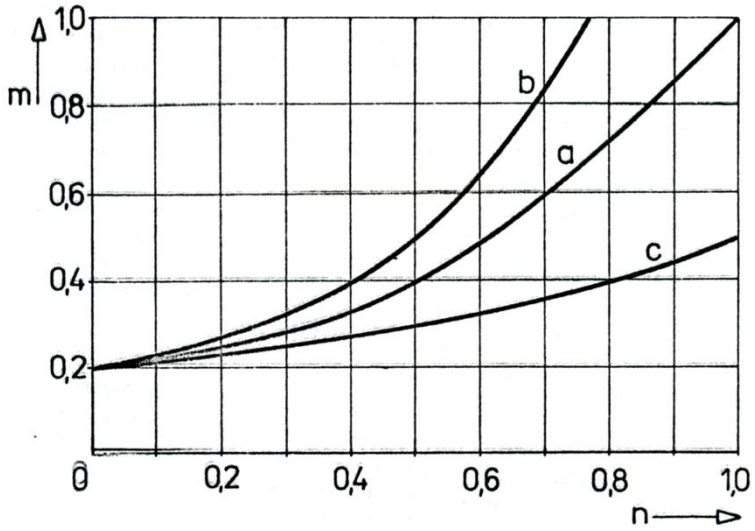
Then the torque characteristic of the load of the drives can be expressed in proportional units:

$$m_P = m_{P0} + (m_{P1} - m_{P0})\left(\frac{n}{n_S}\right)^{\alpha} \qquad m_{P0} = \frac{M_{P0}}{M_N} \sim 0.1 \text{ to } 0.2$$

$$m_{P1} = \frac{M_{P1}}{M_N}$$

$M_{P1}$ - torque at synchronous speed $n_S$

$\alpha$ -factor dependent on the nature of the equipment, opening of valves (fans value 2, for pumps with higher static back pressure the value rises above 2)




*a* -normal drive load
*b* -axial fan or pump with valves open or closed
*c* -conventional fan or pump with valves open or closed

Choice of electric motors for equipment drives

For drives in V.S. power plants, the following specific operating requirements must be considered, determined by the pursuit of optimum reliability and cost-effectiveness for investment and maintenance in the demanding environment of high dust or temperature:

- Sufficient performance in nominal and transient conditions (on the contrary, oversizing would disproportionately degrade the power factor)
- Torque characteristic for smooth start-up
- Ability to perform up to three prolonged hard runs in cold conditions around 40° C
- Ability to double switch on a warm engine around 120° C
- Generally high reliability even with frequent start-ups (150 to 450 times per year)
- Inrush current not exceeding 5.5 times nominal
- Possibility of staying in shorted state for two-pole and four-pole machines 5 sec., for six-pole 10 sec.
- Ability to operate at a reduced voltage of 0.7 $U_N$ and a rated load of at least 15 minutes

- Trouble-free operation for at least 3 years (approx. 15,000 operating hours)
- Ability to run even if the phases of the outgoing and new power supply do not match during auto-locking
- The maximum torque of the motor is at least twice the rated $M_N$
- Noise level below 85 dB

In principle, only asynchronous drives with a short anchor meet these demanding criteria. DC machines and AC commutator machines have better speed control capability but do not meet the reliability requirements. For high power turbocompressors in NPP (~5MW), synchronous motors are used for their higher efficiency and better power factor.

Selection of the main parameters of electric motors

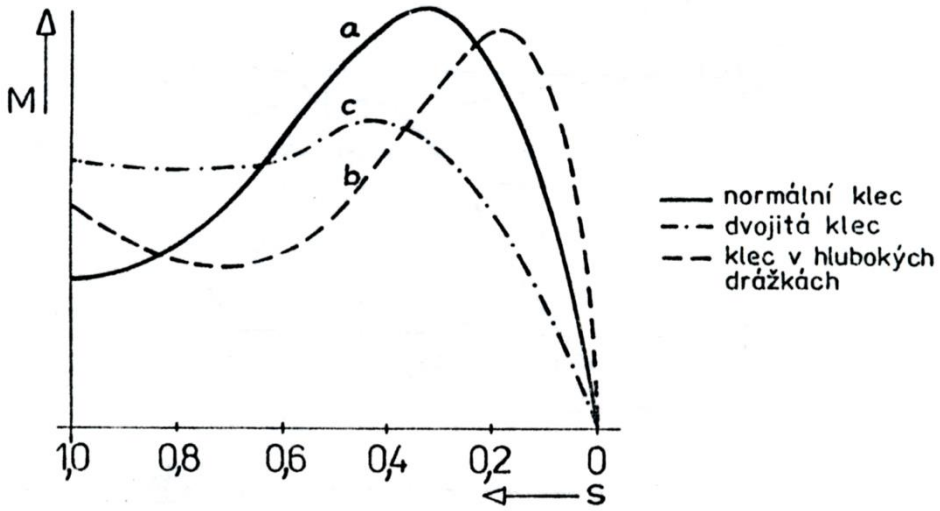
**Electric motor voltage**

380 (400) V is used for drives up to 250 kW, exceptionally 500 V for outputs up to 350 kW. Voltage 6 kV for drives above 300 kW (for multipole machines from 200 kW). In addition to operating losses, the choice of voltage is also due to problems with high overvoltages when switching off small inductive currents of small motors at 6 kV.

**Electric motor power**

The power output is selected to be 1.1 to 1.15 times the input power of the driven device, taking into account all the above requirements, especially smoothness and start-up time. Currently, air-cooled asynchronous drives up to 10 MW are available. For higher outputs, water cooling must be used. In conventional thermal power plants, the largest drive (feeder) is 4 MW for the 200 MW unit and 8.6 MW for the 500 MW unit.

**Moment characteristic of electric motor**




The difference in torque with respect to the load characteristic is essential for starting the device: the so-called dynamic torque $\Delta M = M_M - M_P$ .

For a smooth start-up it is then necessary to: $\Delta M > 0.2 M_N$

This must be met even when the supply voltage is reduced:

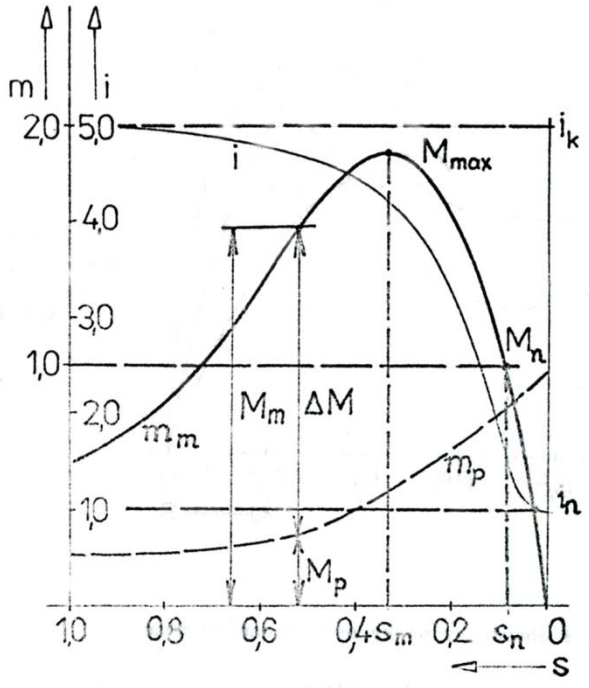
$u_Z = \frac{U_N - \Delta U_{MAX}}{U_N}$ -voltage at the drive terminals when starting from standstill ($s = 1$)

$M_Z u_Z^2 - M_{P0} \geq 0.2 M_N$

$M_Z$ -Motor torque at rest ($s = 1$)

$M_{P0}$ -Moment of engine load at rest ($s = 1$)

$m_Z = \frac{M_Z}{M_N}$ -Relative value of engine torque at rest ($s = 1$)




$M_N \left( \frac{M_Z}{M_N} u_Z^2 - 0.2 \right) \geq M_{P0}$ $\qquad M_N \geq \frac{1}{m_Z \cdot u_Z^2 - 0.2} M_{P0}$

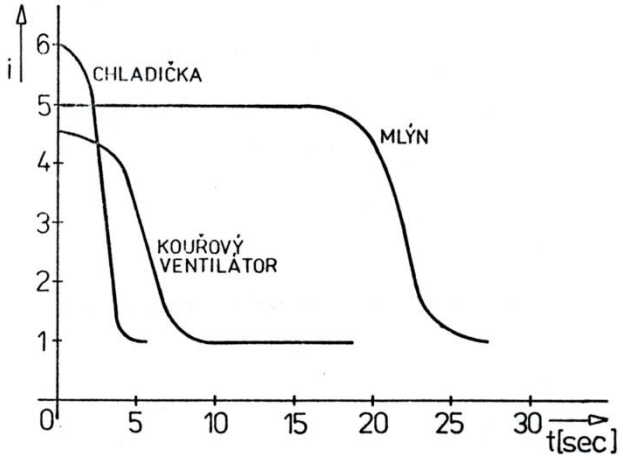
$M_N = \frac{P_N}{\omega_N}$

Therefore, the conditions can be met either by selecting a characteristic with sufficient torque $m_Z$ (the correct - more economical - option) or a higher rated power $P_N$ .

**Drive start-up time**

The start-up time is determined by the torque characteristics of the drive and the load.

| | |
|---|---|
| Fuel Mills | 30 to 35 sec. |
| Smoke fans | 7 to 10 sec. |
| Waterers | 6 to 8 sec. |
| Air fans | 3 to 4 sec. |
| Other smaller drives | 2 to 3 sec. |




Practical limitations on the start-up time are due to motor warming and voltage drop. In the case of inconclusive results of the torque relation at the beginning of the start-up, it is necessary to investigate the whole start-up time course:

$$\Delta M = J\frac{d\Omega_M}{dt} \quad [N\cdot m; kg\cdot m^2; rad/\sec; \sec]$$

If we introduce a relative angular velocity and speed:

$$\omega_M = \frac{\Omega_M}{\Omega_{SM}} = \frac{n_M}{n_{SM}} = \nu \qquad \text{then:}$$

$$\frac{d\Omega_M}{dt} = \Omega_{SM}\frac{d\omega_M}{dt} = \Omega_{SM}\frac{d\nu}{dt} \qquad \text{a} \qquad \Delta M = J\cdot\omega_S\frac{d\nu}{dt}$$

The start-up time is then after integration:

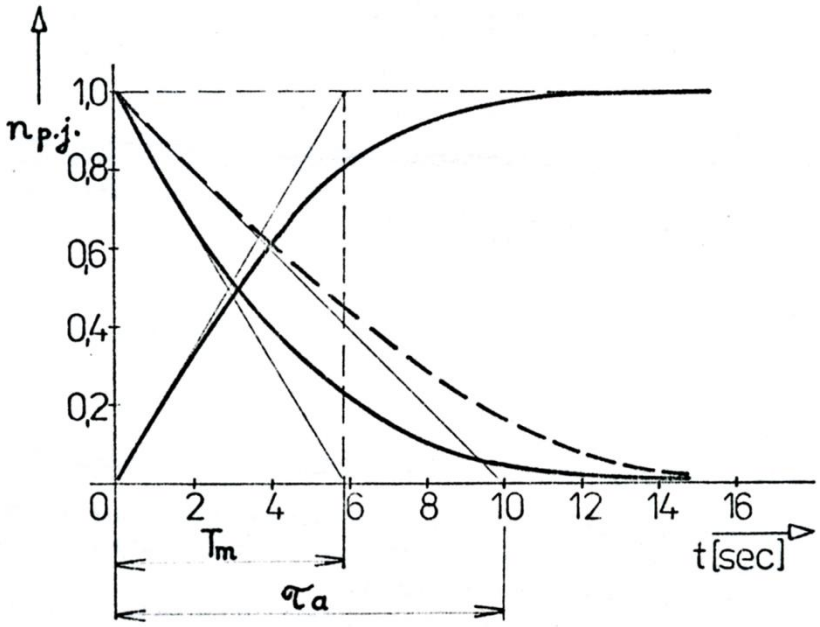
$$t = \int_{\nu_1}^{\nu_2}\frac{J\cdot\omega_S}{\Delta M}d\nu = T_M\int_{\nu_1}^{\nu_2}\frac{1}{\Delta m}d\nu \qquad \text{Where } T_M = \frac{J\cdot\Omega_{SM}}{M_N} = \frac{J\cdot\Omega_{SM}}{\frac{P_N}{\Omega_{SM}}} = \frac{J\cdot\Omega_{SM}^{\ 2}}{P_N}$$

If instead of the moment of inertia $J$ the moment of inertia $GD^2$ is given , where:

$$J = \frac{GD^2}{4g} \quad \left[kg\cdot m^2; N\cdot m^2; m/s^2\right]$$

If none of: $J$, $GD^2$ , $T_M$ is known, $T_M$ can be derived from the timing characteristics of the machine:

$$t = T_M \int_{\nu_N}^{0} \frac{d\nu}{-1} = T_M$$



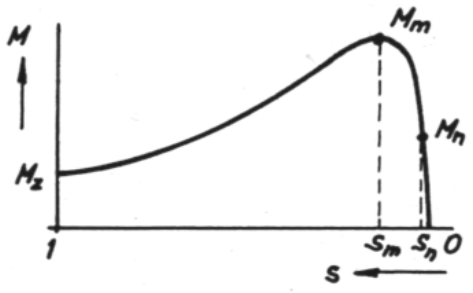

In case the unit has not been operating at its rated power during the run, $T_M$ must be recalculated:

$$T_M = \tau_A \frac{M_P}{M_N} = \tau_A \frac{P_P}{P_N} \eta_P$$ where $M_P$ , $P_P$ , $\eta_P$ are the parameters when the machine is switched off.

If a motor torque curve is not available, it can be obtained from three characteristic values: the take-up torque $M_Z$ for $s_Z = 1$, the rated torque $M_N$ for $s_N = \frac{n_S - n_N}{n_S}$ and the reversal torque (moment of overload) $M_{MAX}$ for $s_{MAX}$ .

From the Kloss relation for the relative torque of an asynchronous motor:

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




for nominal values $m = m_N = 1$ and $s = s_N$ is:

$$1 = \frac{2 \cdot m_{MAX}}{\frac{s_N}{s_{MAX}} + \frac{s_{MAX}}{s_N}}$$

So: $$\frac{{s_N}^2 + {s_{MAX}}^2}{s_{MAX} \cdot s_N} = 2 \cdot m_{MAX} \qquad {s_{MAX}}^2 - 2 \cdot s_N \cdot m_{MAX} \cdot s_{MAX} + {s_N}^2 = 0$$

$$s_{MAX} = s_N \left( m_{MAX} + \sqrt{{m_{MAX}}^2 - 1} \right)$$

The three points obtained are added to the point $M_0 = 0$ for $s = 0$ and interleaved with the curve.

Check for engine warm-up on start-up

The check shall be carried out on long-start machines. From the normal asynchronous motor warming relationships:

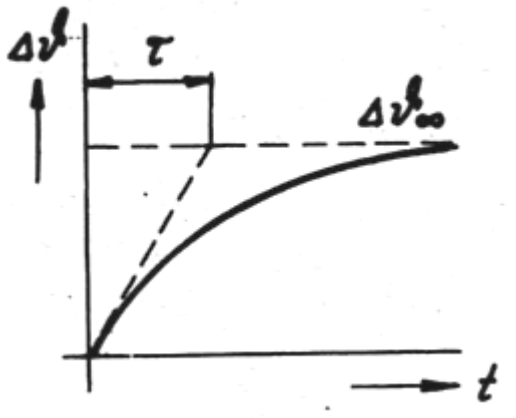
$I^2 \cdot R \cdot dt = m \cdot c \cdot d\vartheta + \mu \cdot S \cdot (\vartheta - \vartheta_E) dt$ Where:

$R$ -active resistance of the winding conductor
$m$ -winding conductor mass
$c$ -mean heat capacity of the winding conductor
-winding conductor temperature
$\mu$ -cooling constant
$S$ -cooling area
$_E$ -external temperature (ambient temperature)

$$\vartheta - \vartheta_E = \frac{R \cdot I^2}{\mu \cdot S}\left(1 - e^{-\frac{\mu \cdot S}{m \cdot c} t}\right)$$

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

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




Divide the equation by the expression:

$$\Delta\vartheta_N = \frac{R \cdot I_N{}^2}{\mu \cdot S}$$

$$\frac{\Delta\vartheta}{\Delta\vartheta_N} = \frac{I^2}{I_N{}^2}\left(1 - e^{-\frac{t}{\tau}}\right) = i^2\left(1 - e^{-\frac{t}{\tau}}\right)$$

If you neglect engine cooling ( $\mu \cdot S \cdot (\vartheta - \vartheta_E) dt \to 0$ ) for start-up:

$I^2 \cdot R \cdot dt = m \cdot c \cdot d\vartheta$ is the solution to the tangent of the original warming characteristic:

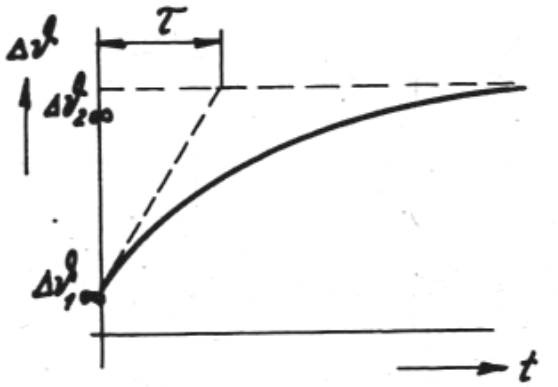
$$\Delta\vartheta = \frac{R \cdot I^2}{m \cdot c} t = \frac{R \cdot I^2}{\mu \cdot S} \cdot \frac{\mu \cdot S}{m \cdot c} t = \frac{\Delta\vartheta_\infty}{\tau} t \qquad \text{a} \qquad \frac{\Delta\vartheta}{\Delta\vartheta_N} = \frac{I^2}{I_N{}^2} \cdot \frac{t}{\tau} = \frac{i^2}{\tau} t$$

For the calculation of the warming during sudden changes in current, therefore:

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

or..:

$$\frac{\Delta\vartheta}{\Delta\vartheta_N} = i_1{}^2 + \frac{i_2{}^2 - i_1{}^2}{\tau} t$$



For example, a change from a cold state:

$$\Delta\vartheta_{1\infty} = 0 \quad a \quad i_1 = 0$$

When starting from a warm state:

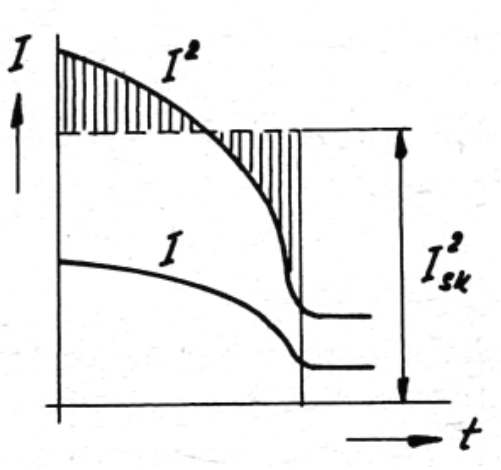
$$\Delta\vartheta_{1\infty} = \Delta\vartheta_N \quad a \quad i_1 = 1$$

At a preliminary 80% warming:

$$\Delta\vartheta_{1\infty} = 0.8 \cdot \Delta\vartheta_N \quad i_1^{\,2} = \frac{\Delta\vartheta_{1\infty}}{\Delta\vartheta_N}$$

$$i_1 = \sqrt{0.8} \approx 0.9$$

The current $i_2$ is a constant equivalent warming current, usually it is enough to consider 93% of the inrush current.




Because: $\Delta\vartheta = \frac{R \cdot I^2}{m \cdot c} t$ , is for nominal conditions: $\Delta\vartheta_N = \frac{R \cdot I_N^{\,2}}{m \cdot c} \tau$ and hence the warming time constant:

$$\tau = \frac{m \cdot c}{R \cdot I_N^{\,2}} \Delta\vartheta_N = \frac{\gamma \cdot q \cdot l \cdot c}{k_V \cdot \rho \cdot \frac{l}{q} (j_N \cdot q)^2} \Delta\vartheta_N = \frac{\gamma \cdot c}{k_V \cdot \rho} \cdot \frac{\Delta\vartheta_N}{j_N^{\,2}}$$

$m$ -winding conductor mass

$c$ -the average heat capacity of the winding conductor (for Cu, 75° C is 390 J/kg· K)

$\gamma$ -winding conductor density (for Cu, 75° C is 8900 kg/m$^3$ )

$q$ -winding conductor cross section

$l$ -winding conductor length

$k_V$ - winding factor

$\rho$ -the average resistance of the winding conductor (for Cu, 75° C is 21.5· 10$^{-9}$Ω· m)

$j_N$ -nominal current density in the winding

$_N$ -monotonic warming of the winding conductor

For $_N$ = 40, $j_N$ = 2· 10$^6$ A/m$^2$ and $k_V$ = 1.05 would be for example:

$$\tau = \frac{150 \cdot 10^{12}}{j_N^{\,2}} \Delta\vartheta_N = \frac{150 \cdot 10^{12}}{4 \cdot 10^{12}} 40\,\text{sec} = 150\,\text{sec}$$

Critical voltages for self-propelled electric motors

During short-term losses and interruptions of the V.S. supply due to short circuits, the magnitude of the voltage drops according to the proximity and severity of the fault. When the voltage drops, there is a reduction in slew rate (increase in slip) and an increase in current inversely proportional to the voltage. If the motor torque curve falls completely below the load torque dependence, intense braking and eventual stopping of the drive occurs. The limiting situation is for the so-called critical voltage:

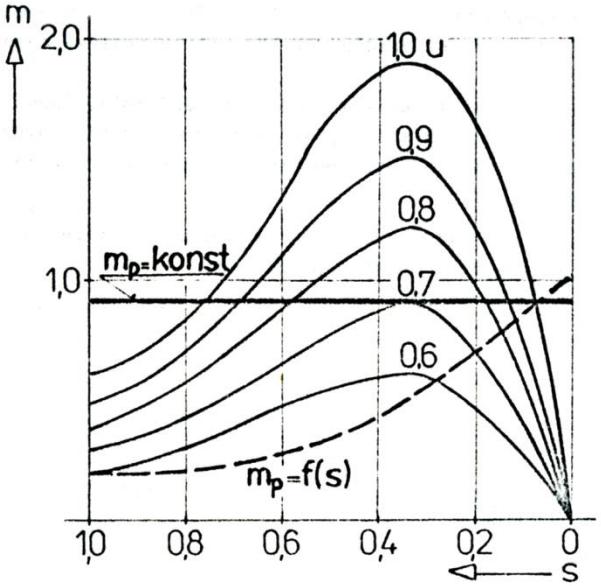
$$M_{MAX}{}^{/} = M_{MAX}\left(\frac{U_{KRIT}}{U_N}\right)^2 = M_P \qquad m_{MAX}{}^{/} = m_{MAX} \cdot u_{KRIT}{}^2 = m_P$$

Because for suitable asynchronous drives, $m_{MAX} \approx 1.8 \div 2.5$ and if $m_P$ is approximately equal to the rated power, or $m_P = 1$, then:

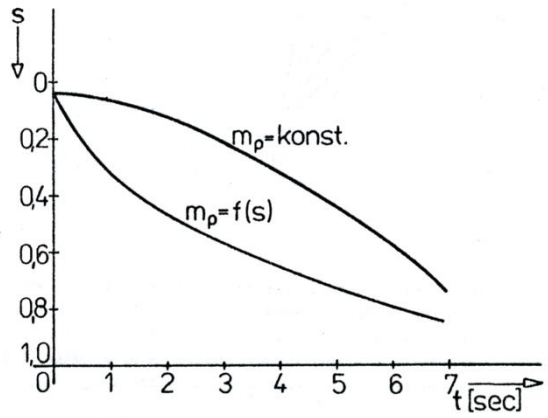
$$u_{KRIT} = \frac{1}{\sqrt{m_{MAX}}} = 0.75 \div 0.63$$

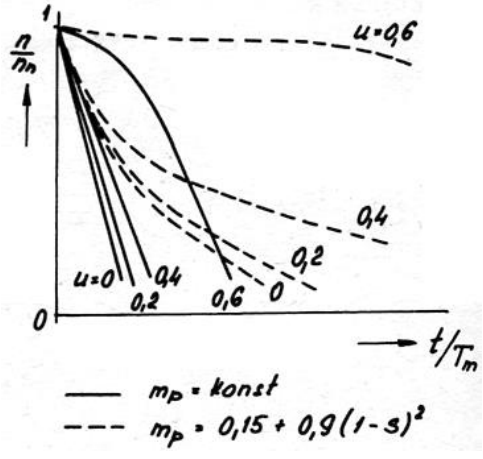
This relationship can be used for other than constant loads as long as the slip does not change too much.

Motor torque dependence on voltage:




Endurance characteristics according to the type of engine load:

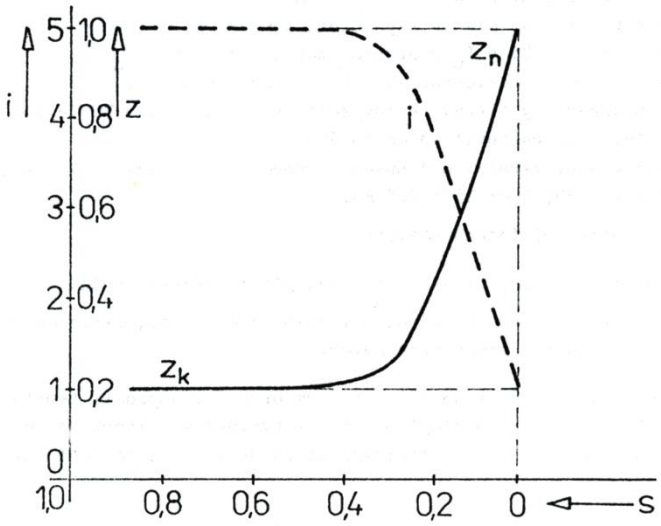


For a certain proportional voltage drop, the speed drop is first independent of the load. For deep voltage drops, the run-up characteristics are similar to a complete loss of power. Thus, for controls, we only deal with complete dropouts.

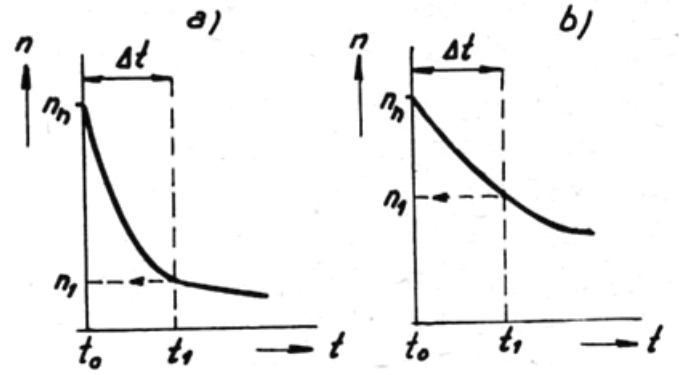
Even after the power supply is restored, the voltage drop is still persistent due to the increase in currents with increased slip of the drives:

With a relatively short power loss, the drive currents will be close to the drive currents.

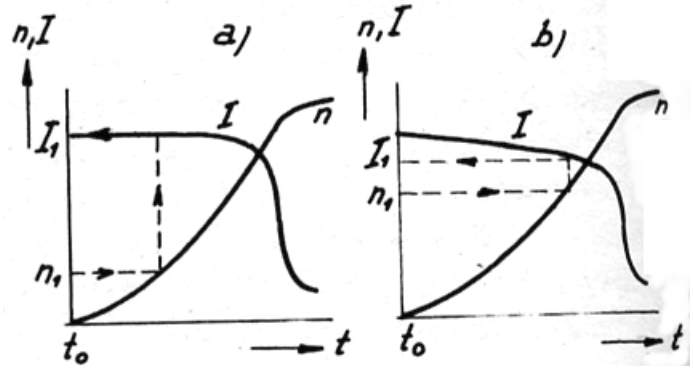



The most accurate calculation for self-propulsion of two drives:

1. Determine the speed drop of the drives for a known power interruption time $\Delta t$ from the measured run time curves or from the torque characteristics and obtain the speed $n_1$ for both drives.



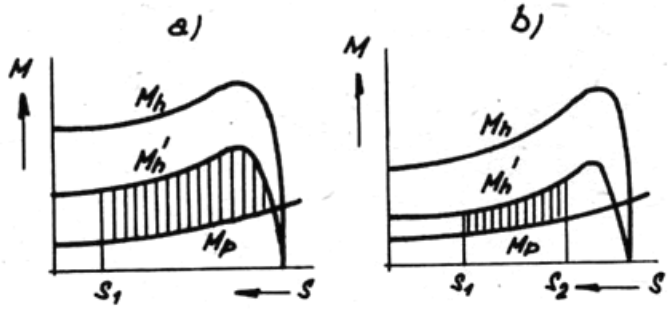

2. Determination of motor currents $I_1$ for reduced speed $n_1$ from the dependencies of the starting characteristics, but at rated power supply:



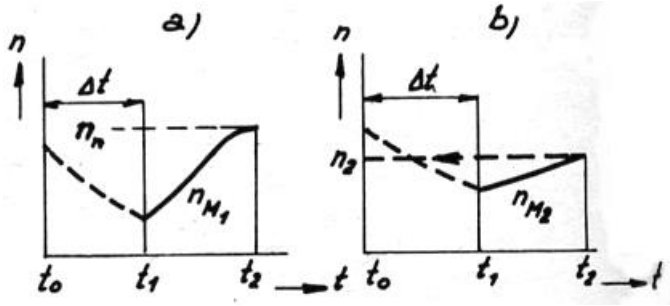
3. The sum current corresponds to the resulting reactance of the motors, i.e. the actual current drawn and the actual voltage of the drives is:

$$x_C = \frac{1}{\sum i_1} \qquad i_C = \frac{u_E}{x_T + x_C} \qquad u_P = \frac{u_E}{x_T + x_C} x_C$$

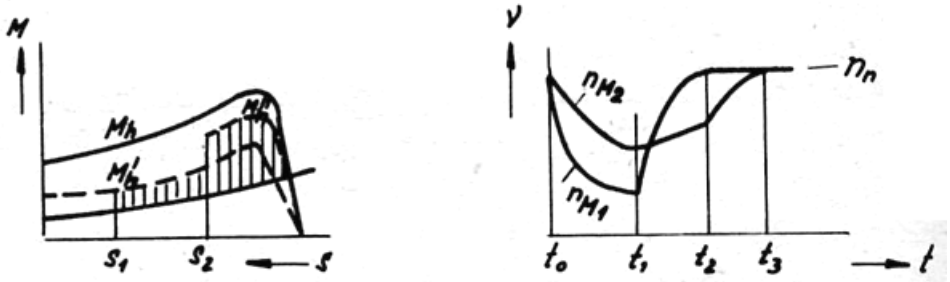
4. We reduce the power characteristics $M_H{}' = M_H \cdot u_1{}^2$ and further assume the voltage on the motors is constant (in fact it consolidates):




5. Use $t = \int_{\nu_1}^{\nu_2} \frac{J \cdot \omega_S}{\Delta M} d\nu = T_M \int_{\nu_1}^{\nu_2} \frac{1}{\Delta m} d\nu$ to determine the starting characteristics until one engine starts:




6. Adjust the speed magnitudes by adjusting the magnitudes of currents, voltages and torques according to points 2, 3 and 4 for the remaining motor and calculate the run-up:




7. If a drive takes too long to start up, you will need to check its warming up.

In the case of a larger number of engines, we group machines with the same parameters and consider them in sum.

For indicative calculations, it is sufficient to check the magnitude of the voltage drop during self-starting and the possibility of starting the drive, or to count on complete stopping of the drives and with inrush currents (to be sure, the worst case, as mentioned earlier). Or even count the inrush current as the same (preferably the largest one just in case):

$$\Delta u_T = \frac{u_E}{x_T + x_Z} x_T < 35\ \% \qquad S_{CM} \le S_T \frac{\Delta u_T}{u_E - \Delta u_T} \cdot \frac{1}{i_{CK} \cdot x_T}$$

Drives that do not fit into $S_{CM}$ are then started with a delay of about 0.5 sec.

Examples of practical parameters of drive start-ups in a 200 MW V.S. unit:

| Drive | Nominal operating values | | | | Start-up values | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $P_N$ [kW] | $U_N$ [kV] | $I_N$ [A] | $n_N$ [rpm] | $U$ [kV] | $I$ [A] | $t$ [sec] | $I_{ZN}$ [A] | $k$ [] |
| Smoke fan | 1000 | 6 | 116 | 494 | 5.8 | 585 | 6.3 | 605 | 5.21 |
| Air fan | 1000 | 6 | 123 | 741 | 5.8 | 530 | 5.5 | 548 | 4.45 |
| The Mill | 700 | 6 | 83.2 | 1480 | 5.85 | 330 | 41.5 | 338 | 4.06 |
| Cooling pump. | 2000 | 6 | 245 | 423 | 5.7 | 1018 | 1.5 | 1070 | 4.37 |
| Electron vaporizer | 4250 | 6 | 490 | 2980 | 5.6 | 2500 | 3.1 | 2680 | 5.47 |

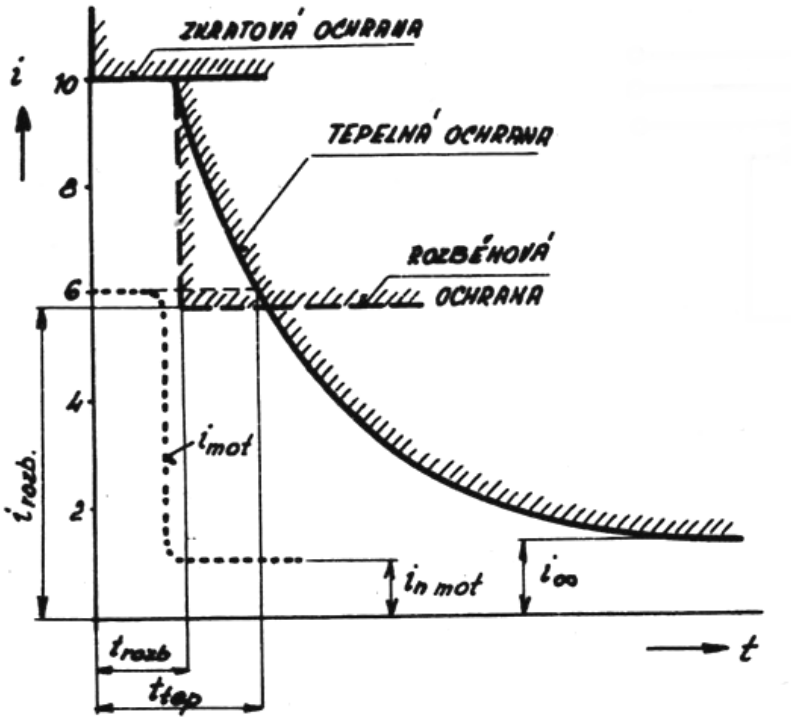
Protecting asynchronous drives

The model of the protection algorithm is based on the motor warming-up process (time-dependent characteristic) supplemented by a fast element for switching off short-circuit currents (time-independent characteristic); for drives above 2MW there is also a differential protection for internal fault protection. Especially drives with high inertia have reverse watt protection.

Other protections can be for supply voltage asymmetry, bearing temperature, machine vibration, etc.

Smaller machines are protected only by circuit breakers or contactors with electrothermal bimetallic relays.

For drives with a long start-up, current information must be combined with temperature information, as the start-up exceeds the limitations of a normal overload of a warm machine:




The basic ALOX type protection provides a response in two stages (1.05 $I_N$ and 1.1 $I_N$ ) with time setting $\tau_1 = 1 \div 15\,\text{min}$ $\tau_2 = 10 \div 150\,\text{min}$ supplemented by a start-up limiting

link (0.75 $I_N$ to 5.4 $I_N$ ) with time setting $\tau_Z = 6 \div 30\,\mathrm{sec}$ and a short-circuit link (4.5 $I_N$ to 12 $I_N$ ) with time setting $\tau_K$ 50, 100, 150, 200 ms. The thermal model approximates the dependence:

$$\frac{\Delta\vartheta}{\Delta\vartheta_N} = \left(\frac{I}{I_N}\right)^2 \left[1 - p \cdot e^{-\frac{t}{\tau_1}} - (1-p)e^{-\frac{t}{\tau_2}}\right]$$