Motor selection example

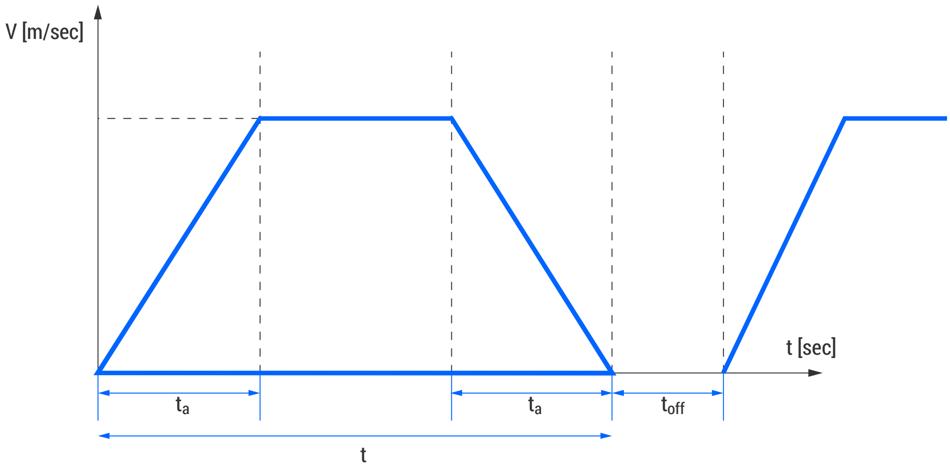
Motor selection guide:
The proper motor selection is done in three steps:

I. Definition of motion profile
II. Continuous and peak forces calculation
III. Motor selection

I. Definition of motion profile

There is a wide range of different motion profiles which can be expressed by basic kinematics equations. The most useful is trapezoid point to point moving profile and triangular profile.

Trapezoid profile:



Moving input data:

L	moving distance (stroke)	[m]
t	moving time	[s]
t_a	acceleration time	[s]
t_{off}	pause	[s]

Average velocity is expressed by:

$$v = \frac{L}{t}\ [m/s]$$

Max speed is defined as:

$$v_{max} = \frac{L}{t - t_a}$$

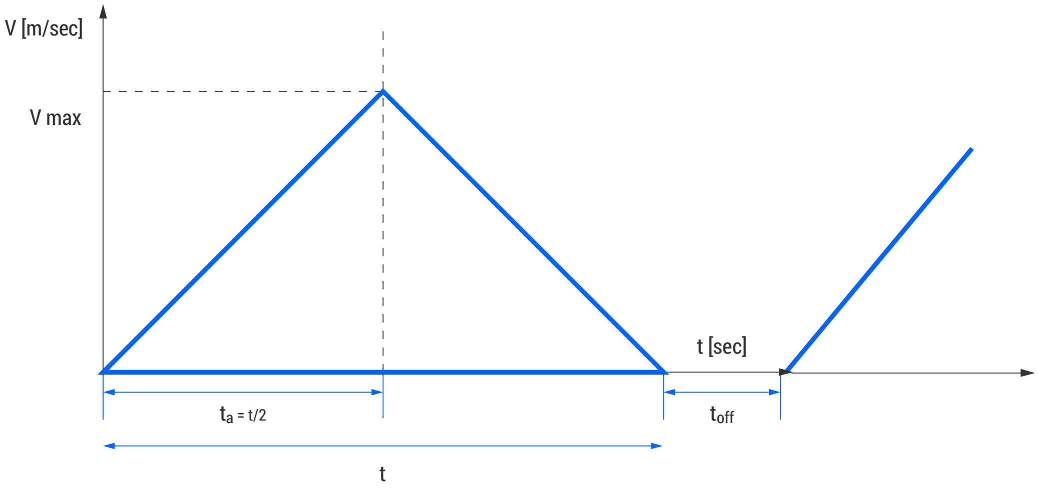
Acceleration/deceleration is defined by:

$$a = \frac{V_{max}}{t_a}$$

Where is:

v	average velocity	[m/s]
v_{max}	maximum velocity	[m/s]
L	moving distance	[m]
t	moving time	[s]
t_a	acceleration time	[s]
a	acceleration/deceleration	[m/s^2]

Triangle profile:



Moving input data:

L	moving distance (stroke)	[m]
t	moving time	[s]
t_a	acceleration time	[s]
t_{off}	pause	[s]

Average velocity is expressed by:

$$v = \frac{L}{t}\ [m/s]$$

Acceleration/deceleration are defined by:

$$a = \frac{4 * L}{t^2}$$

Max speed is defined as:

$$v_{max} = \frac{a}{t_a}$$

Where is:

v	average velocity	[m/s]
v_{max}	maximum velocity	[m/s]
L	moving distance	[m]
t	moving time	[s]
t_a	acceleration time	[s]
a	acceleration/deceleration	[m/s²]

II. Continuous and peak force calculation

There is a wide range of different motion profiles which can be expressed by basic kinematics equations. The most useful is trapezoid point to point moving profile and triangular profile.

Input parameters:

m_{load}	load mass	[kg]
K_{fri}	friction coefficient (usually 0,01)	
F_A	attraction force (you can find it in motor specification)	[N]
α	inclination angle	[°]

The peak forces can be calculated by the following equation:

$$F_p = F_{mass} + F_{fri} + F_{incl}$$

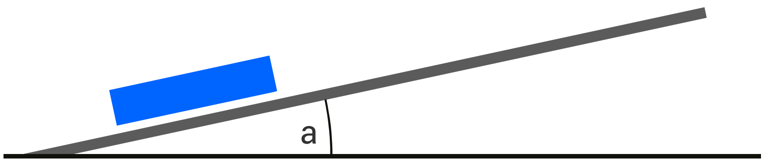
$$F_{mass} = a * m_{load}$$

$$F_{fri} = K_{fri}(g * m_{load} * cos\alpha + F_A)$$

$$F_{incl} = m_{load} * g * sin\alpha$$

Where is:

F_p	peak force	[N]
a	acceleration	[m/s²]
m_{load}	load mass	[kg]
K_{fri}	friction coefficient (usually 0,01)	
g	gravity constant (9,78)	[m/s²]
F_A	attraction force	[N]
α	inclination angle	[°]
F_{incl}	inclination force (in case if motor is placed horizontal (α = 0°) the F_{incl} is 0)	[N]



The continuous forces can be calculated by following equation:

$$F_C = \sqrt{\frac{F_p^2 * t_a + (F_{fri} + F_{inc})^2 * (t - 2t_a) + (F_{mass} + F_{incl} - F_{fri})^2 * t_a}{t + t_{off}}}$$

III. Motor selection

Define motor RMS and MAX current:

$I_{MAX} = \frac{F_p}{K_F}$ < I_p from motor specification.

$I_{RMS} = \frac{F_c}{K_F}$ < I_C from motor specification.

Where is:

F_P	Peak force	[N]
F_C	Continuous force	[N]
K_F	Force constant (you can find it in motor parameters)	[N/A_{RMS}]

Motor voltage calculation:

For proper motor selection, the voltage is also important, which must be applied by servo driver. Maximum voltage is calculated by:

$$V_{mot} = \sqrt{(\frac{v_{max} * K_{BEMF}}{\sqrt{3}} + \frac{F_p}{K_F} * R_{25} * \frac{\sqrt{2}}{2})^2 + (\sqrt{2}\ \frac{F_P * L_p}{K_F * 2 * \tau})^2}$$

Where is:

v_{max}	maximum velocity	[m/s]
K_{BMF}	motor induction voltage Phase to Phase peak (you can find it in motor specification)	[V/m/s]
K_F	Force constant (you can find it in motor parameters)	[N/A_{RMS}]
F_p	peak force	[N]
R25	Phase to phase resistance (you can find it in motor specification)	[Ω]
L_P	Phase to phase inductance	[H]
τ	Magnet pitch (you can find it in motor specification)	[m]

Driver available voltage can be calculated by

$$V_{driver} = \frac{\sqrt{2}\ V_{supply}}{\sqrt{3}} * 0{,}8$$

Where is:

Vsupply	driver supply voltage (for example 230 V AC or 400 V AC)	[V_{RMS}]

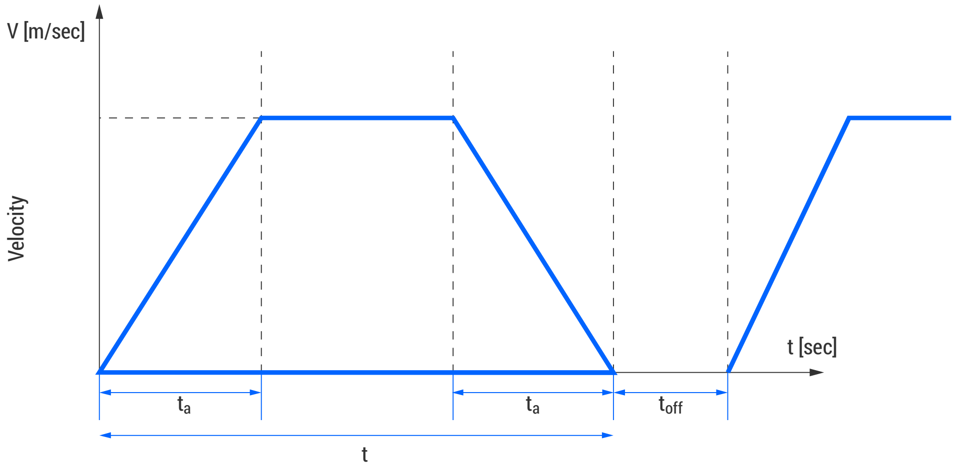
Motor selection condition:

Driver voltage must be higher as max motor voltage.

V_{driver} > V_{mot}

Selection example

I. Definition of motion profile



- Motion distance L = 2 m
- Moving time t = 2 s
- Acceleration time t_a = 0,5 s
- Pause t_{off} = 1 s
- Moving mass m_{load} = 50 kg
- Friction coefficient K_{fri} = 0,01
- α = 0°

Average velocity:

$$V = \frac{L}{t} = \frac{2}{2} = \mathbf{1\ m/s}$$

Max speed is defined as:

$$V_{max} = \frac{L}{t - t_a} = \frac{2}{2 - 0{,}5} = \mathbf{1,33\ m/s}$$

Acceleration/deceleration are defined by:

$$a = \frac{V_{max}}{t_a} = \frac{1{,}33}{0{,}5} = \mathbf{2,66\ m/s^2}$$

II. Continuous and peak force calculation

Peak force:

$$F_{mass} = a * m_{load} = 2{,}66 * 50 = \mathbf{133,3\ N}$$

$$F_{fri} = K_{fri}(g * m_{load} * cos\alpha + F_A) = 0{,}01(9{,}72 * 50 * cos0 + 985) = \mathbf{14,47\ N}$$

$$F_{incl} = m_{load} * g * sin\alpha = \mathbf{0\ N}$$

$$F_p = F_{mass} + F_{fri} + F_{incl} = 133{,}3 + 14{,}47 = \mathbf{147,8\ N}$$

Motor related parameters, can be found in motor specification:

- Attraction force $F_{A\,=}$ 958 N

RMS force:

$$F_C = \sqrt{\frac{F_p^2 * t_a + (F_{fri} + F_{inc})^2 * (t - 2t_a) + (F_{mass} + F_{incl} - F_{fri})^2 * t_a}{t + t_{off}}}$$

$$= \sqrt{\frac{147{,}8^2 * 0{,}5 + 14{,}47^2 * (2 - 2 * 0{,}5) + (133{,}3 + 0 - 14{,}47)^2 * 0{,}5}{2 + 1}} = \mathbf{77{,}88\ N}$$

Motor related parameters, can be found in motor specification:

– Attraction force $F_{A\,=}$ 958 N

III. Motor selection

Motor max current:

$I_{MAX} = \frac{F_p}{K_F} = \frac{147{,}8}{55{,}5} = \mathbf{2{,}66\ Arms}$ **< 9,72 Arms**

Motor continuous current:

$I_{RMS} = \frac{F_c}{K_F} = \frac{77{,}88}{55{,}5} = \mathbf{1{,}4\ Arms}$ **< 3,24 Arms**

Motor related parameters, can be found in motor specification:

– Attraction force F_A = 958 N
– K_F = 55,5 N/A_{rms}
– I_C = 3,24 Arms
– I_P = 9,72 Arms

Motor voltage calculation:

For proper motor selection also voltage is important, which must be applied by servo driver. Maximum voltage is calculated by:

$$V_{max} = \sqrt{\left(\frac{v_{max} * K_{BEMF}}{\sqrt{3}} + \frac{F_p}{K_F} * R_{25} * \frac{\sqrt{2}}{2}\right)^2 + \left(\sqrt{2}\,\frac{F_P * L_p}{K_F * 2 * \tau}\right)^2}$$

$$= \sqrt{\left(\frac{1{,}33 * 35}{\sqrt{3}} + \frac{147{,}8}{55{,}5} * 4{,}75 * \frac{\sqrt{2}}{2}\right)^2 + \left(\sqrt{2}\,\frac{147{,}8 * 0{,}022}{55{,}5 * 2 * 0{,}03}\right)^2} = \mathbf{35{,}9\ V}$$

Motor related parameters, can be found in motor specification:

– Attraction force $F_{A\,=}$ 958 N
– K_M = 55,5 N/A_{RMS}
– K_{BMF} = 35 V/m/s
– R_{25} = 4,75 Ω
– L_p = 22 mH
– τ = 30 mm

Driver available voltage:

V_{supply} = 230 Vac

$V_{driver} = \frac{\sqrt{2}\,V_{supply}}{\sqrt{3}} * 0{,}8 = \frac{\sqrt{2} * 230}{\sqrt{3}} * 0{,}8 = \mathbf{150{,}23\ V > 36{,}2\ V}$