TECNOTION — THE LINEAR MOTOR COMPANY | *Simulation tool use*

[DISCLAIMER]

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[GENERAL INTRODUCTION]

The Tecnotion online simulation tool was introduced in 2017. With this tool every catalogue motor from Tecnotion can be simulated, both linear and torque motors. In the new tool, with all its new possibilities, the help file has been updated. In this file the correct use of the tool is explained, and its possibilities are shown.

[SIMTOOL INTRODUCTION]

The simulation tool is a tool designed to make the motor selection task as easy as possible not only for Tecnotion employees, but also for customers or other interested people. Using this tool saves a lot of time, because the calculations inside are complex, and it gives a quick feel for the possibilities that Tecnotion has to offer.

Most tools on the market only allow you to enter your application data and have the software tell you which linear motor it thinks you need. We realize that things aren't always that simple in practice. For any given application, it is likely that there are multiple motor types that can handle the task, but which one is the best choice? It all depends on what you are trying to accomplish. Are you favouring maximum velocity above everything else? Perhaps you are going for maximum efficiency or cost effectiveness.

Software doesn't know your goals, which is why we decided to go for an iterative approach towards simulating your drive task. At all times during the process you can change movement profiles, application parameters and motor types and the software calculates the new results on the fly. This way you can experiment with a multitude of scenarios and quickly find the one that best suits your application.

We would like to advise you to read this manual before running your first simulation. Not only does it explain all the features and how they work, but you will find lots of tips and tricks throughout this document which will help you understand the ins and outs of linear motor technology and how to best apply them to your application.
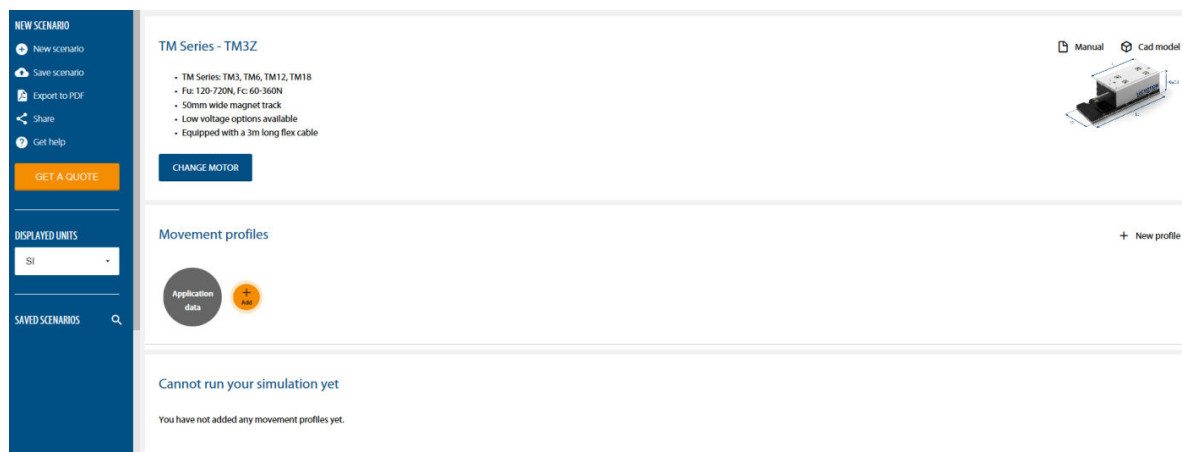
[STARTING THE SIMULATION AND CHOOSING THE MOTOR]

The simulation tool is easy to find online. At the Tecnotion website, www.tecnotion.com, the link can be found under 'simulation tool', at the top of the webpage. Also www.simtool.tecnotion.com should bring you to the tool. A login is necessary to get access to the tool. The landing page is the main screen of the simtool. It is clearly visible that there are several ways to get from this page to your final simulation result. You can start by choosing a motor from the different motor series, by choosing a motor by entering its product number, or by choosing a movement profile.
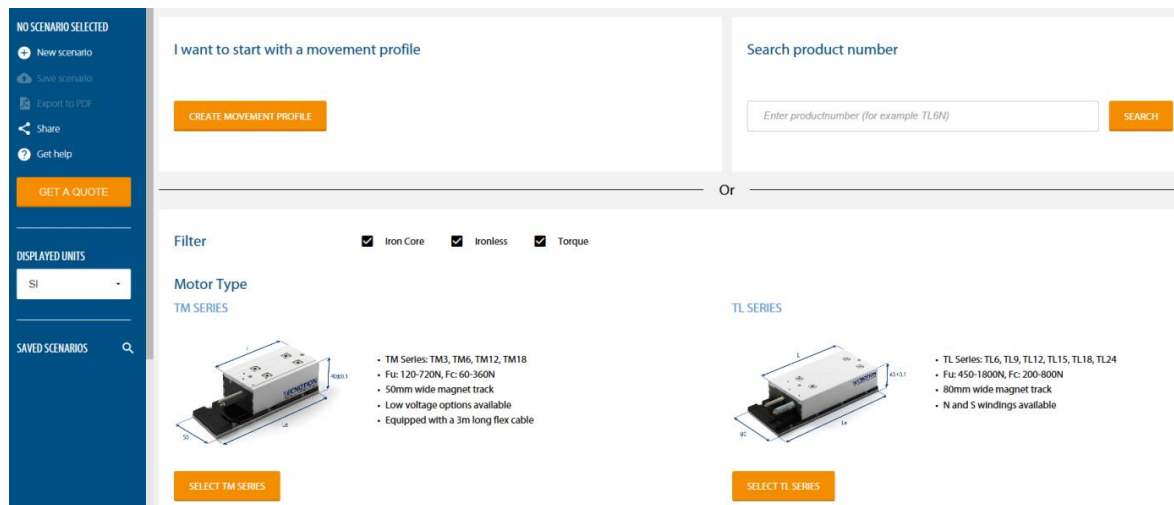
Picture 1 – The characteristic landing page of the Tecnotion online simulation tool.

Let's choose a motor from the motor series listed in the lower part of the main screen. You can toggle which series (iron core, ironless and torque) you want to see, and from the general information next to each series you can determine which motor series would be suitable for the time being for your application. This can be done by relating the force you need in the application to the forces that our motors can deliver. Of course, this is an estimation, therefore the motor series can also be changed afterwards. When you click at one of the motor series, you will see the list of all the motors in the series, with the most important parameters of the individual motors shown. Now, one motor can be selected, but the chosen motor can also be changed afterwards, of course.

Picture 2 - The simulation tool after selecting a motor

[MOVEMENT PROFILES]

The motor is now chosen, we can now start by entering a movement profile or by inserting the application data. Let us examine the first option. We can add a movement profile by clicking the orange 'add'-button. Now a screen arises with information about the movement profile. There are default values shown everywhere, which is handy if you want to do a quick test. First we will adjust the type of movement profile. At the moment there are eleven different profiles possible, all with their own characteristics. The name indicates what the profile looks like, detailed information about the profiles can be found in the appendix of this document. Most of the profiles are trapezoidal or sinusoidal movements, but there are also constant velocities or oscillations possible as a profile.

New movement profile

Name

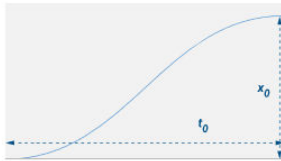Point to point trapezoidal movement (t3rd)

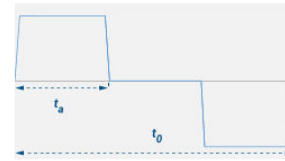| Moving distance	Moving time	Acceleration time
2.000 m	2.000 s	0.500 s

Position

Velocity

Acceleration

Max Vdi volts	Load in newtons
100.000 V	0.000 N

CREATE MOVEMENT PROFILE   CANCEL

*Picture 3 - After choosing a movement profile, this screen pops up.*

Now that the profile type is chosen, we can fill in the desired values. Note that not every profile asks for the same physical quantities. There are five quantities possible to plug in here, although the tool only asks for a maximum of three. The five parameters are moving distance s, moving time t, acceleration time t_a, maximum speed v and acceleration force F_a. These parameters are related by the basic dynamical formulas

$$s_a = \frac{1}{2}at_a^2,$$
$$s_c = vt_c,$$
$$v = at_a,$$
$$F_a = ma.$$

In these formulas, the small a denotes the acceleration phase, and the small c denotes the constant velocity phase. Because the deceleration time and distance in our tool is equal to the acceleration time and distance, we can conclude that the total moving distance is given by

$$s = 2s_a + s_c = at_a^2 + vt_c = vt_a + v(t - 2t_a) = v(t - t_a).$$

With this formula, we can calculate the acceleration time needed, when the velocity has an upper limit. This calculation can be used in a t3rd-profile, but it is also possible to adjust these basic formulas to calculate all the variables in other profiles. Next to the kinematic values, we also have to give two additional parameters, these are the 'Max Vdi volts' and the 'Load in Newtons'.
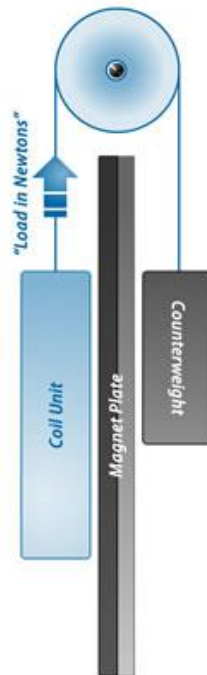
Picture 4 - In this example an external force is applied using a counterweight. Since the direction is the opposite of the gravitational pull on the coil unit, a negative value should be entered as the 'Load in Newtons'.

Max Vdi volts is an optional parameter for advanced users that influences the height of the jerk (this is the change of acceleration, so the third derivative of position with respect to time), which in turn has an effect on the used bus voltage. Please take note that sine squared (sin2) profiles inherently exhibit very low jerk values, much lower than can be achieved by limiting the jerk in a trapezoidal profile. Therefore, it is far more sensible in most applications to opt for a sine squared profile.

When using profiles with a trapezoidal acceleration curve, the maximum jerk can become relatively high. If your system isn't rigid enough to withstand this amount of jerk it will experience resonance, which can result in an unstable control loop. The Vdi is an optional adjustable parameter in some controllers that allows you to limit the jerk.

Picture 5 - In this example an external force is applied through a spring, which only exerts a force when it comes in contact with the coil unit. This means that only profiles dealing with that particular stage of the movement cycle should have a value for 'Load'.

To see what 'Load in Newtons' means, we have to make a distinction between the 'Load in Newtons' that you specify in the 'Movement Profiles' section and the 'Moving Mass' in the 'Application Data' section. The 'Moving Mass' parameter is used to specify the mass of the actual payload you will be displacing. On the other hand, the 'Load in Newtons' parameter is used to specify an additional

external force applied to your application. This force could be anything, from the gravitational pull on a counterweight to the force exerted by a spring on the coil unit. Keep in mind that the 'Load in Newtons' can also be a negative number, if it is opposite in direction to the movement of the coil unit itself. Also note that you have to specify the 'Load in Newtons' individually for each profile within your movement cycle. In the counterweight example on the right, the 'Load in Newtons' is applied throughout the entire movement cycle, so you have to enter the same value for each profile.

On the other hand, in the 'spring' example on the right, the 'Load in Newtons' is only applied during certain stages of the movement cycle, i.e. when the coil unit comes into contact with the spring. In this example, not all profiles will have the same value, and some will have a value of 0.

When these data fields are filled, we can make a second profile if we want to, or even much more. We have to be aware of the fact that the simulation tool does its calculations with a 100% duty cycle. Therefore, if we have only one profile, this one will be repeated for ever. If there is a rest between the repeated movements in real life, we also have to incorporate this by adding a second profile which has zero velocity for some time. In the old simulation tool, there was a stop-profile, but this profile is not present anymore in the new tool.
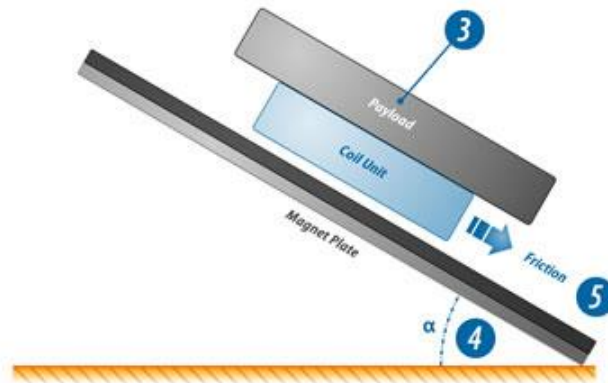
[APPLICATION DATA]
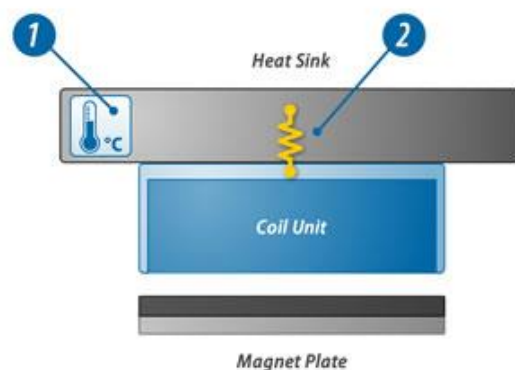
Picture 6 - Picture of the thermal resistance between coil unit and heat sink at a certain temperature.

Now that one or more movement profiles are chosen, we can move on to the application data. These data are constant everywhere in the simulation, and cannot be adjusted for one individual profile. The first one is the estimated temperature of the heat sink that the motor is attached to. In case water cooling is used, the inserted temperature should be the water temperature.

The second parameter is is the thermal resistance between the motor housing and the heat sink. The thermal resistance of the heatsink must be determined by the application user, common values for this thermal resistance are:

Mounting to heatsink or slide   0.05 K/W
Forced air cooling   0.04 K/W
Water cooling   0.02 K/W
Vacuum (only radiation present)   10 K/W

This is not the only thermal resistance in the system. Also between the coils and the housing there is a thermal resistance, this value is motor dependent and can be found in the catalogue. This value is generally higher than the numbers listed above, except for the vacuum case. Therefore, it is very important that the custom has a proper heat sink, in order to have good thermal transport.

Picture 7 - Picture of the influence of moving mass, inclinement angle and friction

The third parameter is the moving mass of the motor. We do not have to take the motor mass into account, this is done automatically. Also, if the application is moving magnet, and the motor is stationary, we have to consider the moving mass of the magnet track and subtract the mass of the motor to compensate for the mass the tool takes into account.

The fourth parameter is the inclinement angle. For a horizontal track we have to insert 0 degrees, and for a vertical track this is 90 degrees. Of course, also intermediate values can be used.

Application data

Temperature heatsink	Moving mass	Friction force
40 °C	55.000 kg	30.000 N

Rtherm heatsink	Inclinement angle	Power supply
0.05 °K/W	0.000 deg	400.000 V

◉ AC   ○ DC

CLOSE

Picture 8 - After choosing 'application data' and then 'edit all parameters', this screen pops up.

The fifth parameter is the total amount of friction that is expected on the application. Take everything into account from bearings to cable chains. A formula that might give indication on how large the friction will be, is given by
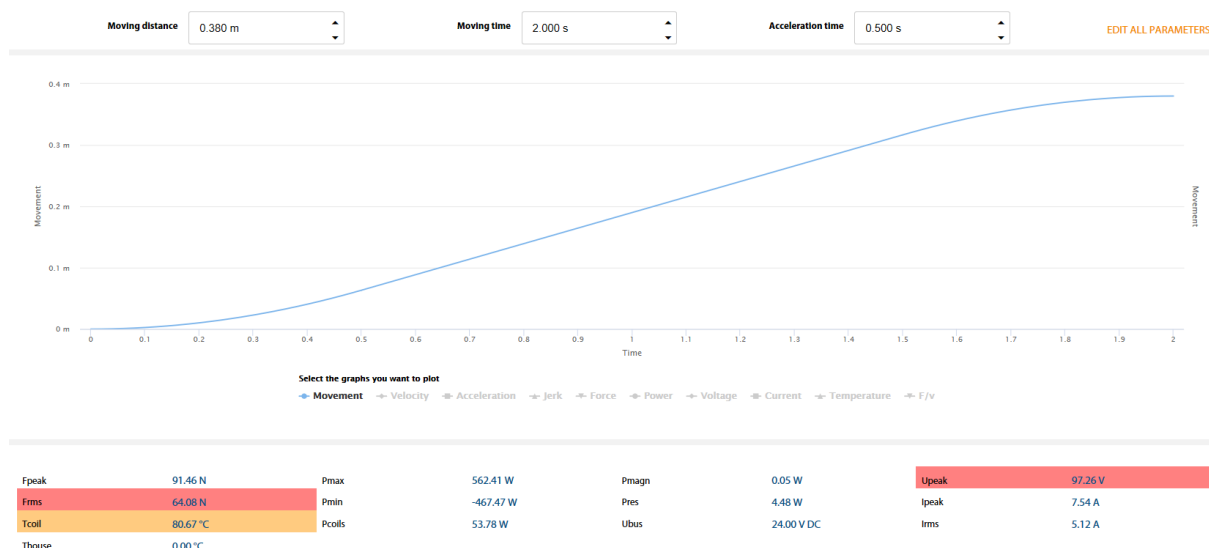
$$F_{friction} = \mu_{bearing}(gm_{load} + F_{att}) + F_{cable}$$

In this formula, the $\mu_{bearing}$ denotes the dimensionless bearing coefficient, which is typically around 0.0001 for air bearings, 0.001 to 0.002 for ball bearings. The default worst-case value that is often used is 0.05, but in real life this would indicate that we are working with bad bearings. The m_{load} is the moving mass, and g the gravitational acceleration. F_{att} denotes the attraction force between magnet plate and motor, this value can be found in the catalogue. Note that ironless motors do not have an attraction force. The second term in the right-hand side of the equation is simply the force due to the cable mass. It is dependant on the linear density of the cable and the length of the cable. This number can be estimated from the application type and movement length of the application.

The sixth parameter that needs input is the voltage of the power supply. You can toggle whether this value is the AC or the DC value. When the AC value is selected, the tool multiplies this by $\sqrt{2}$ in order to find the peak voltage.

[SIMULATION RESULTS]

Now that the motor is chosen, the movement profile is determined, and the application data is inserted, the tool will automatically start the simulation. The results of the simulation are presented in two ways, there is a large figure in the middle of the screen, and a list of calculated values of the most important quantities. The figure automatically shows the movement profile, distance plotted against time. All the physical quantities that can be plotted are listed directly below the figure, and will be shown versus time.

| Moving distance | 0.380 m | Moving time | 2.000 s | Acceleration time | 0.500 s | EDIT ALL PARAMETERS |

Fpeak	91.46 N	Pmax	562.41 W	Pmagn	0.05 W	Upeak	97.26 V
Frms	64.08 N	Pmin	-467.47 W	Pres	4.48 W	Ipeak	7.54 A
Tcoil	80.67 °C	Pcoils	53.78 W	Ubus	24.00 V DC	Irms	5.12 A
Thouse	0.00 °C					

Picture 9 - Possible results screen during a simulation. Note that we have to look for another motor or have to change the movement profile or application data in order to make this motor suitable.

Some of them (movement, velocity, acceleration and jerk) are only determined from the inserted movement data, others (force or torque, power, voltage, current and temperature) also use the data that was inserted in the application data section. The only exception to these nine graphs is the Fv-diagram, which shows both motor characteristics and your application's characteristics in terms of force and velocity. This is therefore the only graph without time on the x-axis. It is possible to show several graphs at the same time, only for the Fv-diagram this is not possible. In the table below the details of each plot can be seen.

Plot	Interpretation
Movement	Motor position set against time.
Velocity	Motor velocity set against time.
Acceleration	Motor acceleration set against time.
Jerk	Motor jerk (change of acceleration) set against time.
Force/Torque	Force/Torque produced by the motor in Newton/Newtonmeter set against time.
Power	Power draw of the motor in Watt set against time.
Voltage	Phase-phase voltage in Volt set against time.
Current	Current draw of the motor in Ampere set against time.
Temperature	Thermal behaviour of the coils of the motor in degrees Celsius set against time.
Fv	The pink plot is the typical characteristic of the motor, dependent on bus voltage and winding type. The black plot shows the forces needed at a certain velocity in the profile. As long as the black plot stays within the boundaries of the pink plot, the motor can handle the movement cycle.

Table 1 – Plots in the simulation tool

From the movement and application data, there are also thirteen physical quantities calculated and shown under the large graph. Here, two force/torque values, two temperature values, five power values, two voltage values and two current values can be found. In the table below, the interpretation of the quantities can be found.

Quantity	Interpretation
F_{peak}/T_{peak}	Peak force/torque in Newton/Newtonmeter
F_{rms}/T_{rms}	Continuous force/torque in Newton/Newtonmeter
T_{coil}	Temperature of the coil in degrees Celsius
T_{house}	Temperature of motor housing in degrees Celsius
P_{max}	Maximum electrical power in Watt
P_{min}	Minimum electrical power in Watt
P_{coils}	Dissipated power in coils and track in Watt
P_{magn}	Dissipated power in magnet plates in Watt
P_{res}	Dissipated power in brake resistor in Watt
U_{bus}	Bus voltage in Volt
U_{peak}	Peak voltage in Volt
I_{peak}	Peak current in Ampere
I_{rms}	Continuous current in Ampere

Table 2 - Physical quantities in the simulation tool

Some of the above listed quantities can sometimes be shown in a red rectangle, this indicates that the value resulting from the application is too high for the motor. For the peak force and peak current this happens when the catalogue value of the ultimate (for ironless motors peak) force or current is exceeded, for the peak voltage it happens when 90% of the inserted bus voltage is exceeded. For the coil temperature the red rectangle appears when the maximum coil temperature (100 °C for iron core motors and torque motors, 80 °C for UC-motors, and 110 °C for other ironless motors) is exceeded. When the temperature is between 20 °C below the maximum temperature and the maximum temperature, the field lights up in orange, as a warning sign.

[TWEAKING THE RESULTS]

Now that the simulation results are shown, we can proceed with an attempt to improve the results. If all the physical quantities are still listed without red warning boxes, probably an overdimensioned motor has been used. This can easily be changed by clicking the blue 'change motor' button on the top of the page. This allows us to choose a motor which is optimal for the customer. If the peak voltage in your movement cycle exceeds 90% of the bus voltage you can, for example, rerun the simulation with an S-type (or even Y- or Z-types, when available) motor instead of an N-type (S-type motors run on decreased voltage, but increased current).

A different possibility is playing with the movement profiles or the application data. All the parameters that have been chosen in the previous steps can be altered. This is done by either clicking the grey 'application data' button, or one of the individual profiles. After clicking, a horizontal bar with three of the most used parameters shows up. These three parameters can now be changed by inserted a new number, or by clicking the small up or down buttons in each field, which causes the value to change by 10%. Because the graph and the numerical results are changing instantly, it can easily be seen what the influence is of this change. By clicking 'edit all parameters', we can change the data which is not shown in the horizontal bar. Here, the small up and down buttons are not available.

These are of course only a couple of examples of how you can refine the results and choose the right motor for your application. For certain applications it might even be more economical or efficient to use two smaller motors instead of one big motor. You can get a reasonably good approximation of motor performance in this way by selecting a smaller motor and dividing the moving mass of your application by two. Please also keep in mind that the friction force will be different now, and that the current will double. Most importantly, always use common sense when interpreting the results. A bigger motor might solve your problem, but may also cost a lot more. Perhaps a slight change in your movement cycle can create the perfect combination of price and performance. In case of uncertainties, please contact Tecnotion.

At the left side of the simulation tool there is also an option to use imperial units instead of the metric system. Of course this does not influence the physics, but the results (graph and physical values) are now showing imperial units. When you have selected a torque motor, it is possible to choose between inserting degrees (deg), radians (rad) or revolutions (rpm), next to the possibility to get the results in metric or imperial units.

Note that while the results of the simulation may tell you that the motor is capable of handling the task you set out for it, the simulation won't tell you anything about accuracy, settling time, et cetera. This is because those figures are dependent on your entire servo loop, i.e. the dynamic behaviour of

the mechanics, accuracy of the feedback device and bandwidth of the servo controller and amplifier. We always advise that you test the motor first, before running the full application.

[SHARING THE SIMULATION]

If you are satisfied with the simulation after tweaking the results, we can save the simulation. This is done by clicking 'save scenario' at the left side of the screen. You can give the simulation a name, and after doing so the saved simulation will show up at the left side of the screen under 'saved scenarios' with the assigned name. In the future you will be able to return to this simulation just by clicking its name. If this is done, and adjustments are made in the simulation, the program will ask you if you want to save the changes under its current name or under a new name, so that you will not lose old simulations if you don't want to.

If more simulations are made and saved in the future, they will all appear under 'saved scenarios', there is no limit of simulations that can be saved. Be careful that you do not give them names with classified information or company names, because of safety reasons. Also, if you show the simtool on a screen while being with a potential customer, everyone can see the names of your scenarios, so be careful with the simulation names. The names can always be changed, by clicking on the simulation and changing the name by clicking the pencil next to the simulation name at the left top of the screen. Deleting a scenario is also possible, by clicking the trash bin next to the simulations listed at 'saved scenarios'. It is also possible to look for a certain scenario by clicking the search function next to 'saved scenarios'.

After a simulation is saved, it can be exported to a pdf-file, so that the results are also offline available. A report like this can be sent to potential customers to show them what we can achieve with our motors. In this report, the motor parameters, inserted application data and movement profile description are summarized at the top. Furthermore, the values for the physical parameter is shown at the bottom of the first page, these numbers are an exact copy of the data shown in the online tool. After the first page all the graphs that can be made in the tool are shown, some of them with an explanation.

There are also options to get in touch with Tecnotion by sharing your simulation. The first option to do so is by clicking 'share'. You can type in an e-mail adress together with a message for the receiver with a question or remark. Similar is the 'get help' button, but then the message will go to the Tecnotion sales e-mail adress. You can ask a specific Tecnotion person by mentioning a name in the upper box, the message will be forwarded to the intended employee. The last options is the 'get quote' button, in which you can choose the simulation with a certain motor that you want a quote for, and you can also enter an additional message. Tecnotion will make sure that the relevant sales person gets in touch with you.

In general, if there are any problems while using the simtool in any way, please feel free to contact support@tecnotion.com, and we will make sure that we will look into your simulations, remarks or bugs and help you find the right solution.

[APPENDIX]

There are four general profile forms: trapezoidal (t3rd), sinusoidal (sin2), constant velocity and oscillation profiles. The 3rd order form will set the motor velocity across the profile as a trapezoid. The sine squared form will set the motor acceleration and deceleration as a sine. Additionally, you have four ways to describe both the 3rd order and sine squared forms. Next to the general constant velocity profile, there is also a specific constant velocity profile, this is the standstill with velocity equal to zero. The last profile is the oscillation, in which the movement is a perfect sine, and therefore every derivative (velocity, acceleration, jerk and so on) is also a perfect sine, with only a phase shift between position and there derivatives. Following is a description of each of the profile types.

Point to point trapezoidal movement (t3rd) and point to point sinusoidal movement (tsin2)
These profiles will cause the motor to accelerate from a standstill, move with a constant speed and decelerate back to 0 m/s, based on stroke and movement time. Use one of these profiles when you need the motor to move from A to B and maximum speed is of no importance.
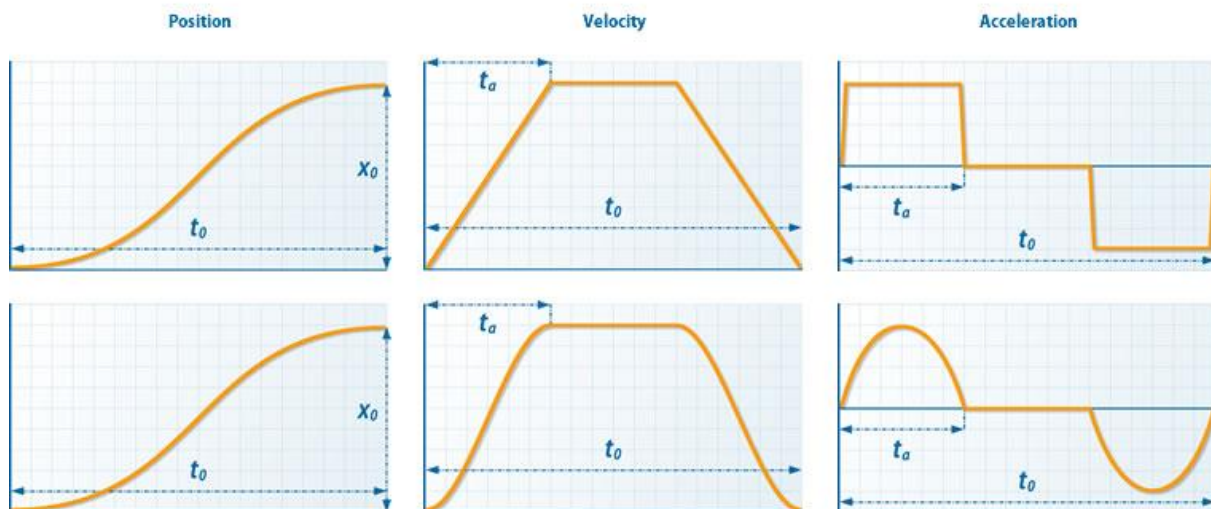
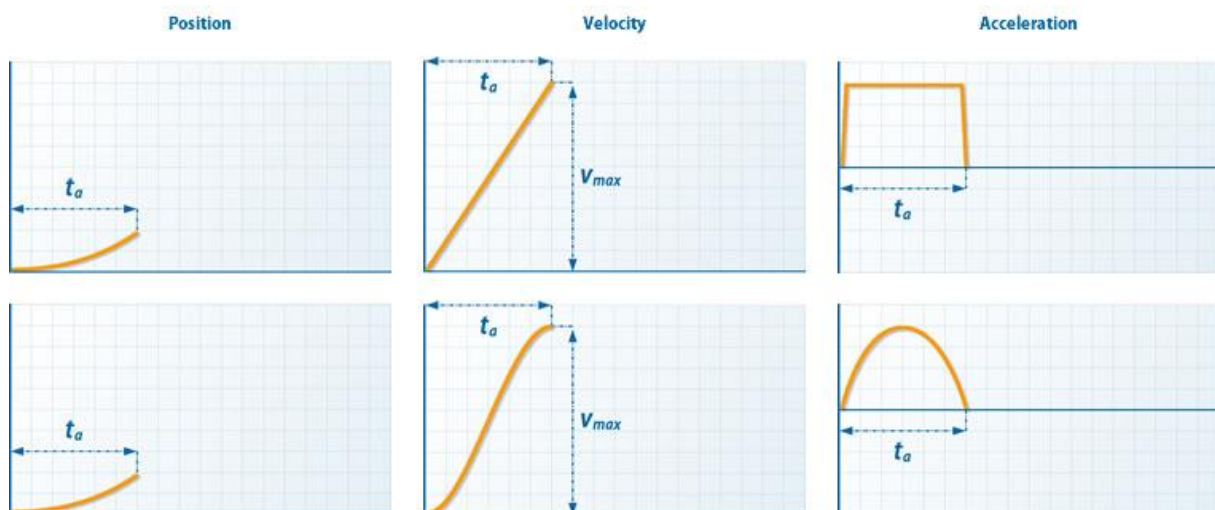Picture 10 - Characteristics of a 3rd order trapezoidal profile (top) and a sinusoidal profile (bottom).

Constant velocity trapezoidal movement (m3rd) and constant velocity sinusoidal movement (msin2)

These profiles will cause the motor to accelerate from a standstill, move with a constant speed and decelerate back to 0 m/s, based on stroke, maximum velocity and acceleration force. Use one of these profiles when you need the motor to move from A to B with a defined maximum speed.
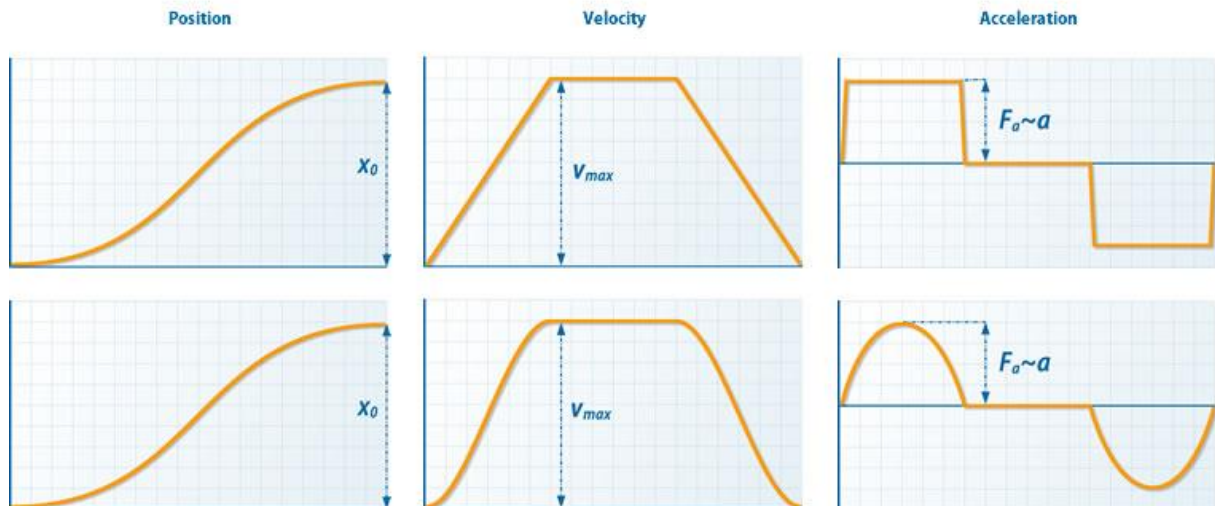
Picture 11 - Characteristics of a constant velocity trapezoidal movement profile (top) and a constant velocity sinusoidal movement (bottom).

Acceleration ramp trapezoidal defined by time (a3rd) and acceleration ramp sinusoidal defined by time (asin2)
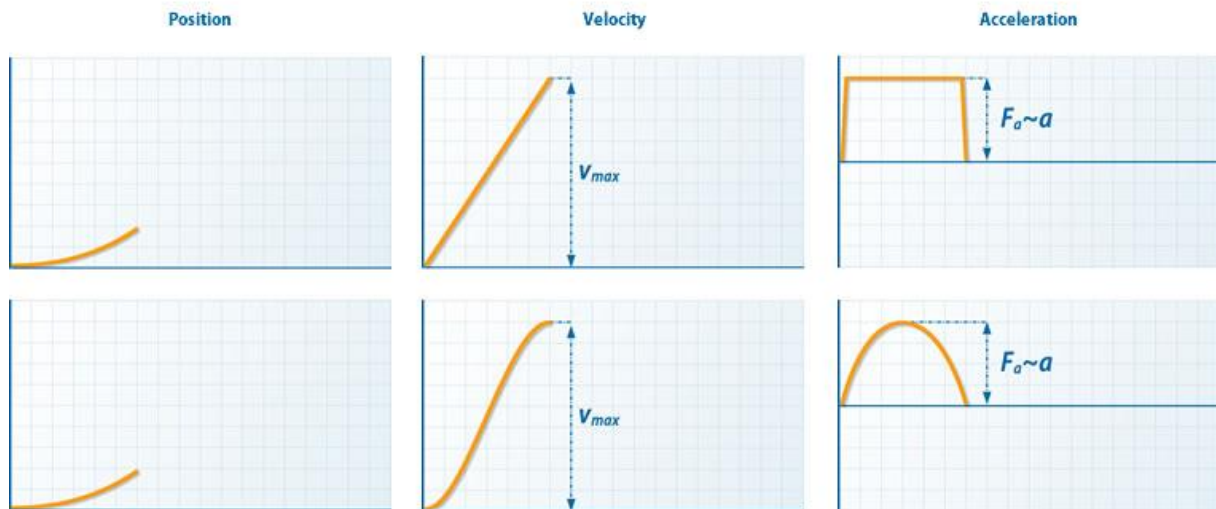

Picture 12 - Characteristics of a trapezoidal acceleration ramp defined by time (top) and a sinusoidal acceleration ramp defined by time (bottom).

These profiles define only one ramp, i.e. accelerate or decelerate to the specified velocity, based on acceleration time.

Acceleration ramp trapezoidal defined by force (q3rd) and acceleration ramp sinusoidal defined by force (qsin2)
These profiles define only one ramp, i.e. accelerate or decelerate to the specified velocity, based on acceleration force.
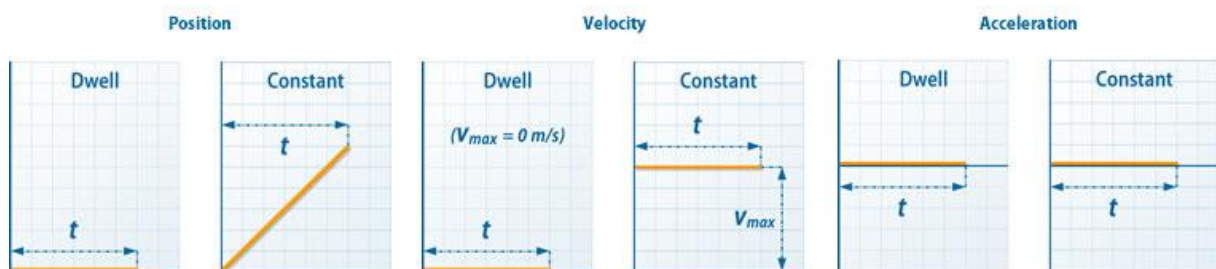

Picture 13 - Characteristics of a trapezoidal acceleration ramp defined by force (top) and a sinusoidal acceleration ramp defined by force (bottom).

Constant velocity (cons)
This profile causes the motor to move at a constant velocity for the specified amount of time.

Standstill (dwell)
This profile causes the motor to stand still for the specified amount of time.

Picture 14 - Characteristics of a dwell movement and a constant velocity movement.

Oscillation (occ)
This profile makes sure that the position of the motor is a perfect sine wave. A maximum speed should be set here.