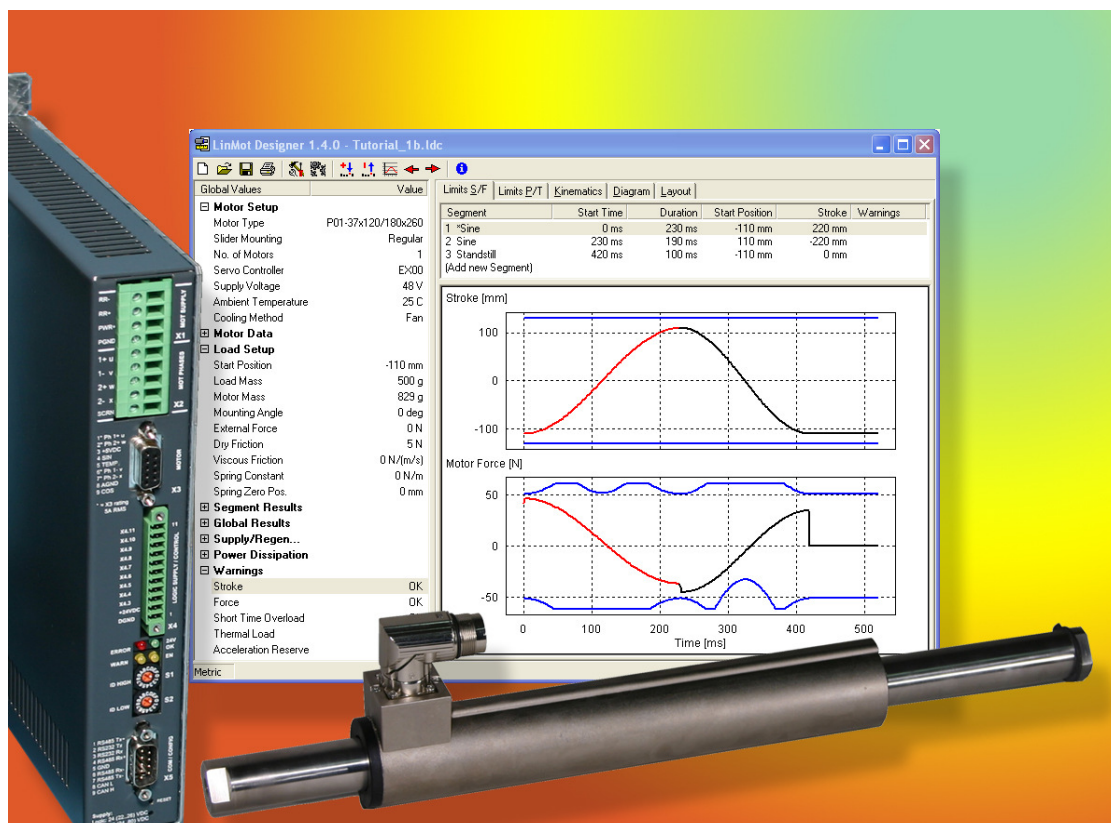


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# LinMot®

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## Tutorial LinMot® Designer 1.8

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<b>TUTORIAL FOR THE LINMOT DESIGNER MOTOR SIZING TOOL .....</b>	<b>1</b>
WHY USE A DESIGN PROGRAM? .....	1
MODE OF OPERATION OF A DESIGN PROGRAM.....	1
EXAMPLE 1: HORIZONTAL LINEAR MOVEMENT.....	2
<i>Step 1: Start LinMot Designer and input global Data.....</i>	<i>3</i>
<i>Step 2: Segmentation of the Motion.....</i>	<i>4</i>
<i>Step 3: Checking the Limits .....</i>	<i>7</i>
<i>Step 4: Interactive Optimizing .....</i>	<i>10</i>
EXAMPLE 2: ROTATING MOVEMENT .....	11
EXAMPLE 3: IMPORTING CUSTOM CURVES .....	14
ADDITIONAL INFORMATION .....	16
<i>Power Supply.....</i>	<i>16</i>
<i>Efficiency (Linear Motor ↔ Pneumatic Cylinder) .....</i>	<i>17</i>
<i>Time Graphs .....</i>	<i>18</i>
<i>Layout.....</i>	<i>19</i>

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November 19<sup>th</sup> 2013

## Tutorial for the LinMot Designer Motor Sizing Tool

LinMot Designer is a sizing tool for the LinMot motor system. It helps to choose the right linear motor and servo drive for a specific application. It also helps to find the right rotary motor for a given linear-rotary application. The examples in this Tutorial will introduce the use of the LinMot Designer sizing tool. The first example will explain the designer functionality for the use of linear motors in linear applications. Example 2 shows, how a rotary application can be designed. In example 3, the import of a custom curve as a motion profile is discussed.

### ***Why use a design program?***

One can pose the question why a design program for linear servo motors is required at all, if the relationships may be simply explained by the formula  $F = m \times a$ . The reason is that, for exact drive design, certain additional limiting conditions must be considered during calculation:

- The maximum feeding force produced by a linear motor is speed-dependent in practice, and is particularly influenced by the properties of the servo amplifier. As in the case of rotational servomotors, where the maximum torque is reduced with increasing rotation speed, linear motors suffer a reduction in maximum force with increasing speed on account of the counter-voltage.
- Long-stroke movements mostly result in the drives running into a force limit during acceleration and braking phases, whereas otherwise maximum speed is the limiting factor.
- For estimating whether a motor does not overheat under given conditions, the power dissipation for an entire motion cycle must be calculated.

The choice of a suitable motor is an iterative process, as the own mass of that part of the motor in motion is included in the total mass in motion. This means that the design of a drive becomes an iterative process.

From the academic point of view, it can be exceptionally interesting to consider the above-mentioned factors in drive design. For most users on the other hand, it is more sensible to invest time in constructional considerations while leaving mathematical calculations to a program.

### ***Mode of operation of a design program***

Using the LinMot Designer motor sizing program is divided into four steps:

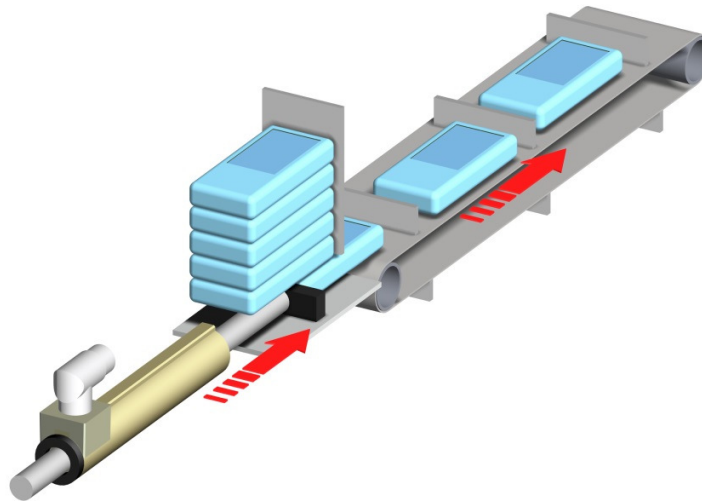
- **Step 1: Start LinMot Designer and input global Data**
- **Step 2: Segmentation of the Motion**
- **Step 3: Checking the Limits**
- **Step 4: Interactive Optimizing**

A design program should not only be used to select a drive, but also to promote an integral way of looking at things: What happens if the load mass can be reduced by 10%? What effect does a reduction or increase of the movement times of individual segments have? Which movement profile is optimal for this application? All these questions can be computed for different solution variants and displayed graphically by a design program in few minutes.

**Important:** The LinMot Designer is a sizing program that simulates behaviour of the LinMot linear motors under static and dynamic load conditions. The LinMot designer offers the constructing engineer fast help in the analysis and optimization of drive technology for a given task. The simulation and calculation comes as close as possible to the behaviour of the linear motor in the real application, but is always dependant on the accuracy of the input parameters. It is recommended to discuss and verify the simulation and results with your local LinMot Distributor.

### Example 1: Horizontal linear Movement

In a production line, a pneumatic cylinder pushes 30 products per minute from a stack into a conveyor belt. To increase productivity, a faster second production line will be installed and the pusher has now to handle the products from the two lines. The maximal production rate for the pusher will increase to 82 products per minute.



To handle the 82 products per minute, the minimal cycle time to push one product onto the conveyor belt is 730msec. In order to guarantee gentle product handling (and for dynamic reasons), a LinMot linear motor will replace the pneumatic cylinder.

The mechanical construction should not be changed. The weight of this construction (without the slider of the linear motor weight) is 500g. The product weight itself is 700g.

The questions to answer during the motor sizing are:

- Which type of linear motor may do the job?
- Which size servo controller will be needed to control the motor?
- Do we need additional cooling for the linear motor?
- What's the minimal cycle time for this application?

**Note:** You will find all configurations from this Tutorial in the LinMot Designer folder on your PC (filenames: Tutorial\_Ex?.ldc).

## Step 1: Start LinMot Designer and input global Data

### Starting the LinMot Designer

The last LinMot Designer project will automatically be loaded at start up. To start a new project, click on the “Start new Project” Button and select the design type “Linear Motor Design”. This will reset all parameters to the default values.



“Start new Project” Button

### Define Global Settings according to the Example

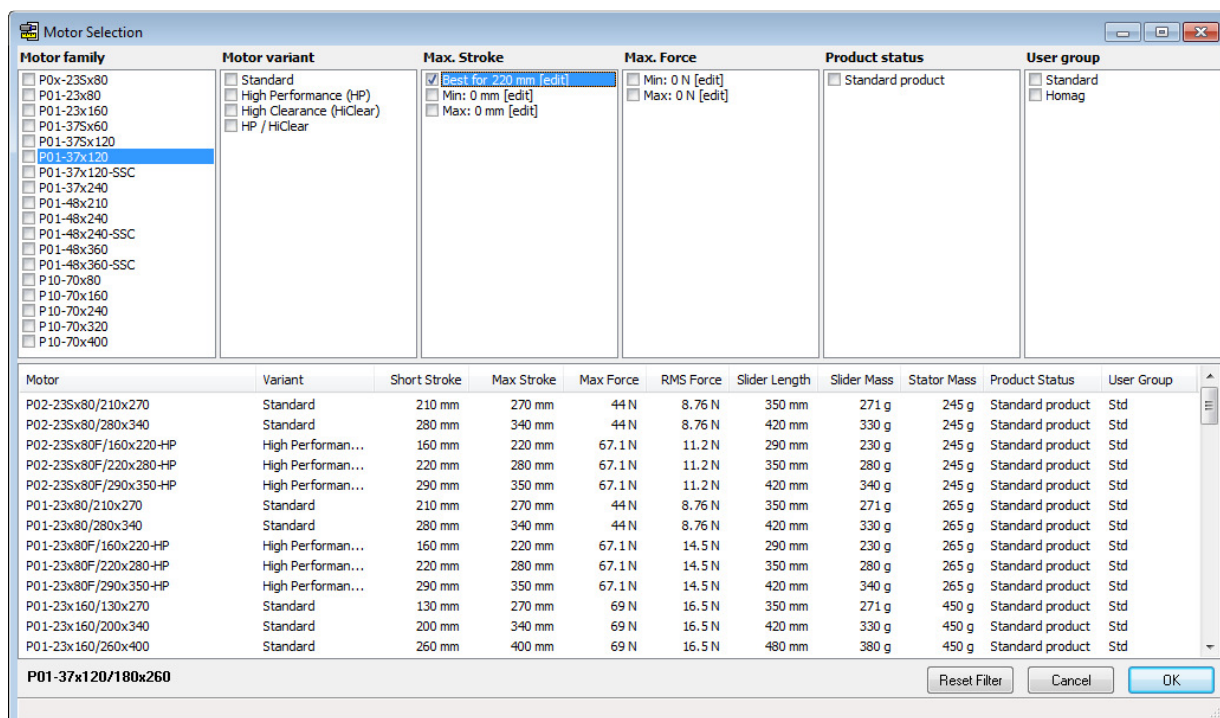
In the “Global Settings” window, all motor and construction-specific characteristics must be specified. As at the moment you don’t have any information on the linear motor, we select a motor type with a stroke range slightly bigger than the stroke needed in the application.

The motor has to be selected in the “Motor Selection” window. The window shows a list of all available motors, whereby filter and sort capabilities helps you to find an appropriate motor. The filter can be used to reduce the motor list to a reasonable set of motors for the application.

**Filter:** The filter structure consists of several filter types (Motor family, Motor variant, Stroke, …) Each filter type has one or more filter entries defining the filter criteria. A filter type can be activated by selecting one or more of its listed criteria. All motors that fulfill at least one criterion for every activated filter type, will be displayed in the filtered list. (Note: A filter type with no selected criterion is inactive.)

**Sorting:** To sort the motor list by a certain parameter in ascending order, just click on the parameter name in the header row.

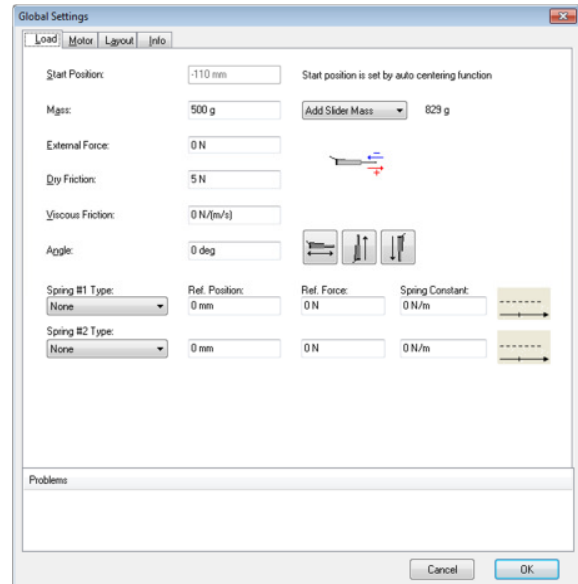
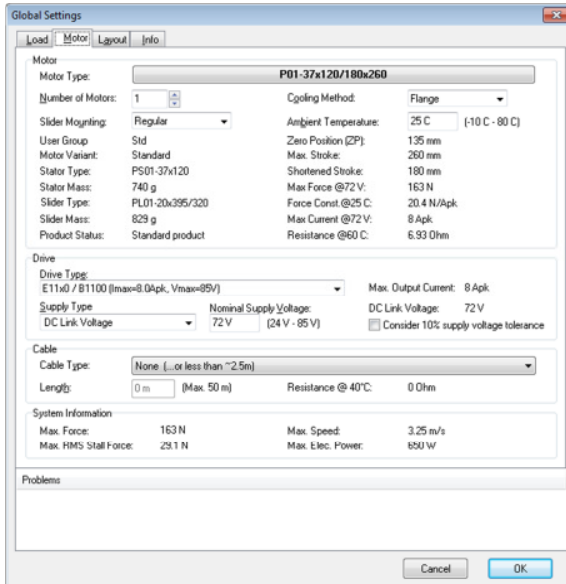
To find appropriate motors regarding the required stroke, activate the stroke filter criteria “Best for …mm” and define the value (double click on the entry) with the stroke given by the application.



For the servo drive unit, we select an “E11x00 / B1100” with a nominal dc link voltage of 72V. If the checkbox “Consider 10% supply voltage tolerance” is set, the LinMot-Designer calculates with a 10% reduced dc link voltage. The cable between drive and motor only has to be defined for longer cables. Its resistance can result in a reduction of the force limit. As soon as we defined the motion sequence, we will come back to the “Global Settings” Menu in order to select a linear motor and its drive which will be the best for this application.



“Global Settings” Button



In the “Load” menu, the specification about the mechanical configuration (mounting, friction, zero Positions, etc.) has to be specified according to the construction.

In the example the maximal stroke is 220mm. We choose a start position, which is half of the total stroke, in order to have the motion symmetrical to the Zero Position (ZP) of the linear motor. A symmetrical motion relative to the Zero Position of the linear motor will give the best performance for the motion. If the “Auto centering mode” button is pressed, the start position will be set automatically.



“Auto centering mode” Button

The constant mass of the pusher construction (500g) has to be set in the “Global Settings”. The 700g product mass will be set later in the “Local Settings”, as it has to be considered only for the forward (push) motion. Additional to the mass of the construction, the program will automatically add the mass of the moving part of the motor. In the construction of this application the slider is moving, we have to select “Add Slider mass”.

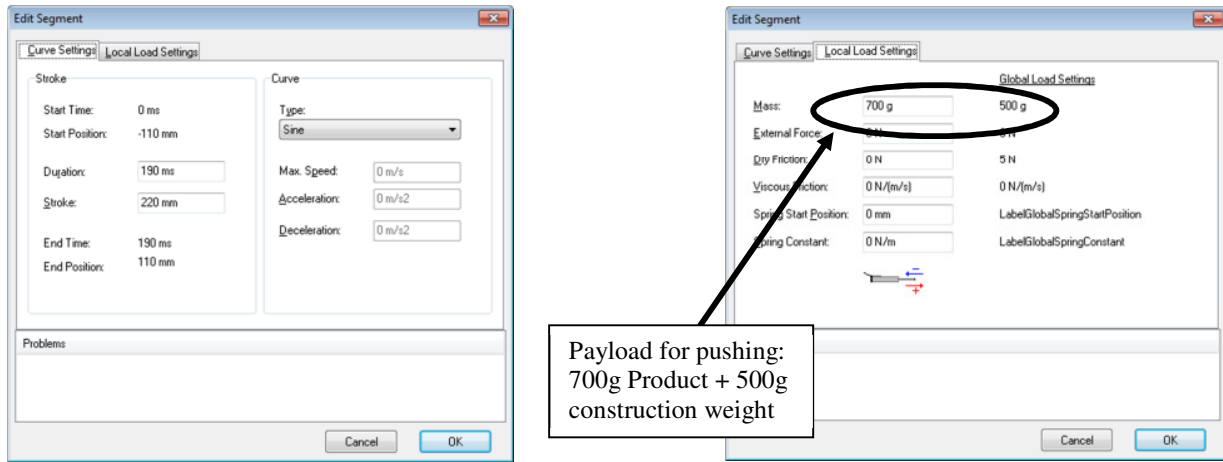
## Step 2: Segmentation of the Motion

During the segmentation of movement, the complete motion is subdivided into individual integral movement sections. In our example we can divide the entire motion into three different segments (e.g.: “controlled forward movement”, “fast backward movement”, “Standstill”).

Motion	Stroke	Time	Total Payload
Forward	220mm	190msec	1200g
Backward	-220mm	190msec	500g
Standstill	0 mm	370msec	500g

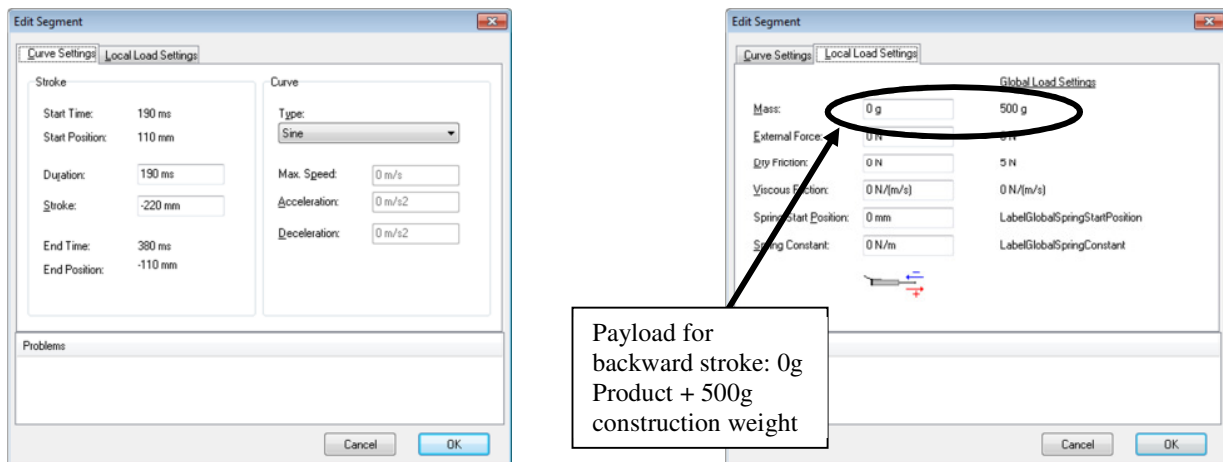
**Define the “Forward” Motion**

Open the “Edit Segment” window for the first segment of the motion (double click on text “1 Sine”). In the “Curve Settings” window we specify the 220mm motion for the forward movement (pushing). As we have to consider the additional product mass of 700g during pushing (construction and slider mass will be considered automatically).



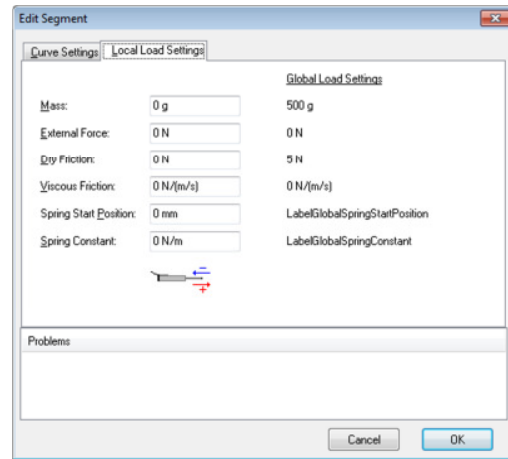
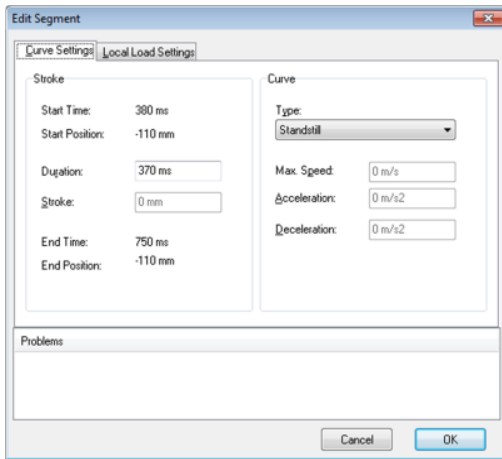
**Define the “Backward” motion**

Add a new segment for the backward stroke and open the “Edit Segment” window (double click on text “Add new segment”). In the “Curve Settings” window we specify the -220mm motion for the backward movement. We do not have to consider additional mass, as for the backward movement there is now additional payload.

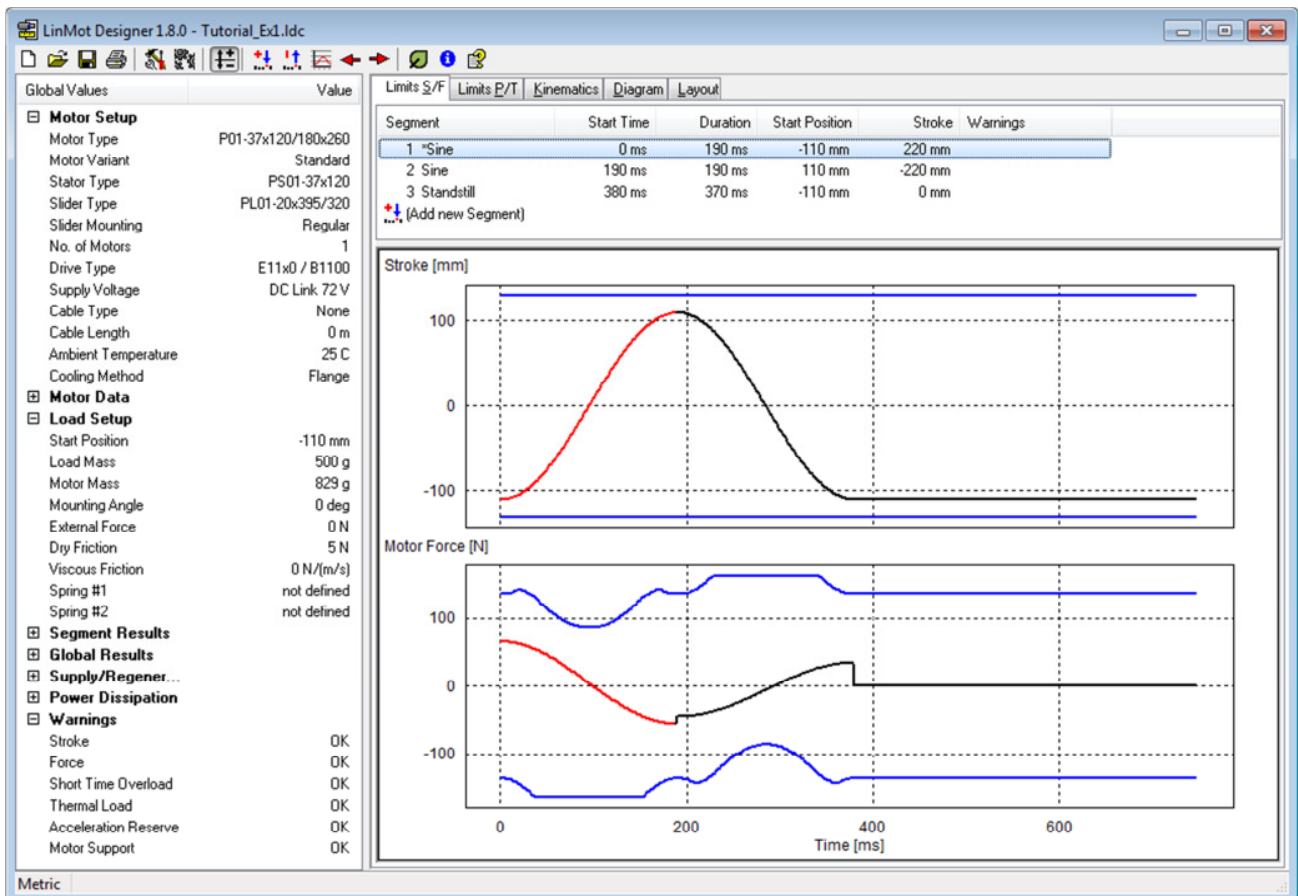


### Define the “Standstill” time

Add a new segment for the standstill part of the motion sequence and define the motion according to the screenshots. It is important that you specify the entire cycle of you motion (including standstill time) in order to achieve correct results for RMS force calculation and the thermal load.



After defining the entire motion sequence, the desktop of the LinMot Designer will have the following appearance. If there are any “Local Load Settings” defined in an existing segment, a “\*” is prefixed to the corresponding segment name.





### Step 3: Checking the Limits

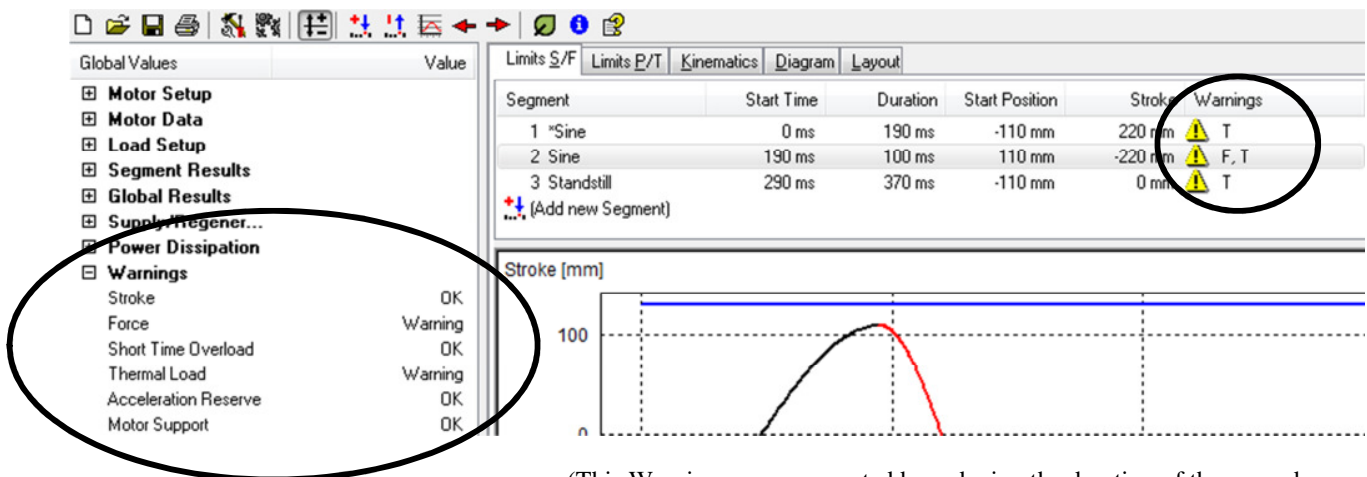
For the defined application, LinMot Designer calculates diverse physical parameters that are important concerning the design. The most important dynamic parameters are shown as time-dependent values in diagrams (Stroke, Motor Force, Power Dissipation, Short Time Overload Protection Value, Thermal Load, Speed, Acceleration). In the “Global Values” window relevant static parameters as well as peak-, rms- and mean-values of dynamic parameters are shown.

A realisation of the defined application will only be successful, if all of the following dynamic parameters don't exceed their corresponding limits:

Dynamic parameter	Warn flag
Stroke	S
Force	F
Short Time Overload Protection Value	O
Thermal Load	T
Acceleration Reserve at Standstill	A

The limit checks are done by the LinMot Designer. The results of the checks are shown under “Warnings” at the bottom of the “Global Values” window. If a value exceeds the corresponding limit, a “Warning” is displayed. Warn flags in the “Curve Settings” window show, in which segment(s) the corresponding limits are exceeded.

In addition to the dynamic parameter check, also a system check is done. If the selected motor isn't supported by the selected drive, a “Motor Support”-warning is generated and displayed in the “Global Values” window.



(This Warnings were generated by reducing the duration of the second segment in the example.)

In the “Limits S/F” window, the mechanical parameters “Stroke” and “Force” of the motion with their corresponding limits are shown in time-diagrams. In the “Limits P/T” window, the thermal parameters “Power Dissipation” (without limits), “Short Time Overload Protection Value” and “Thermal Load” with their corresponding limits are shown in time-diagrams.

#### Stroke Limits

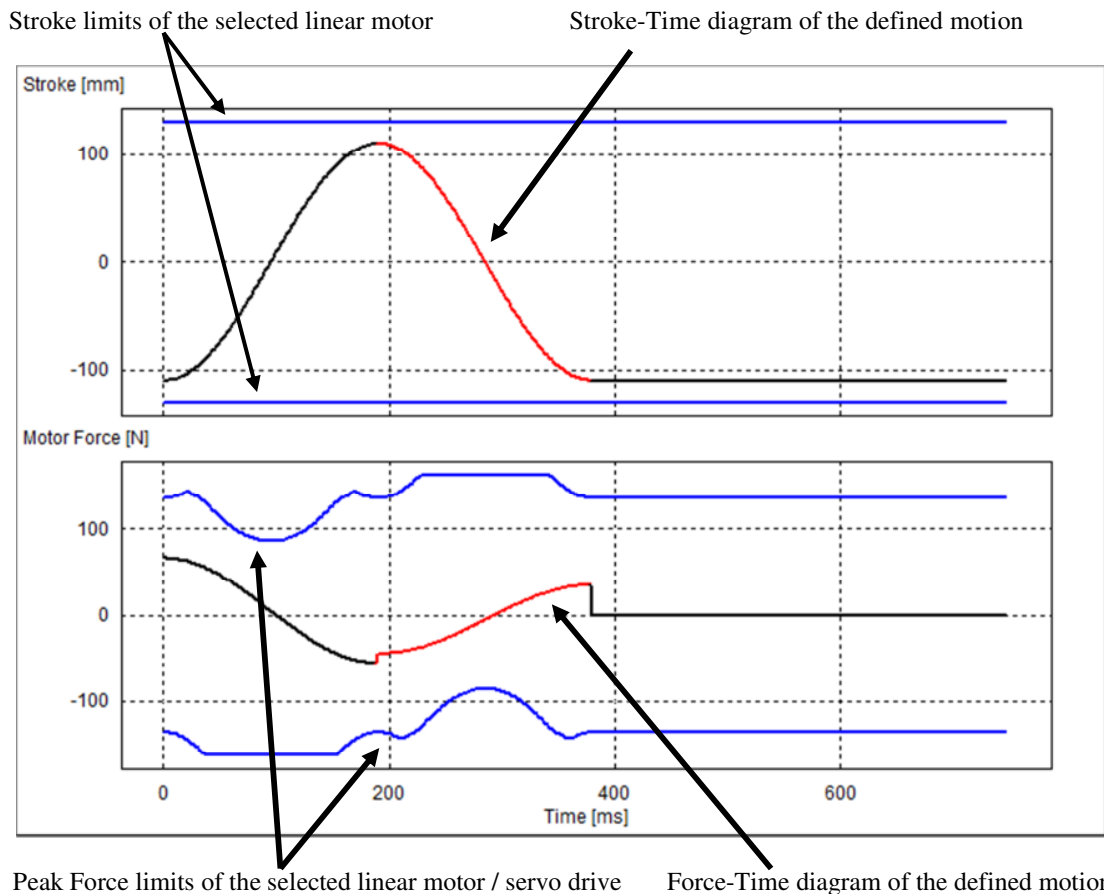
The Stroke and its limits are shown in the upper diagram of the “Limit S/F” window. The graph of the motion (black-red line) has to be within the limits (blue lines) of the selected linear motor.

If the stroke of the motion is too long, you have to select a motor type with a longer maximal stroke. The maximal stroke of the linear motor should be selected as close to the maximum stroke needed in the application in order to minimize the moving mass (slider).

The motion should be symmetrical to the Zero Position (0mm) of the motor. If the motion is not symmetrical you have to adjust the parameter “Start Position” in the “Global Settings” window (see Step 2).

### Dynamic Force Limits

The Force diagram shows the dynamic force the linear motor has to produce during the motion (black-red line). You will also find the peak force limits for the selected linear motor (blue lines). If the force the motor has to produce is within the motor limits, the selected motor can perform the requested motion. If the motor force is not within the limits, you have to select another linear motor or servo drive. If the requested force is still not within the limits, extending the execution time in the critical segments or reducing the payload will help to come down with the requested motor force.



**Note:** Peak force limits of a linear motor depends on the actual position (see stroke force diagram in the data sheets) and on the actual velocity (peak force is decreasing with higher velocities). The peak force may change if another linear motor is selected due to differences in slider mass.

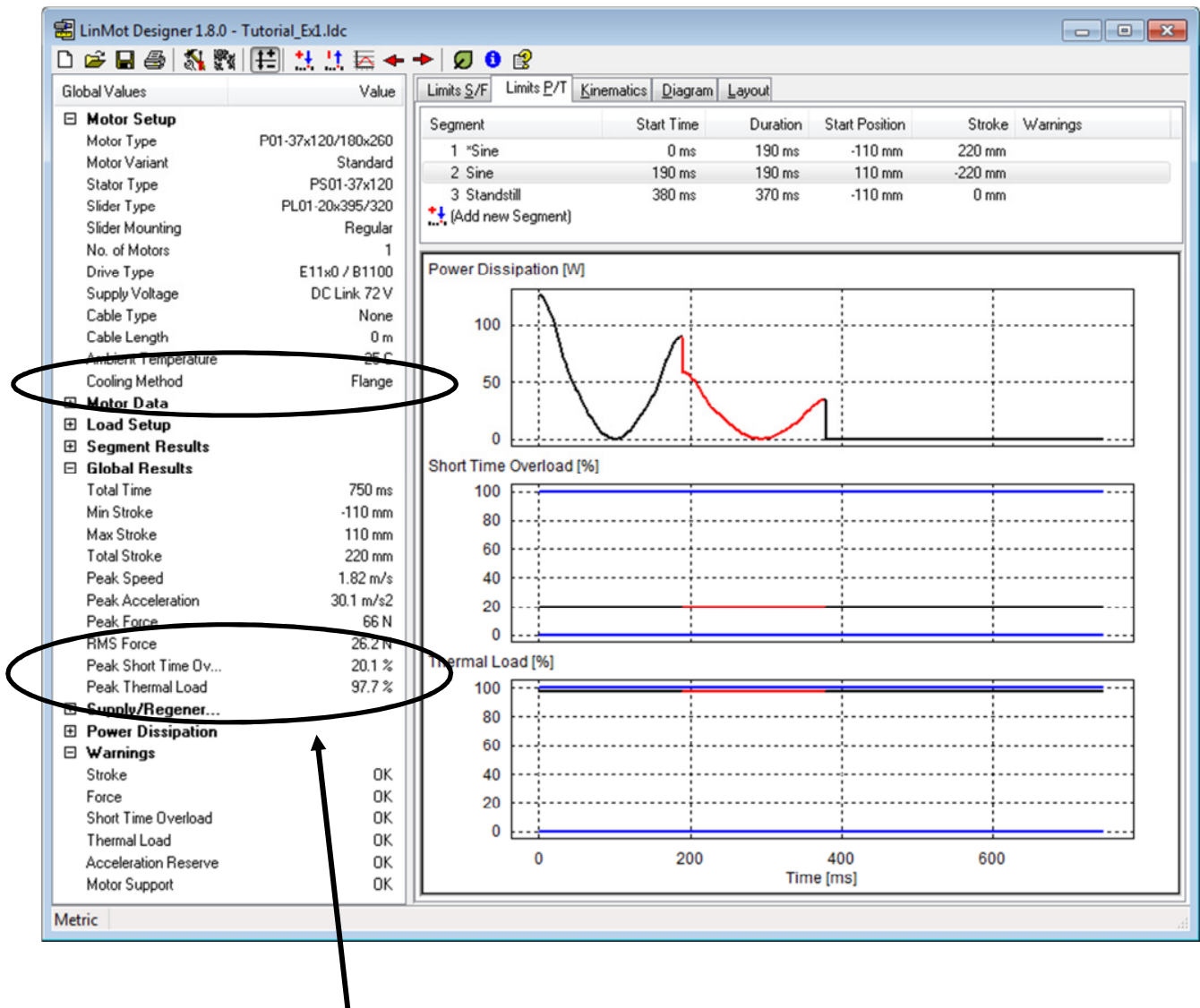
### Short Time Overload

The power losses in the motor coils, given by the Power Dissipation, will first heat up the motor winding prior to the other parts of the motor. A short time overload protection mechanism of the LinMot servo drives prevents the motors from overheating in case of rapid increasing winding temperature due to high power dissipation values. This parameter, the Short Time Overload Protection Value (black-red line) is independent from the motor cooling and approximately constant for short cycle times. The minimal value is 0% and the limit is at 100% (blue lines).

### Thermal Load

The power losses in the motor coils, given by the Power Dissipation, will heat up the motor. Depending on the ambient temperature and the cooling method, the corresponding Thermal Load (black-red line) of the motor will result. For short cycle times, the value will approximately be constant. The minimal value is 0% and the limit is at 100% (blue lines). At a Thermal Load of 100%, the thermal hardware protection would turn off the linear motor in the real application (at a case temperature around 65°C). To reduce the thermal load, use the more efficient cooling method (“Fan” in place of “Flange” at “Global Settings”) or use a motor with higher continuous force.

**Note:** The Short Time Overload Protection Value and the Thermal Load are calculated for the thermal steady state.



The Peak Short Time Overload Protection Value is definitely under the limit. The Peak Thermal Load is about equal to the limit, so the linear motor will not overheat in the application. If payload or friction will increase (or cycle time will be reduced), the Thermal Load will increase and exceed the limit. Then, the linear motor has to be mounted on a flange with fan cooling.

### Acceleration Reserve at Standstill

This acceleration parameter is the ratio between the “Max Force” of the drive system (servo drive & motor) and the moving mass. It’s a constant value within a segment. It changes from segment to segment with the change of the moving mass. This acceleration value has always to be bigger than the **limit of 10N/kg**. Concerning the example, for the Max Force value of 122N, the maximum moving mass is 12.2kg. In case of an Acceleration Reserve Warning, reduce the load mass or choose another motor/drive so that the Max Force value gets bigger.

### Step 4: Interactive Optimizing

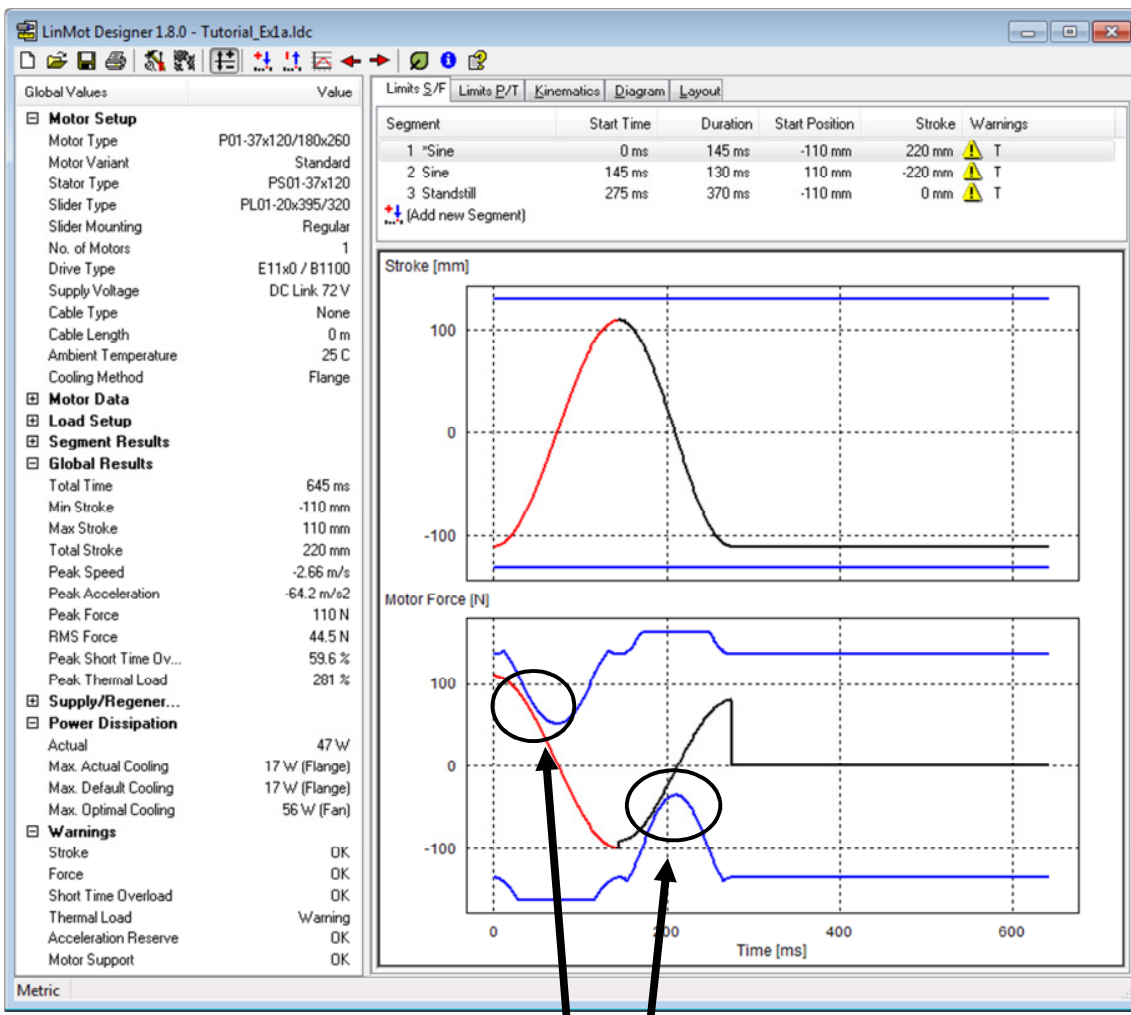
#### Motor and Servo Drive

Because no Warning was generated, a system with the selected linear motor type P01-37x120/180x260 and a servo drive of the Series E11x0 / B1100 with 72V supply will be the solution for this project.

In your LinMot Designer folder you will find the file “Tutorial\_Ex1.ldc” with the LinMot Designer data for this project.

#### Optimizing the motion time

If the application requires even faster cycles, the motion times can be minimized for the selected linear motor by reducing the time for the different segments. The time can be reduced as long as the force needed stays within the peak force limits from the selected linear motor.



Limiting parameters for minimal motion time

Minimizing the motion time in our example shows that the minimal times will be around 145ms for the forward (push) movement and 130ms for the backward movement.

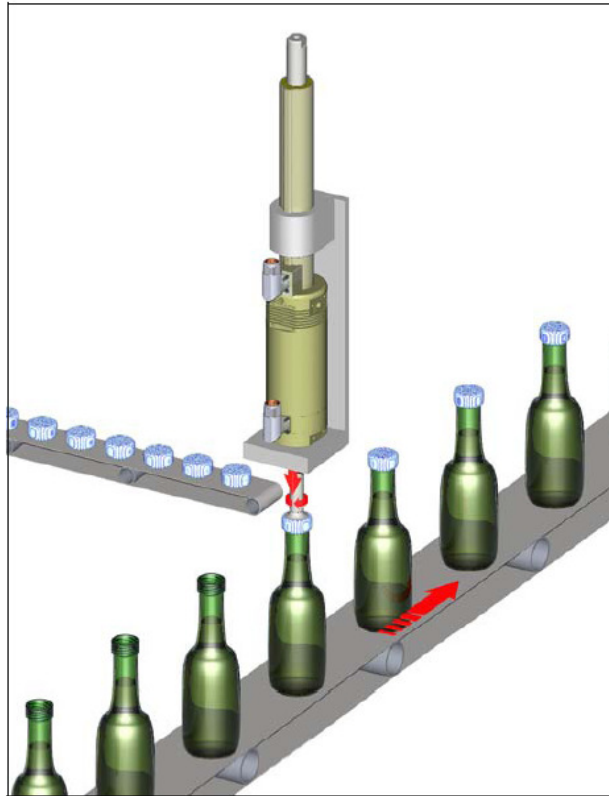
Reducing the time for the forward and backward motion will increase the Peak Thermal Load over the 100%-limit (281%), if the motor is mounted with the standard flange (Cooling Method: Flange). With a change of the Cooling Method to “Fan”, the Peak Thermal Load decreases under its limit to 84.4%.

With the Fan Cooling Method, we can then reduce standstill time to 280ms. This will result in a Peak Thermal Load of 98.1%, which is still within the motor limits.

In your LinMot Designer folder you will find the file “Tutorial\_Ex1a.ldc” with the LinMot Designer data for this project.

### Example 2: Rotating Movement

The following Example refers to an application for capping of bottles. To screw the cap on the bottle, a combination of a linear and a rotating movement is required, predestined to use a Linear-Rotary Motor of the LinMot series PR01. The linear motor P01 can be designed and checked analog to example 1. The rotary motor R01 is discussed here, the configuration is saved in "Tutorial\_Ex2.ldc".

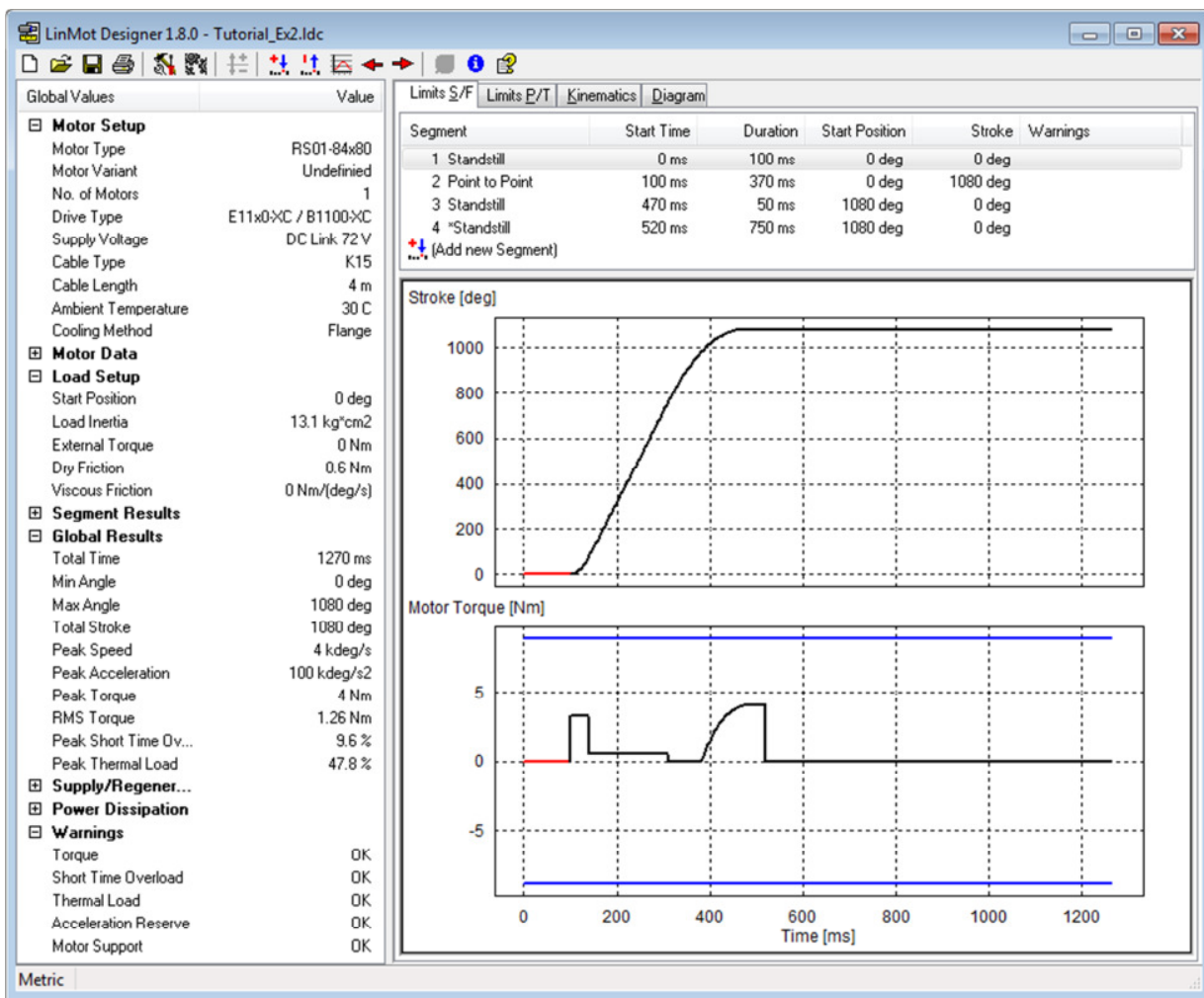


Cycle of the application:

- 1) Moving cap with capping head to the bottle thread (linear movement)
- 2) Screwing the cap on the bottle (linear and rotary movement)
- 3) Tightening the cap with increasing torque to an upper limit (linear and rotary movement)
- 4) Stop tightening, torque to zero (standstill)
- 5) Moving capping head back to start position (linear movement)


Requirements for rotary motor:

- T\_Cycle: **1.3s** (2'770 bottles/hour)
- T\_Screw&Tigthen: **< 0.5s**
- Stroke Screw&Tighten: **1080deg** (3 turns)
- Stroke Tighten: **100deg** (ca. 1/4 turn)
- J\_CappingHead: **13.1 kg/cm2**
- J\_Cap: **negligible**
- Friction torque: **0.6Nm**
- Max. tightening Torque: **4Nm**



**Segment and load definition**

- 1) **Standstill**  
No rotation, while the cap is moved linearly to the top of the bottle.
- 2) **Point to Point**  
Screwing process with a constant friction torque of 0.6Nm (global definition). During the tightening process at the last 100 degrees, the torque increases towards the limit torque of 4Nm. This behavior is simulated with a global spring:

Spring #1 Type:  Ref. Position:  Ref. Torque:  Spring Constant:  

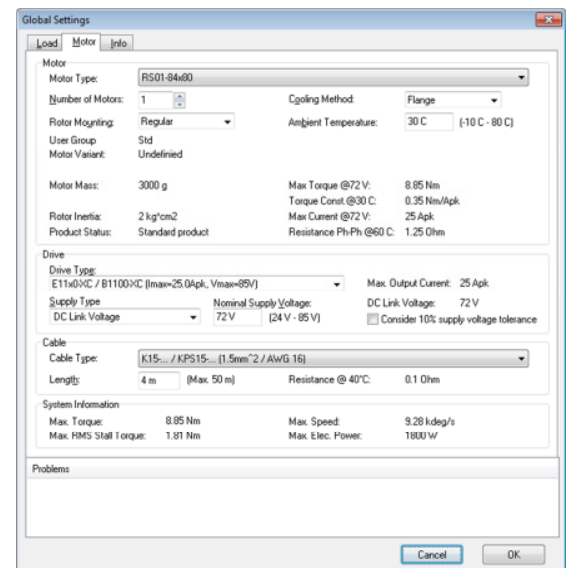
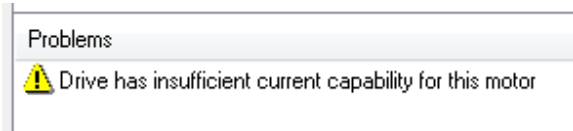
The Moment of Inertia of the capping head is defined in the Global Load Settings.

- 3) **Standstill**  
Keep the limit tightening torque of 4Nm for 50ms.
- 4) **Standstill**  
Release the tightening torque to zero by compensating the spring torque through an external torque of 4Nm in the segment. The duration of 750ms are used to move the capping head up linearly, to pick a new cap and to replace the capped bottle by an uncapped one.

## Definition of the motor system

The Motor Type RS01-84x80 is selected because of the required torque of 4Nm. The selected Drive Type is a XC-Type (25Apk).

For this application, also a HC-Drive Type (15Apk) could be used. The smaller max. current of the drive would result in a smaller but still sufficient peak torque of the system (5.3Nm instead of 8.8Nm). In that case, a warning is generated and showed in the Problems window.



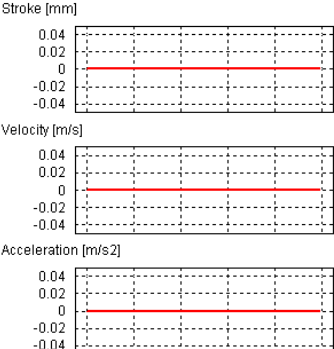
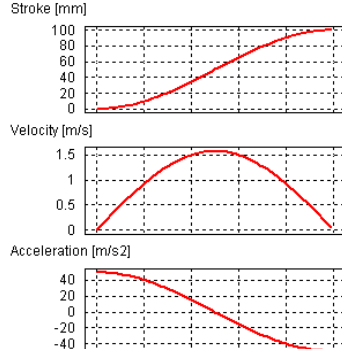
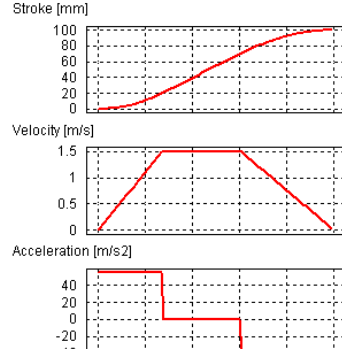
## Results

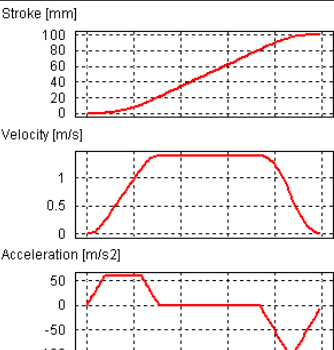
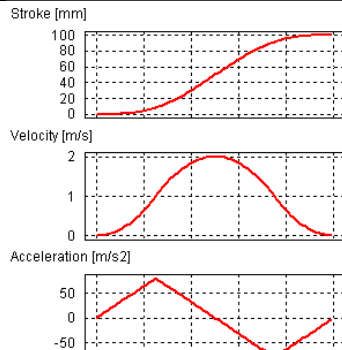
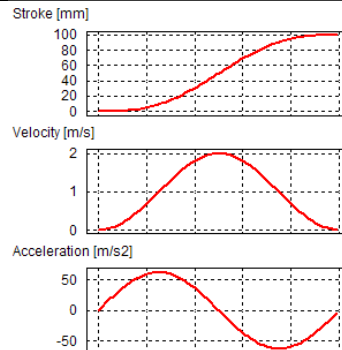
This simulation shows, that the rotary part of the application can be realized with the selected system. Even a HC-Drive would be sufficient. With a peak thermal load of ca. 50% at an ambient temperature of 30°C, the motor also won't work at its thermal limit. So, there is still potential to increase the speed of the capping process.



### Example 3: Importing custom Curves

To define the motion profile, LinMot Designer provides different curve types that can be defined by a few parameters:

<b>Standstill</b>	<b>Sine</b>	<b>Point to Point</b>
Parameters: <ul style="list-style-type: none"> <li>• Time</li> </ul>	Parameters: <ul style="list-style-type: none"> <li>• Time</li> <li>• Stroke</li> </ul>	Parameters: <ul style="list-style-type: none"> <li>• Stroke</li> <li>• Max. velocity</li> <li>• Acceleration</li> <li>• Deceleration</li> </ul>
		

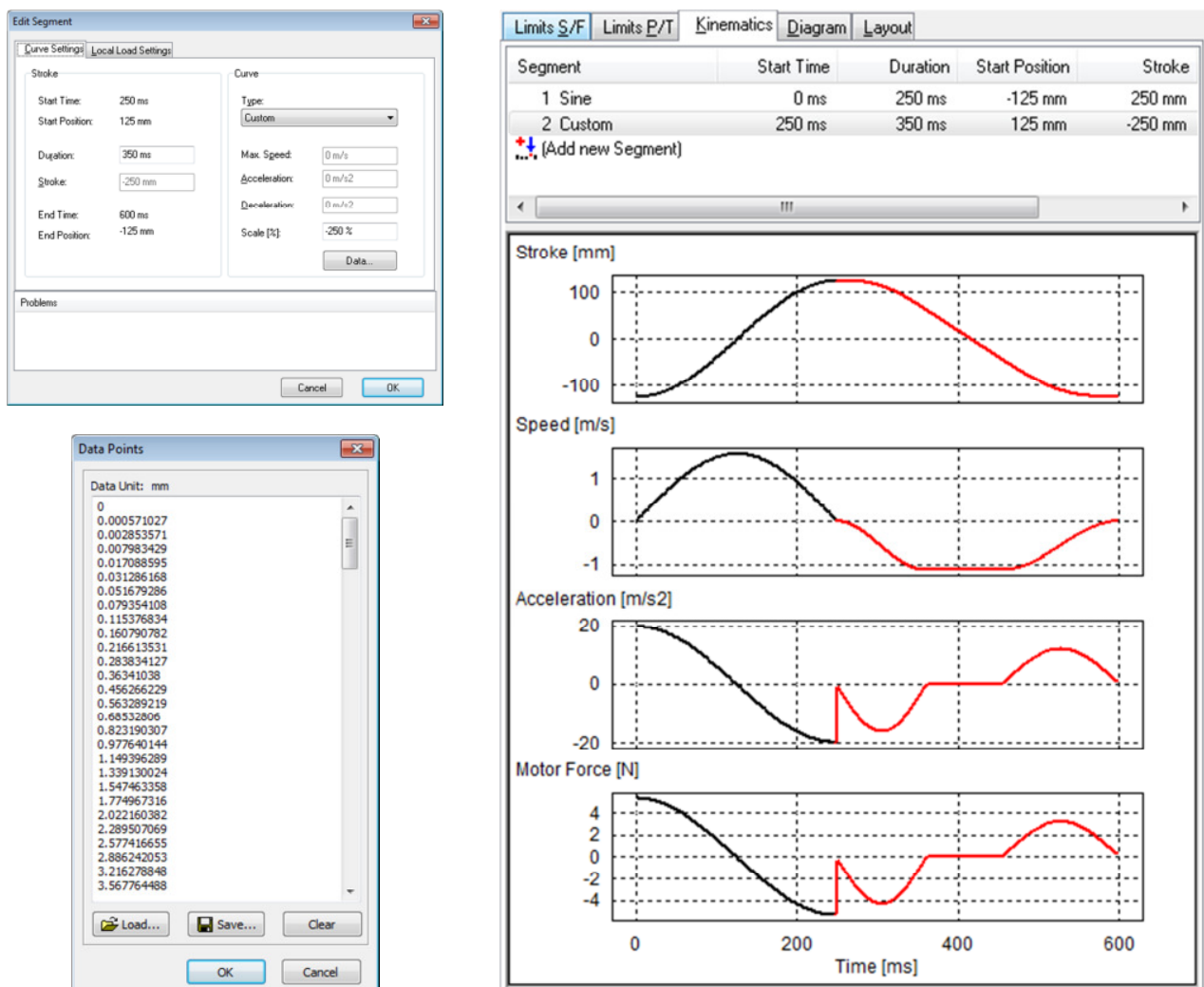
<b>Limited Jerk</b>	<b>Minimal Jerk</b>	<b>Besthorn</b>
Parameters: <ul style="list-style-type: none"> <li>• Stroke</li> <li>• Max. velocity</li> <li>• Max. acceleration</li> <li>• Max. deceleration</li> <li>• Jerk</li> </ul>	Parameters: <ul style="list-style-type: none"> <li>• Time</li> <li>• Stroke</li> </ul>	Parameters: <ul style="list-style-type: none"> <li>• Time</li> <li>• Stroke</li> </ul>
		



It is also possible to import a custom motion profile or just a segment of it into LinMot Designer. In order to do that, choose the **“Custom”** curve type. Open the **“Data Points”** window to define the custom position vector. There are two possibilities to do that:

1. **Load** the *csv-File*, where the numerical values of the position vector are saved.
2. **Copy** the vector from any other program and **paste** it into the Data Points window

The numerical data vector is interpreted in the data unit as it is defined under **“Measurement Settings”** of LinMot Designer. In the Curve Settings dialog box, the curve time and also a scale factor for the stroke have to be defined.



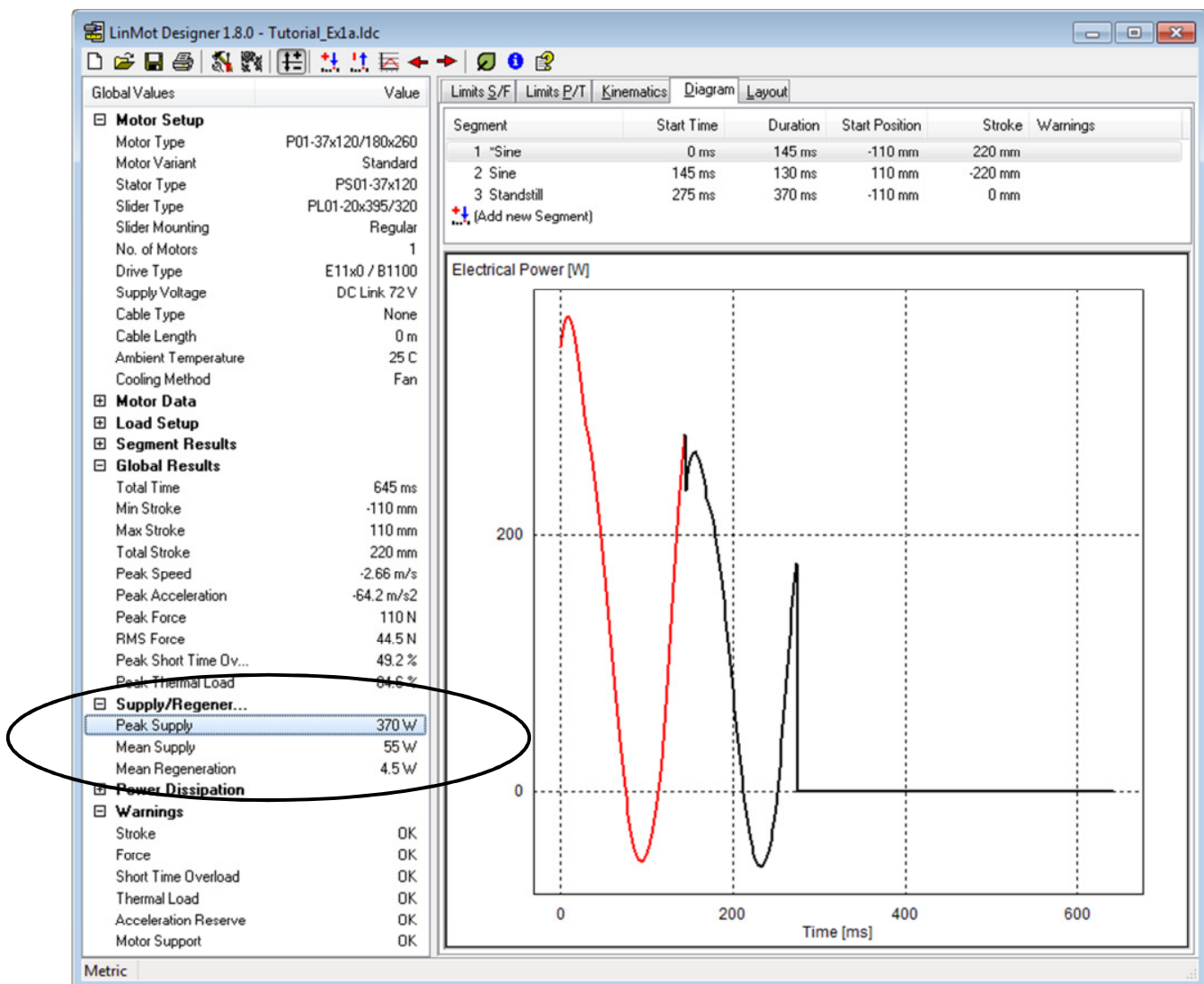
In **“Tutorial\_Ex3.ldc”** a Custom curve (Segment 2) follows on a Sine curve (Segment 1). The data vector of the custom curve was imported (loaded) from the csv-file **“Tutorial\_Ex3.csv”**. With a (negative) Scale value of **-250%**, the curve data points (forward motion from 0..100mm (in)) are scaled to a backward motion from 0..-250mm, starting at the end of Segment 1.

## Additional Information

### Power Supply

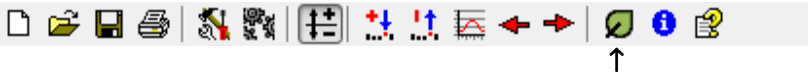
Power information to choose an appropriate power supply for the linear drive system can be found under **Supply/Regeneration**. The LinMot Designer calculates the required electrical power of the motor. The power supply has to deliver the electrical motor power added by the power loss of the drive, whereas the latter makes around up to 10% of the electrical motor power. Depending on the dc link capacitance, the electrical power waveform and the allowed temporary drop of the dc link voltage, the required power of the supply has to be between 110% of the Mean Supply value (absolute minimum) and 110% of the Peak Supply value. To go for sure, use a supply with a power above 110% of the Peak Supply value.

The regeneration power waveform (together with the dc link capacitance and the allowed raise of the dc link voltage) can be used to estimate, whether an external regeneration resistor is necessary. The waveform shows the generated electrical power of the motor during break phases.



## Efficiency (Linear Motor ↔ Pneumatic Cylinder)

The “Efficiency” tab can be shown/hidden by pushing the green leaf button in the menu bar and is only available for linear motor designs.



The “Efficiency” tab shows the required electric power as well as the electricity consumption, the CO2 emission and the energy costs per year for the defined application in case of continuous operation. The upper table shows the calculated values for the selected linear motor system. The lower table shows the values, if the defined application is driven by a pneumatic cylinder. The values are calculated for different standard diameters of pneumatic cylinders. The values can help to decide, whether a pneumatic driven application should be substituted by a linear motor.

The “Total Moving Distance per Cycle”, the “Total Cycle Time” and the “Electric Motor Power” of the linear motor are values from the current application. The “Total Moving Distance per Cycle” is calculated from the segment definition, the “Total Cycle Time” and the “Electric Motor Power” are copied from the “Global Values” window. The assumptions for the calculations are shown in the footnotes below the tables.

The content of the efficiency tab is only printed, if the tab is activated.

**Global Values**

Global Values	Value
Motor Setup	
Motor Type	P01-37x120/180x260
Motor Variant	Standard
Stator Type	PS01-37x120
Slider Type	PL01-20x395/320
Slider Mounting	Regular
No. of Motors	1
Drive Type	E11x0 / B1100
Supply Voltage	DC Link 72 V
Cable Type	None
Cable Length	0 m
Ambient Temperature	25 C
Cooling Method	Fan
Motor Data	
Load Setup	
Segment Results	
Global Results	
Total Time	645 ms
Min Stroke	-110 mm
Max Stroke	110 mm
Total Stroke	220 mm
Peak Speed	-2.66 m/s
Peak Acceleration	-64.2 m/s <sup>2</sup>
Peak Force	110 N
RMS Force	44.5 N
Peak Short Time Ov...	49.2 %
Peak Thermal Load	84.6 %
Supply/Regener...	
Peak Supply	370 W
Mean Supply	55 W
Mean Regeneration	4.5 W
Power Dissipation	
Warnings	
Stroke	OK
Force	OK
Short Time Overload	OK
Thermal Load	OK
Acceleration Reserve	OK
Motor Support	OK

**Efficiency and CO2 Emission** *calculated from segment definition*

Total Moving Distance per Cycle: 0.440m  
 Total Cycle Time: 0.645s

**Linear Motor (LinMot)**

Electric Motor Power (1) [W]	Electric Power (2) [W]	Electricity Consumption per Year (3) [kWh]	CO2 Emission per Year (4) [kg]	Electricity Costs per Year (5) [EUR]
55	91	728	364	87

1) Mean Supply Value calculated by LinMot Designer  
 2) Linear Motor plus Drive (+20%, +15W) and Supply (+10%)  
 3) Continuous operation (8000h/year)  
 4) CO2 Emission Factor: 0.5 kg/kWh  
 5) Energy Cost Factor: 0.12 EUR/kWh

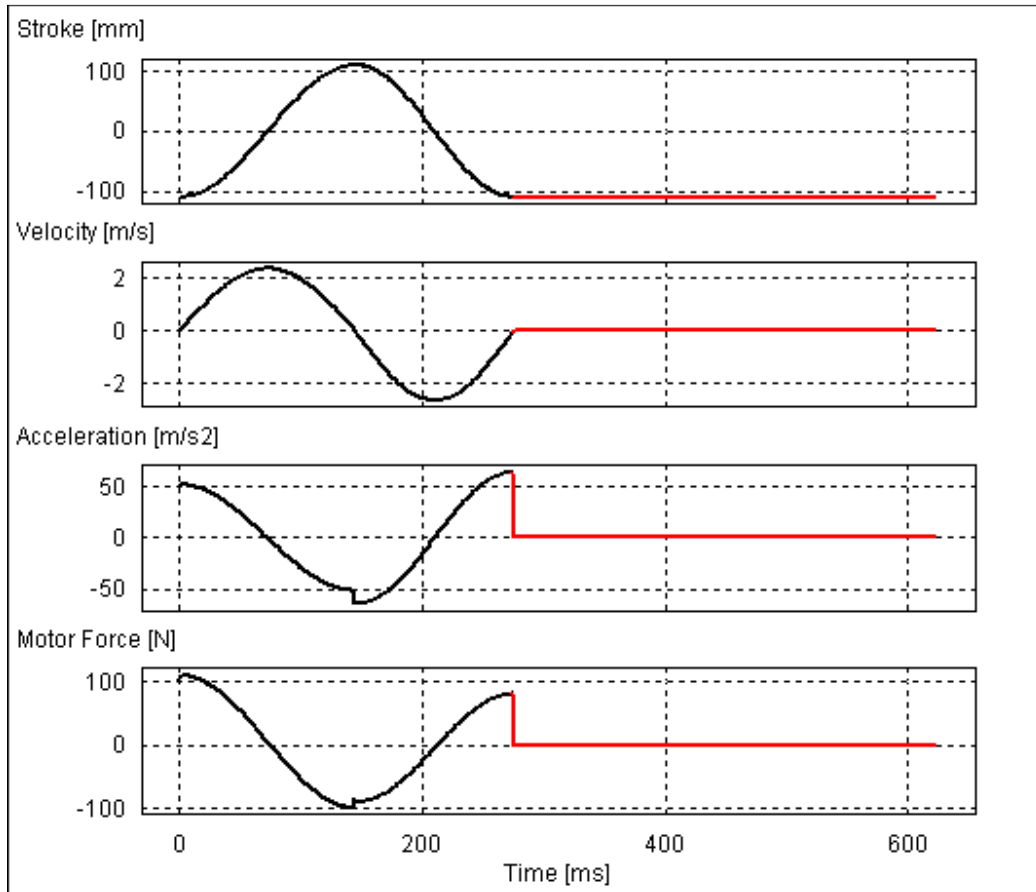
**Pneumatic Cylinder**

Air Piston Diameter [mm]	Air Consumption per Year (1) [Nm <sup>3</sup> ]	Electric Power [W]	Electricity Consumption per Year (2) [kWh]	CO2 Emission per Year (3) [kg]	Air Costs per Year (4) [EUR]
10	11'881	176	1'404	702	270
12	17'109	253	2'022	1'011	389
16	30'416	449	3'595	1'797	691
20	47'525	702	5'617	2'808	1'080
25	74'258	1'097	8'776	4'388	1'688
32	121'665	1'797	14'379	7'189	2'765
40	190'102	2'808	22'467	11'233	4'320
50	297'034	4'388	35'104	17'552	6'751
63	471'571	6'966	55'731	27'866	10'718
80	760'407	11'233	89'866	44'933	17'282
100	1'188'136	17'552	140'416	70'208	27'003

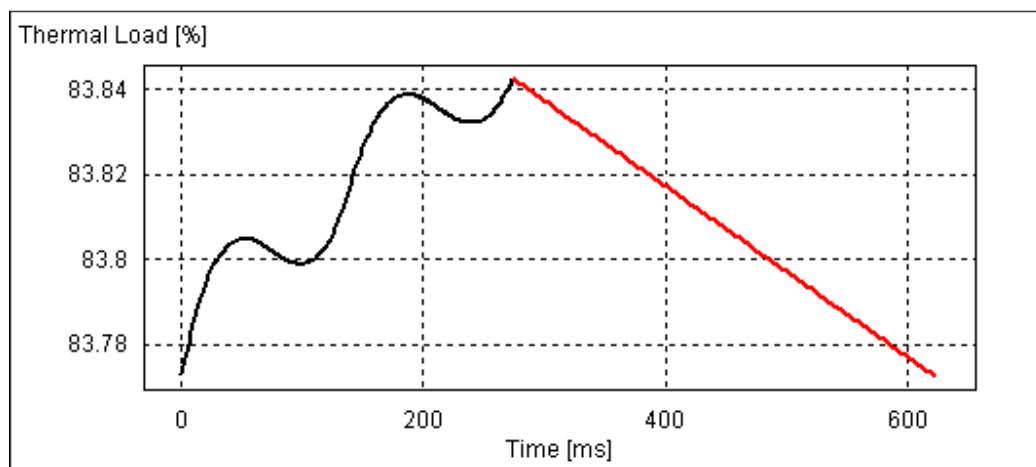
1) Air Pressure: 6 bar, continuous operation (8000h/year), leakage and distribution losses: 10%  
 2) Electricity Consumption Factor: 0.13 kWh/Nm<sup>3</sup>  
 3) CO2 Emission Factor: 0.5 kg/kWh  
 4) Air Production Cost Factor: 0.025EUR/Nm<sup>3</sup> (According to pneumatic suppliers, including electricity costs)

### Time Graphs

In the “**Kinematics**” tab, time graphs of the stroke, velocity, acceleration and motor force give an overview of the motion.

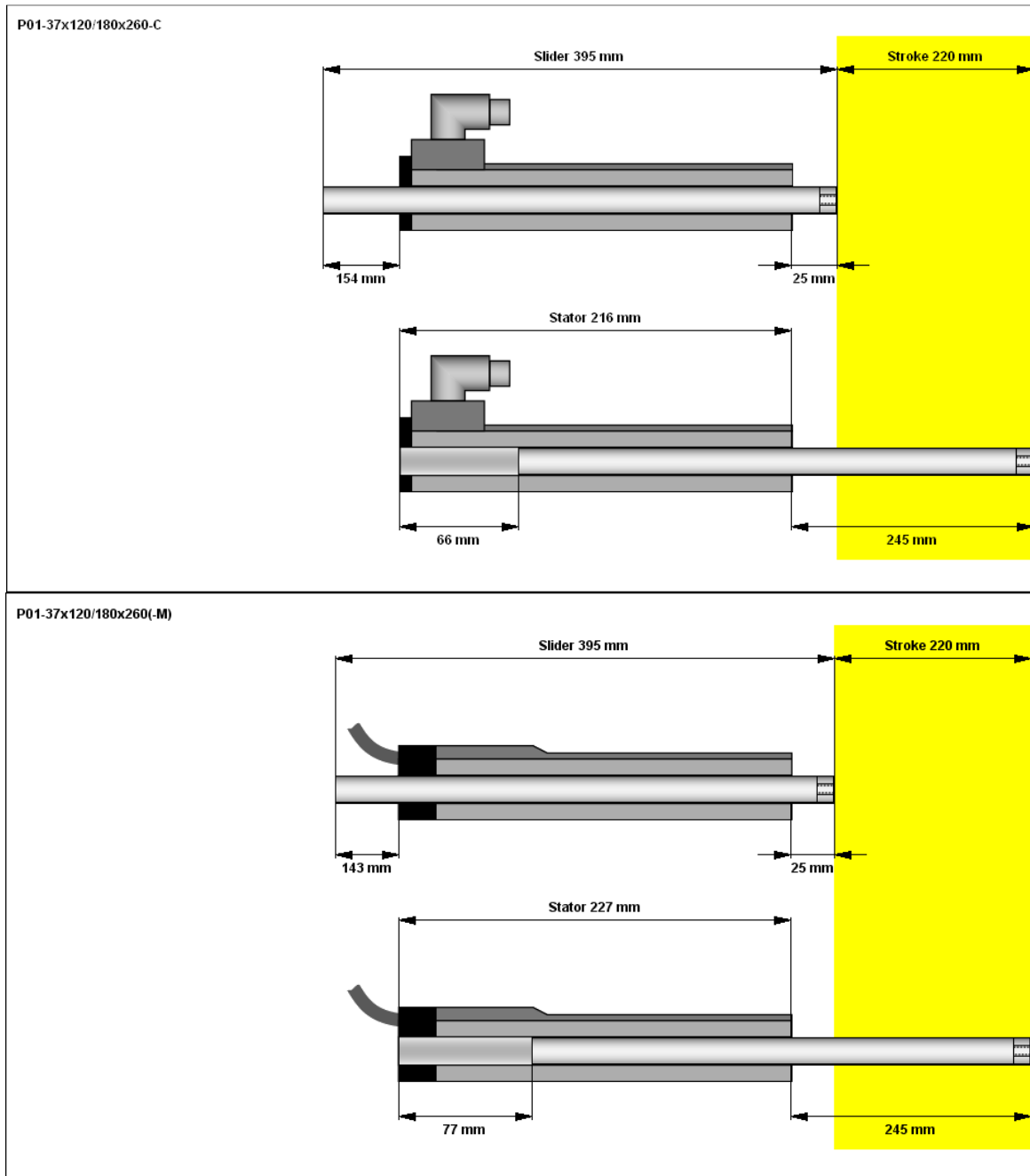


In the “**Diagram**” tab, any calculated parameter can be by double clicking a corresponding characteristic value in the “Global Values” window (e.g. min, max, peak, rms, mean values).



### Layout

The “Layout” tab shows you the mechanical dimension of the Linear Motor and the end positions for the different types of motors. The Layout is dependent on the “Layout Motor”-parameter and the “Slider Mounting”-parameter in “Global Settings”.



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