How to tune the servo loop

(short practical guide for tuning)

Section from the User Manual
Release 1.3.16

1. Tips and Tricks for the controller

1.1 Introduction

This section enlarges upon tips and tricks for the new controller in textual form, without going into the complicated theory. It cannot and does not intend to impart theoretical knowledge for adjusting the controller. The interested user who likes to wrestle with theory is advised to consult the relevant literature.

The following picture shows the structure of the controller. The words printed with italic letters announce parameters which can be adjusted. Basically it is a PID-Controller with Feed-Forward structures and an additional v/a-Limiter for the prefiltering of the reference signal. As an option there is a profile generator integrated.

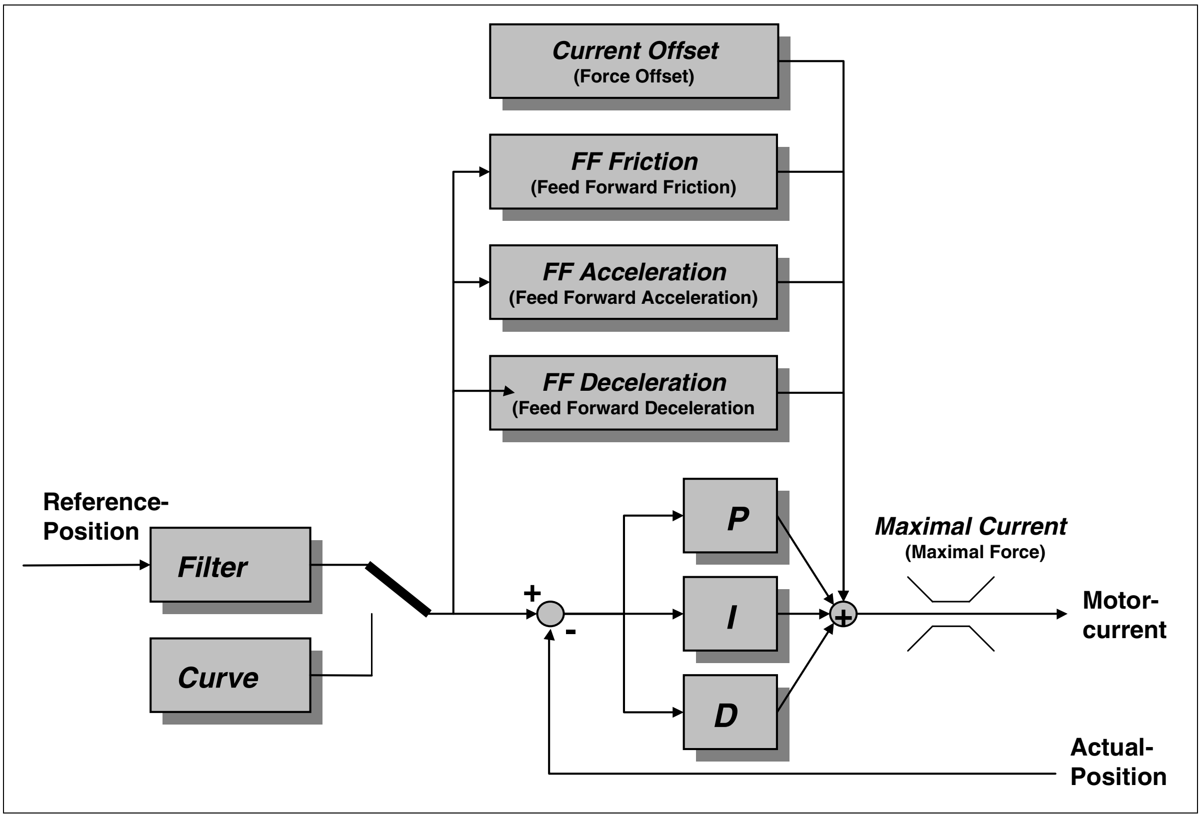

Figure 1-1: Structure of the controller

The default setting of the controller parameters is suitable for operating the motors under a lot of normal conditions. Specially if the load mass exceeds that of the slider by factors, or when using motors with long sliders, the controller should be adapted to this duty. Adapting the control parameters is advisable also if major friction forces occur or highly dynamic movements are demanded from the motor.

It is important to follow exactly the following guide lines. Tuning without following proper rules is nearly impossible or needs a lot of time.

1.2 Selection between PD- or PID- Controller

PD-Controller

A PD controller is one working with only proportional and derivative action (I=0). This type of controller is simple to adjust and has a very robust behaviour. Its disadvantage is that any static deviations present are not corrected automatically

PID Controller

A PID controller works with proportional, integral and derivative control. This kind of controller corrects automatically any static controller deviations by virtue of its I action. The disadvantage of this controller is that system oscillations may occur. When adjusting the controller the values may be taken over from the PD controller, and the I term increased slowly. The higher the I term is set, the faster the controller will correct any position deviations occurring. An overlarge I term may lead to instabilities in the control behavior however. With high load masses a small I term is advisable thereof

1.3 Adjusting of the prefilter (Filter)

The prefilter limits the max acceleration and velocity to the goal of the user. Using the prefilter it is possible that a PC or PLC can send a rectangular position jump but the motor moves smoothly, limited by the max acceleration and velocity. Basically the reference signal is not allowed to change 'faster' than the motor can follow! <u>The right set up of the prefilter is more important than the optimal tuning of the controller!</u>

Which max velocity and acceleration a motor can reach depends in a complex way with the parameters of the application (mass, friction, profile, amplifier, ...). It is proposed that the user simulates the application with the program *LinMot*® Designer (see LinMot CD or www.linmot.com) to calculate the possible max values. In the case of using profiles the prefilter is switched off. Max values for acceleration and velocity must be observed during the creation of the profiles.

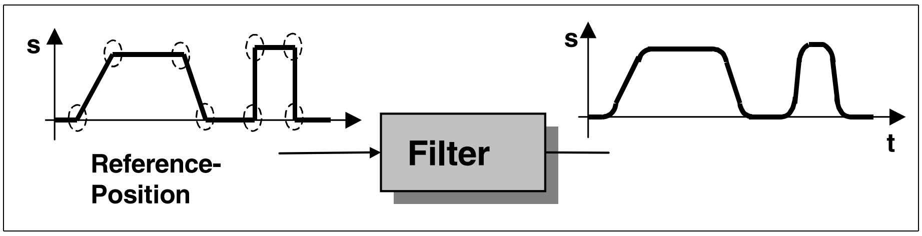

Figure 1-2: Reference signal before and after Filter

1.4 Using profiles for reference position

Using a mode which is based on profiles it is important to realize the following 4 points:

a) the motor must be able to fulfill the profile based on the maximal possible velocity and accelerations. The profile should not change faster than the motor is able to follow. It is proposed that the user simulates the application with the program *LinMot*® Designer (see LinMot CD or www.linmot.com) to calculate the possible max values.

b) All profiles should be smoothed. No jump in position or velocity is allowed. Use sine or hyperbolic functions while generating ramps which are offered by the Curve Inspector of *LinMot*® Talk.

c) Accept the number of points which are proposed by the “Curve Inspectors’ of *LinMot*® Talk (use Release 1.3.9 or higher). If the movement sounds ‘raw and hard’ reduce (!) the number of points!

d) If the profile will be produced by a third party program the following rules should be used: every profile should consist at least of 16 points but the time between the points should not be shorter than 1 ms (if there is a position step of 20 mm in 14 ms the number of points should be 14). In any other cases the distance between the points should be about 5 ms.

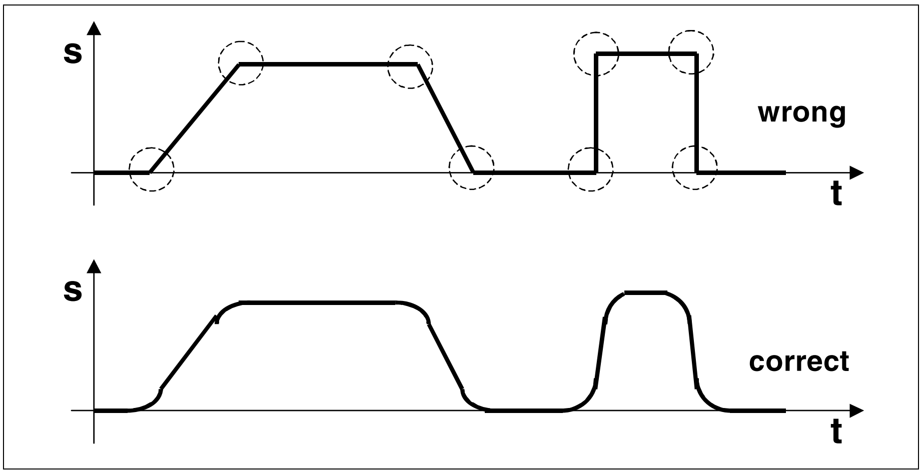

Figure 1-3: Profiles must be ‘smoothed’

1.5 Adjustment of the Feed-Forward Parameters

The term **Feed Forward** is used in control engineering to imply the anticipatory calculation of a control variable. This **anticipation** enables the controller to respond much better to the problem faced. When the controller **knows** that there is high friction in the system and knows the coefficient of friction, it can provide in advance the current necessary for a desired forward motion in order to overcome this friction. There is then much less discrepancy from the outset between the actual and target positions.

The controller integrated in the *LinMot*® servo controller includes these three anticipatory parameters with which the control behavior and hence the attainable dynamics can be improved

FF Friction

With the **FF Friction** parameter the sliding friction of the system can be compensated. Its value may be calculated as follows:

FF Friction = F_{FR} / c_f	FF Friction	Feed forward friction [A]
	F_{FR}	Sliding friction [N]
	c_f	Force constant motor [N/A]

where F_{FR} is the sliding friction and c_f is the force constant of the chosen motor.

Tip:
FFR can be measured with a spring scale (disconnect motor) and the value for the force constant cf can be read from the data sheets. In applications with long strokes it is also possible to measure the current during the constant movement with the scope. This measured motor current is exactly the value of FF Friction.

FF Acceleration

The parameter **FF Acceleration** helps the controller when accelerating by providing in anticipation a current proportional to the acceleration demanded. This parameter should be used wherever very fast and dynamic movements are needed, or where big load masses are connected. The value of this parameter can be calculated as follows:

FF Acceleration = (m / c_f)	FF Acc.	Feed forward [mA/(m/s^2)]
	m	Moved mass [g]
	c_f	Motor force constant [N/A]

where m is the moved mass (load mass + slider or stator mass) and c_f is the force constant of the chosen motor. The value for the force constant c_f can be read from the data sheets.

FF Deceleration

This parameter is the counterpart to **FF Acceleration** and is used for anticipatory control of the current while the motor is being braked. The value of this parameter can be calculated as follows:

FF Deceleration = (m / c_f)	FF Dec.	Feed forward [mA/(m/s^2)]
	m	Moved mass [g]
	c_f	Motor force constant [N/A]

where m is the moved mass[1] (load mass + slider or stator mass) and c_f is the force constant of the chosen motor. The value for the force constant c_f can be read from the data sheets.

1.6 Adjusting of the Current Offset

Current offset with horizontal moves

For applications with horizontal moves the circumstances for the forward and backward movement are identical and the parameter **Current Offset** should be zero.

Current offset with vertical moves

In applications with vertical moves the weight of the load mass leads to an asymmetrical controller behavior for the up and down moves. With the parameter **Current Offset** in the directory **\Drives\Drive X\Control Parameters** this asymmetry may be compensated. The value may be computed as follows:

Current offset= $(m * g) / c_f$	m	Load mass [kg]
	g	Gravitation 9.81 m/s^2
	c_f	Motor force constant [N/A]

The mass m is the moved mass (load mass + slider or stator mass). The force constant c_f can be read from the data sheets. The sign of the parameter **Current Offset** depends on the direction of the mounting. If the cable exit is in direction to the floor then the sign is positive otherwise its negative.

1.7 The Tuning Tool

The Tuning Tool was introduced in the software Release 1.3.10. It helps the user to calculate and set the **Feed Forward Parameters** and the **Current Offset** without need of reading the motor data sheet. The Tuning Tool is started by clicking the button “Show Tuning Tool” in the Parameter Inspector (see Figure below).

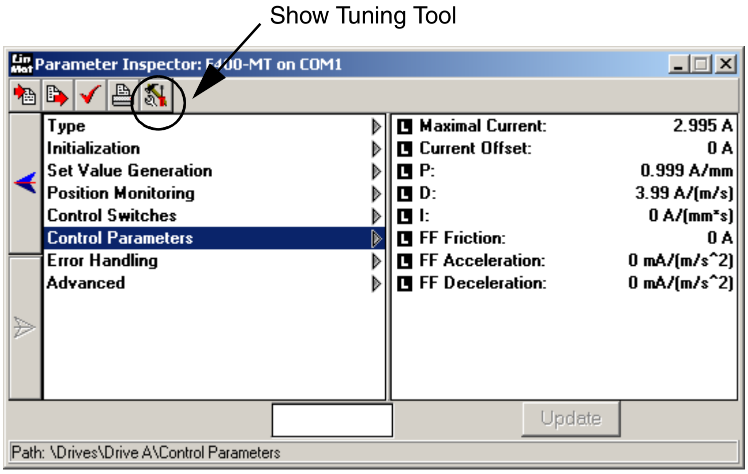

Figure 1-4: Parameter Inspector

Example: Using the Tuning Tool

A linear motor **P01-37x240/60x260** in vertically mounted (positive direction opposite to the gravity force) and moves a load mass of **1.2 kg** attached to the slider. The linear motor has a force constant c_f of 40.8 N/A and the slider mass is 829 g. This sums up to a moved mass of 2029 g.

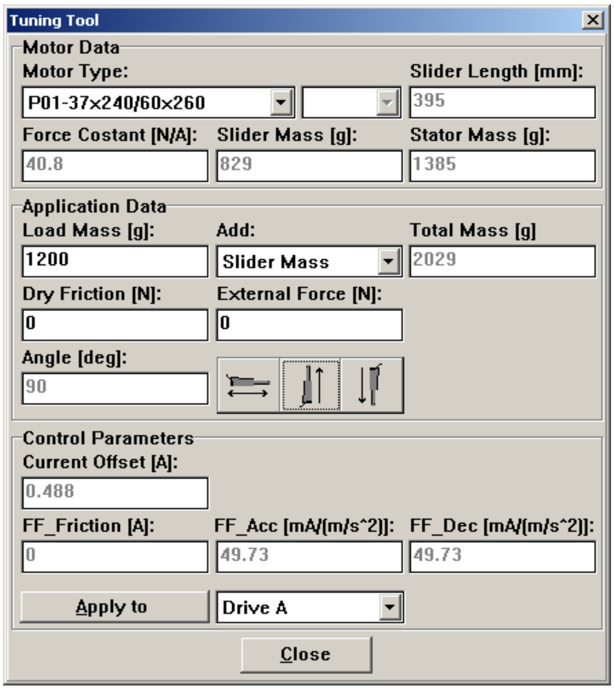

Figure 1-5: The Tuning Tool

Motor data

In the “Motor Type” pop-up menu select your motor type. If you have a special motor “F” (Fast type) or “S” (Short type) you can specify this in the pop-up menu on the right side of the motor type field. The slider length, slider mass, stator mass and force constant will be displayed.

Note:

If your motor is not in the motor type list then select the type “Other ...” and set the Force Constant, the Slider Mass and the Stator Mass in the appropriate fields (in this case you have to look up these values from the data sheet).

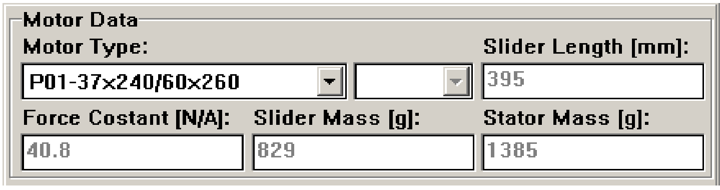

Figure 1-6: Choose the motor type

Application data

Set the load mass in the “Load Mass” field and select in the “Add” pop-up menu the moving part of the motor. The mass of the moving motor part will be added to the load mass. The total mass will be displayed in the “Total Mass” field. Set the dry friction in the “Dry Friction” field. If any external constant force exists (like MagSpring) set its value in the field “External Force”. The sign of this force is positive if it is in the same direction as the positive position direction of LinMot otherwise it is negative (see Figure 1-8, “Positive direction of LinMot motor”). Set the direction of the movement by clicking on the appropriate button. (see Figure 1-7, “Set application data”).

Note:

If there are more motors working in parallel in the master/booster or gantry mode, add the load mass and the mass of the moving part of all motors together and then divide this value by the number of motors. Set the resulting value in the “Load Mass” field and select “None” in the “Add” pop-up menu. With this method you can calculate and set the FF Parameter and the Current Offset for the master motor and all motors used for gantry!

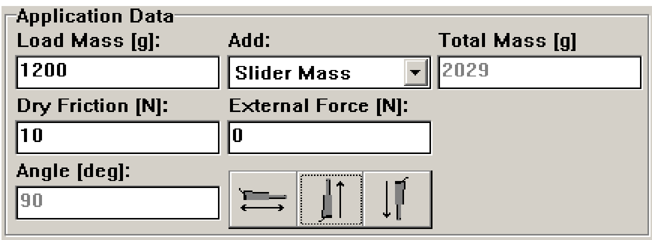

Figure 1-7: Set application data

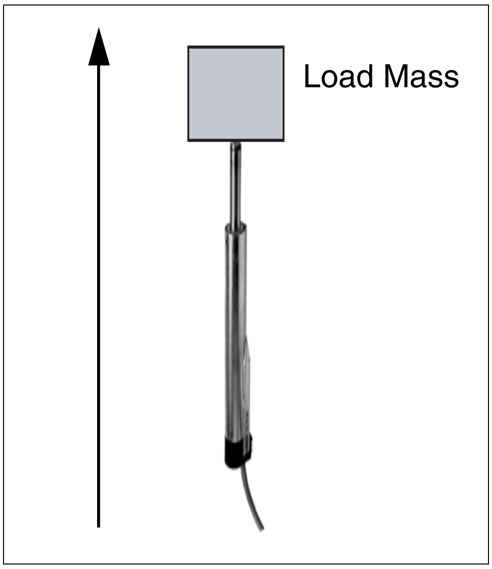

Figure 1-8: Positive direction of LinMot motor

Resulting control parameters values

The calculated values for the Feed Forward Parameters and the Current Offset will shown in the “Control Parameters” group (see Figure 1-9, “Resulting control parameters”). To take these values for the motor select the drive in the pop-up menu and press the button “Apply to”. If you are connected with a Controller these values will be written into it and they take immediately effect (live parameters).

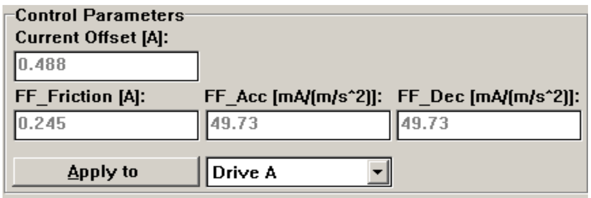

Figure 1-9: Resulting control parameters

Tip:

If the mass of an application is not known, the following method can be used: Stop the motor on a certain position. Reading out the needed motor current using the scope or reducing the max current down to the point where the motor can not longer hold the position.

1.8 Configuration of the max Current

The maximal current may be set with the parameter **Maximal Current** in the directory **\Drives\Drive X\Control Parameters**. The following values should be used

	Series E100		Series E1000 / E1001	
Motor type	**24 V Supply**	**48 V Supply**	**48 V Supply**	**72 V Supply**
P01-23x80/…	2.0 A	3.0 A	3.0 A	3.0 A
P01-23x160/…	1.0 A	2.0 A	2.0 A	2.8 A
P01-37x120/…	—	3.0 A	6.0 A	6.0 A
P01-37x240/…	—	3.0 A	3.3A	5.0 A

If smaller values are used the peak force according to the data sheets is reduced. Bigger values lead to unstable operation. Note that the current range of the E100 Servo Controller Series has to be switched (**\Drives\Drive X\Control Switches)** as well to adjust the max current.

1.9 Basic set up parameters for the Controller

The following settings can be used for general applications. Note that the current range of the E100 Servo Controller Series has to be switched (**\Drives\Drive X\Control Switches)** as well to adjust the max current.

	PS01 - 23x80	PS01-23x160	PS01-37x120	PS01-37x240
Max Current	2.99 A	2 A	2.99 A	2.99 A
Current Offset	0 A	0 A	0 A	0 A
P	1 A/mm	1 A/mm	1 A/mm	1 A/mm
D	4 A/(m/s)	4 A/(m/s)	4 A/(m/s)	4 A/(m/s)
I	0 A/(mm*s)	0 A/(mm*s)	0 A/(mm*s)	0 A/(mm*s)
FF Friction	0 A	0 A	0 A	0 A
FF Acceleration	0 mA/(m/s^2)	0 mA/(m/s^2)	0 mA/(m/s^2)	0 mA/(m/s^2)
FF Deceleration	0 mA/(m/s^2)	0 mA/(m/s^2)	0 mA/(m/s^2)	0 mA/(m/s^2)
Filter max Speed	0.781 m/s	0.781 m/s	0.781 m/s	0.781 m/s
Filter max Accel.	30.5 m/s^2	30.5 m/s^2	30.5 m/s^2	30.5 m/s^2
Control Switches	3 A	3 A	3 A	3 A

Figure 1-10: Basic set up for E100 Controller with 48V supply

	PS01 - 23x80	PS01-23x160	PS01-37x120	PS01-37x240
Max Current	4 A	2.8 A	6 A	5 A
Current Offset	0 A	0 A	0 A	0 A
P	1 A/mm	1 A/mm	1 A/mm	1 A/mm
D	4 A/(m/s)	4 A/(m/s)	4 A/(m/s)	4 A/(m/s)
I	0 A/(mm*s)	0 A/(mm*s)	0 A/(mm*s)	0 A/(mm*s)
FF Friction	0 A	0 A	0 A	0 A
FF Acceleration	0 mA/(m/s^2)	0 mA/(m/s^2)	0 mA/(m/s^2)	0 mA/(m/s^2)
FF Deceleration	0 mA/(m/s^2)	0 mA/(m/s^2)	0 mA/(m/s^2)	0 mA/(m/s^2)
Filter max Speed	0.781m/s	0.781m/s	0.781m/s	0.781m/s
Filter max Accel.	30.5 m/s^2	30.5 m/s^2	30.5 m/s^2	30.5 m/s^2

Figure 1-11: Basic set up for E1000 / E1001 Controller with 72V supply

1.10 Tuning of the controller

There are many very different ways of adjusting a PID controller. The following method has acquitted itself in practice:

1 Set phase current parameters according to chapter ‘Configuration of the max Current” on page 10

2 Set the filter parameters according to chapter ‘Adjusting of the prefilter (Filter)” on page 3 or create a profile according to chapter ‘Using profiles for reference position” on page 4

3 Set feed forward parameters according to chapter ‘Adjustment of the Feed-Forward Parameters” on page 5

4 After these two steps the following parameters in the list **\Drives\Drive X\Control Parameters** have to be set:

P = 0.25 A/mm D = 2.00 A/(m/s) I = 0.00 A/(ms)

5 Now the desired motion profile can be loaded. Then the motor has to be started in the **Continuous Curve** mode.

6 Now increase the parameter **D** by 1.0 until the motor begins to oscillate. Then reduce the D value to 60%.

7 Now increase the parameter **P** by 0.25 until the motor begins to oscillate. Then reduce the P value to 80%.

8 The parameter **I** should only be set if the steady state position difference between the actual and demand position in standstill is to big.
To set the parameter **I** increase the value by 5.0 until the steady state position difference is minimized and at the same time there is no overshoot when accelerating or decelerating.

1.11 Checking results

Correct adjustment of the controller is best verified with the oscilloscope integrated in the *LinMot®* talk software. Of prime importance is the comparison between the actual position and the target (demand) position.

In addition it is a good idea to check the required motor current with the scope. If the motor current stays in its limitation for to long it is a signal that the motor is overloaded and therefore proper tuning is not possible.

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