Filter design for the APCI-8001 and APCI-8008 for the regulation of torque-controlled drive systems

The present Application Note shows how you can determine the PID filter parameter for the motion control boards APCI-8001 and APCI-8008 when using current controlled (torque-controlled) drive systems.
In **speed-controlled** drive systems the determination of filter parameters can be calculated experimentally quite simple, as the parameters Kp and kfcv can be set independent from each other experimentally and afterwards can be composed. And later, an integral part (Ki) can be added. This value is determined also experimentally, without changing the previously determined values for Kp and kfcv. With the speed controller, the parameters Kd, kpl and kfca are usually not required and stay on the value 0.
However, in a **current-controlled** system this procedure is not so simple. For the regulation of a current-controlled drive system at least one controller with PD characteristics is required. Especially, Kp and Kd influence each other. In practice, the acceleration pre-control (kfca) and an integral part (Ki) are required. By the alternating influence from Kp on Kd and vice versa, the single parameters cannot be determined experimentally in such a simple manner.
In order to simplify the setting of the bearing control loop in current-controlled drive systems, the program mcfg.exe was equipped with the functionality described in the following. This procedure is not possible in speed-controlled drive systems.

Version notes and requirements

The following described procedure is only valid under use of the following or more recent software versions:

mcfg.exe	V2.5.3.36
rwmos.elf	V2.5.3.31
mcug3.dll	V2.5.3.23

For the successful comprehension of the following description, it is required that the user knows to handle the program *mcfg.* He shall know to realise the following points:

- How to realise a set value jump onto the drive system with the “Motion-Tool-Window”.
- How to start a traversing profile
- How to indicate a traversing movement with the window „Graphic Analysis“

Furthermore, the user shall be aware of that sometimes axes are traversed not regulated and that therefore it is possible at any time that, e.g., due to a wrong entry, unexpected traversing movements occur. Therefore, it must be proved that the respecting motor can turn freely and that a “Stop” is possible at any time via emergency stop or other devices.

What is a current-controlled drive system?

In a current-controlled drive system, the current amplifier has the function of a current controller (no speed controller). Therefore, usually no return of the speed real value is required (no tacho signal) here.
The set value input of the power electronics is like an armature current. As in servo motors the torque is proportional to the armature current, a system controlled in this way is also called torque-controlled drive system.
In order to apply the following described procedure, it must be ensured completely, that you have a current-controlled drive system. In speed-controlled drive systems, this method of filter parameter determination cannot and must not be applied.

Recording a step response of a drive system

The filter parameter calculation for current-controlled drive systems is based on the evaluation of the step response of the drive system. The step response marks the behaviour of the drive, if this is controlled by a jump of the manipulated variable (e.g. 1 Volt for 1 second).
In order to record the step response, a “Graphic Analysis Window” and a “Motion Tools Window” must be opened for the corresponding axis, e.g. according to Figure 01. The axis may be not locked by missing amplifier release, emergency stop conditions or other I/O conditions. Now the output jump is defined in the “Motion-Tools” window (in Figure 01, e.g. 1V for 1s).

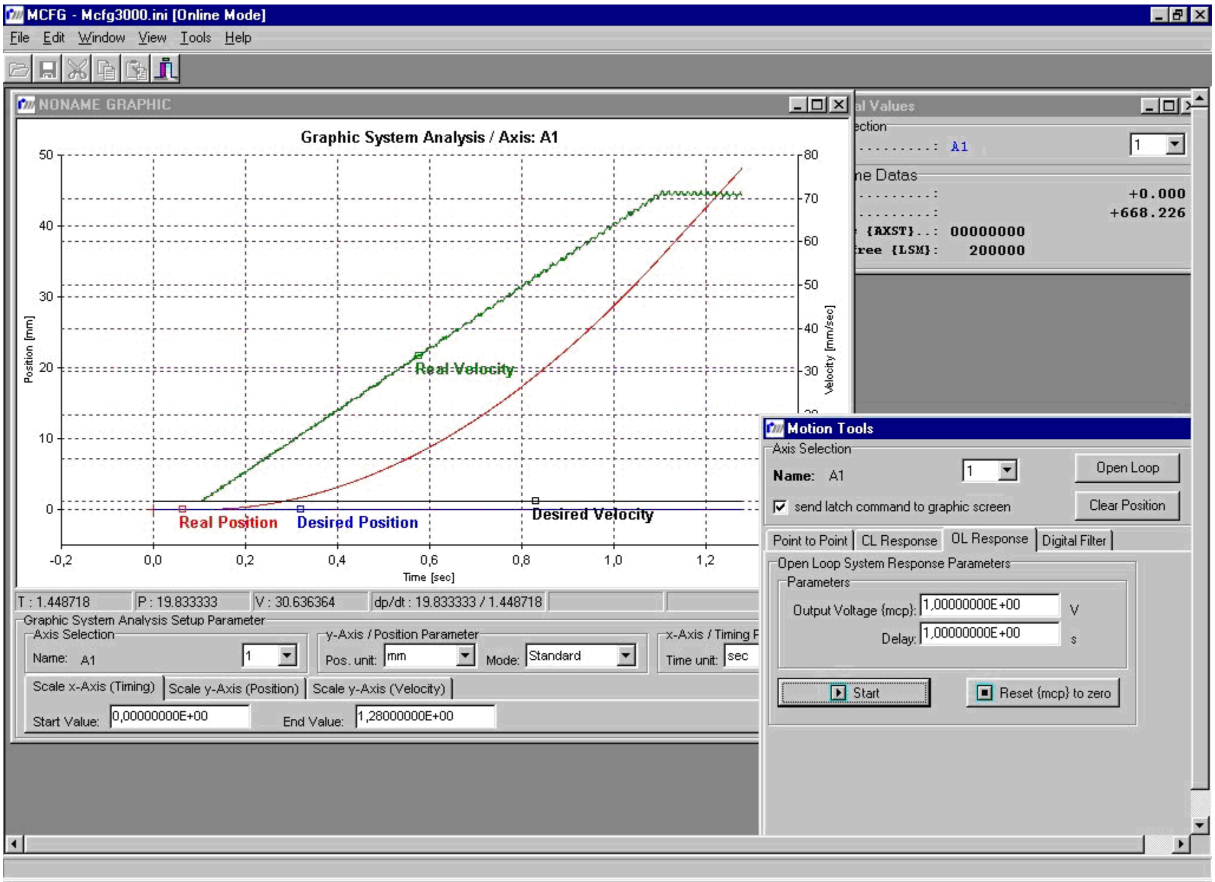

Figure 01: Step response of a current-controlled drive system in mcfg

- Click with the left mouse key on the start button in order to start the output and recording process.

Please note that when recording the step response (OL Response), firstly (at the time 0), the system sets possible defined outputs for the amplifier release (PAE). Firstly after 100 ms the control releases the predetermined voltage value for the predetermined period. Then the amplifier release is immediately withdrawn.

- Click with the right mouse key into the graphics window and select the menu “Update Screen” in order to make the recorded axis movement visible. can be shown be clicking with the r

In a current-controlled drive system a figure similar to Figure01 shall appear. One characteristic for the recorded step response is the linear increase of the real velocity and the parabolic increase of the real position. The range for the increase of the real velocity is limited by the duration of the set value output and by reaching the maximum velocity of the drive.

Step response of a speed-controlled drive system

In order to inform the user more detailed about the difference between current-controlled and speed-controlled systems, the following figure shows the step response of a speed-controlled system.

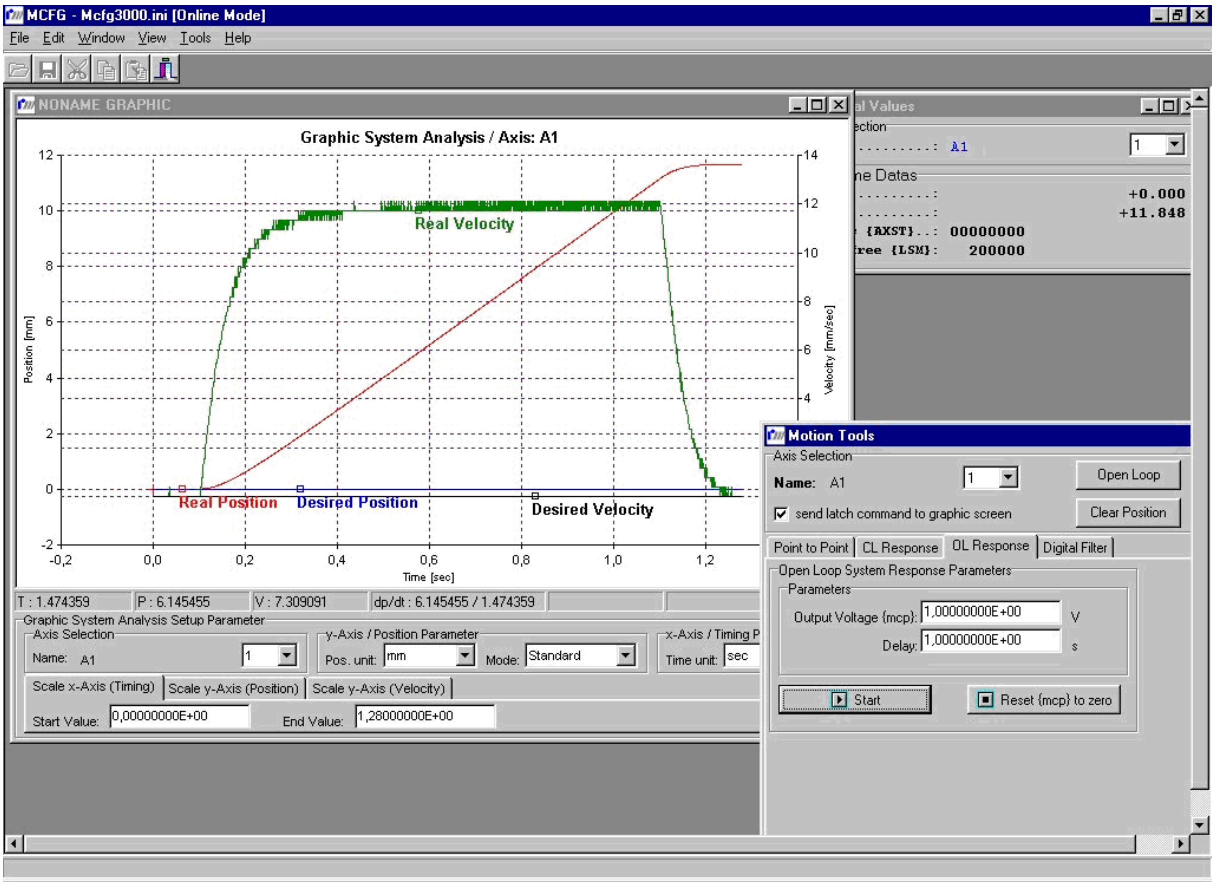

Figure 02: Step response of a speed-controlled drive system

One characteristic of such a drive system is the increase of the real velocity up to a max. value, which is proportional to the manipulated variable. In the optimal case, the increase is realised by an e-function. However, in practice also not so well-attenuated increase functions are possible.
Even with current-controlled drive systems, in the case of incorrect interpretations the step response may be as shown in Figure 02. Here, however, the maximum speed is reached with even a low manipulated variable output, i.e. the speed end value is not proportional to the manipulated value.

Phase angle of the drive system

For the successful filter design, it is required, that the phase angle of the system is set correctly, i.e. the output of a positive manipulated variable (voltage) must cause a traversing of the drive system to positive counter values. Figure03 shows the step response of a drive system with angle rotation.

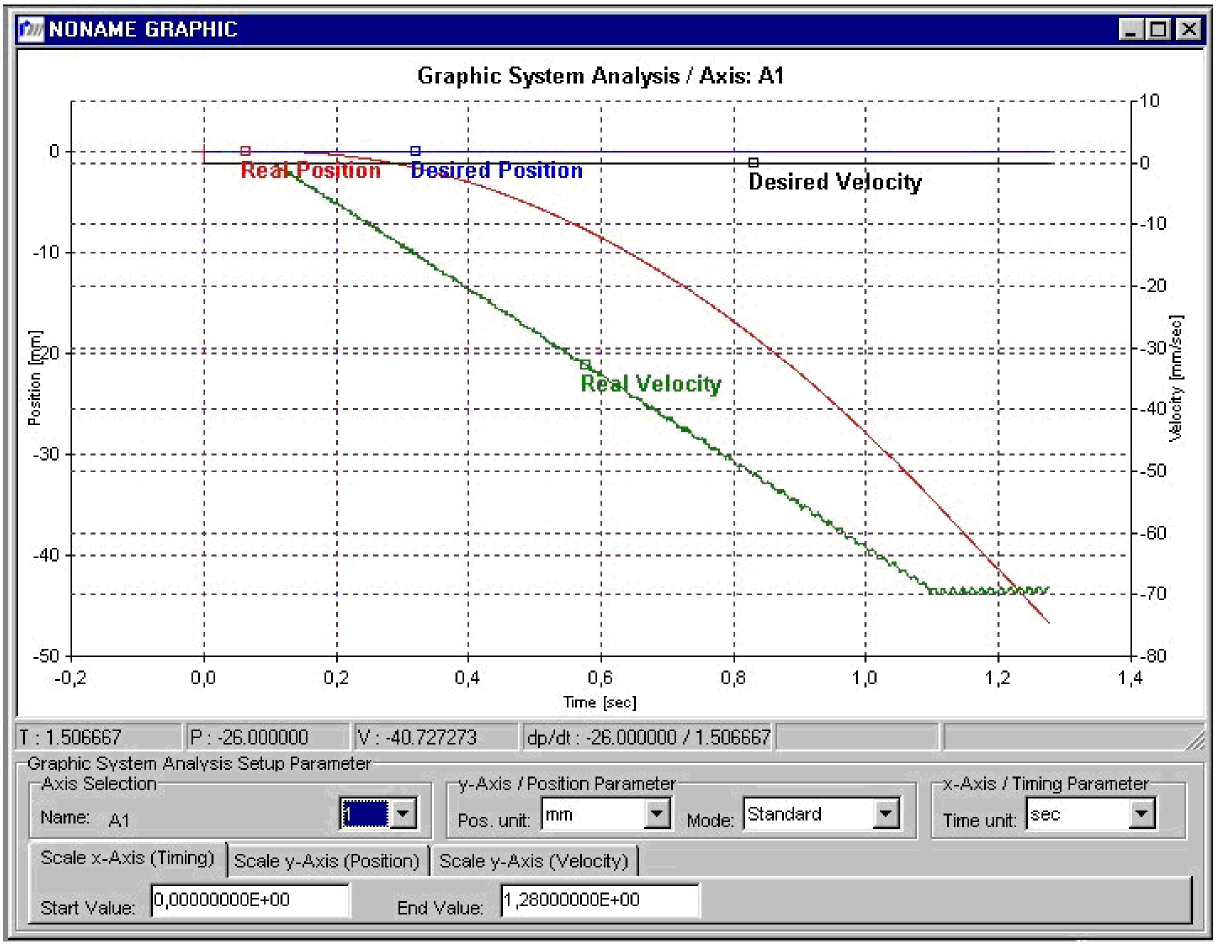

Figure 03: Step response of a current-controlled drive system with turned phase angle

Also this figure was recorded by the output of a set value voltage of +1 V. This figure may only appear, when a negative set value voltage is put out. However, a positive voltage was put out, here a system with angle rotation is shown. When during the recording of the step response an angle rotation is detected, firstly the phase angle must be corrected. This can be realised through software configuration in mcfg, through changes in wiring or through the respecting configuration of the current amplifier.

Filter design with the program mcfg.exe

After step response of the drive system is recorded, i.e. according to Figure01, the actual filterdesign can be realised.

- Enable the graphic window by pressing the ALT key (keep it pressed continuously)

The cursor in the graphic window turns to a cross hairs. Now the cursor is positioned for example on the starting point of the increase of the real velocity (Figure 04).

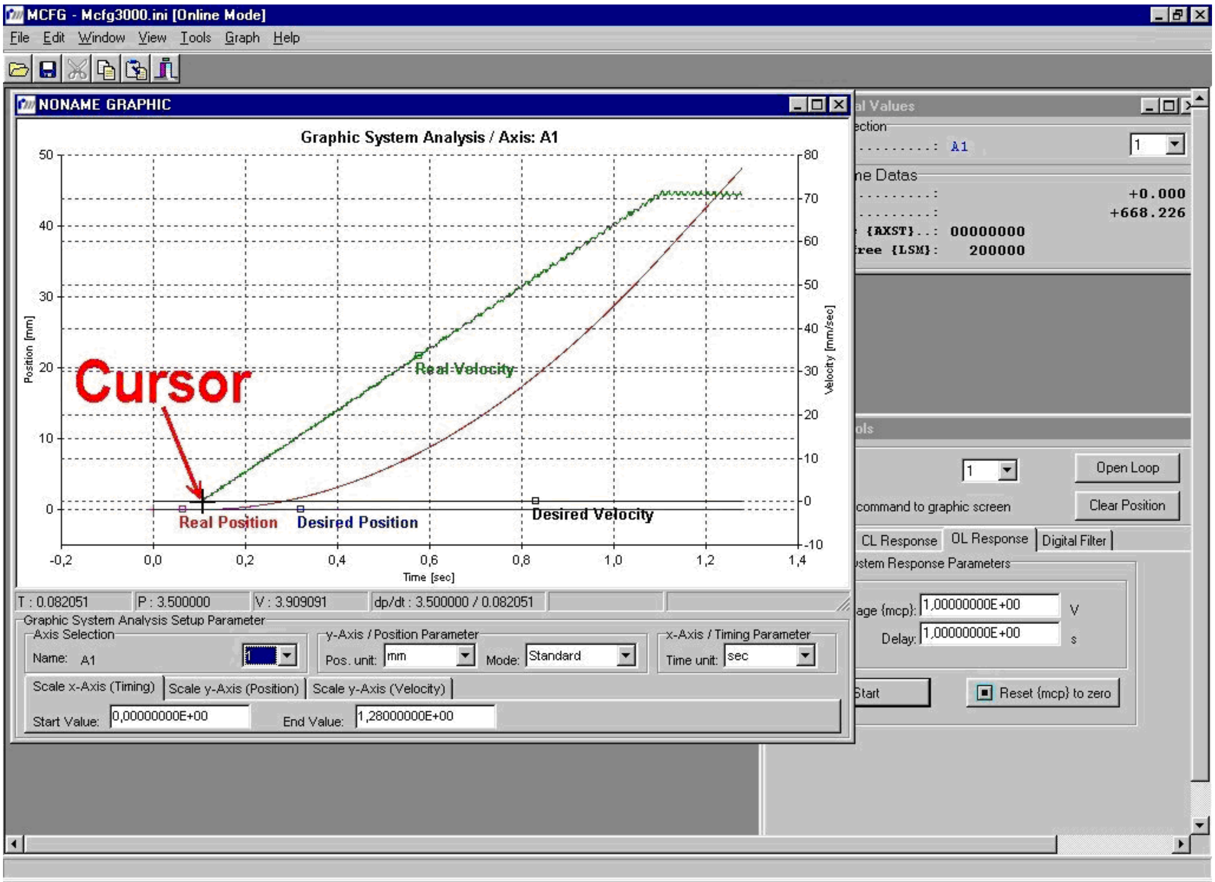

Figure 04: Positioning the cursor on the starting point

- Press the left mouse key to get a broken straight line out from this point. Keep the Alt key pressed during this procedure.

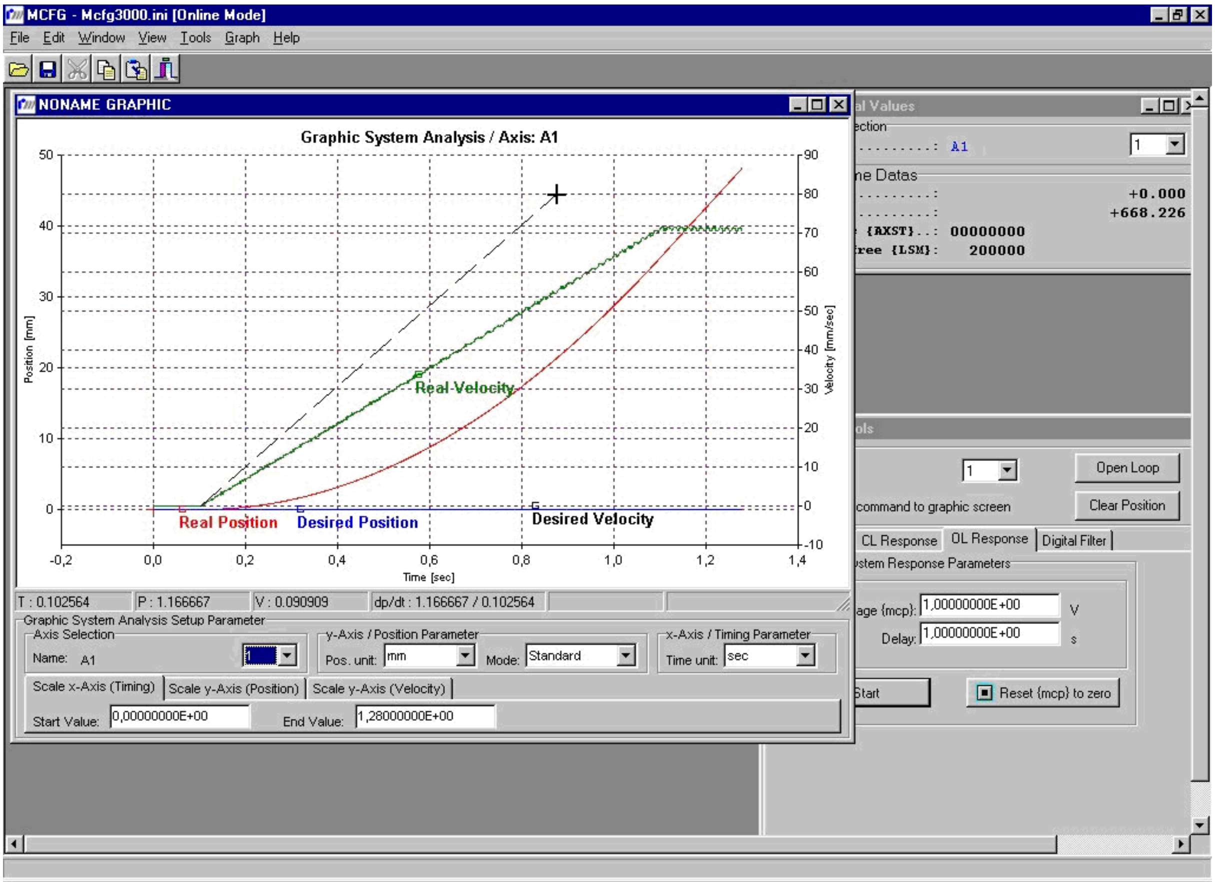

Figure 05: Drawing a straight line out of the starting point

This straight line is positioned in the way that it covers with the Real Velocity. So the increase of the velocity shall be calculated. Thus, it is of no importance where starting and end points are placed, but it is important that the inclination of the drawn line corresponds with the inclination of the real velocity.

Zooming in the graphic window

If the increase of the real velocity cannot be recognized so clearly as in this example, because the increase is nearly vertical, firstly, the increase line must be zoomed out so that the determination of the increase can be realised with sufficient precision. Hereto follow the steps below:

- Position the cursor on the edge of the window you want to show zoomed out, for example left below.
- Confirm the Shift-key and draw with the left mouse key a field window (keeping the Shift-key pressed)
- After releasing the mouse key, the selected window is shown zoomed.

If needed, the zoom procedure can be repeated various times. In order to return to the original presentation mode:

- Click with the left mouse key and pressed Shift-key into the graphics window.

Starting the parameter calculation

After positioning the increase straight line in the way that it corresponds with the inclination of the real velocity, release the left mouse key (and afterwards also the Alt-key). Now a screen window opens, like in Figure 06.

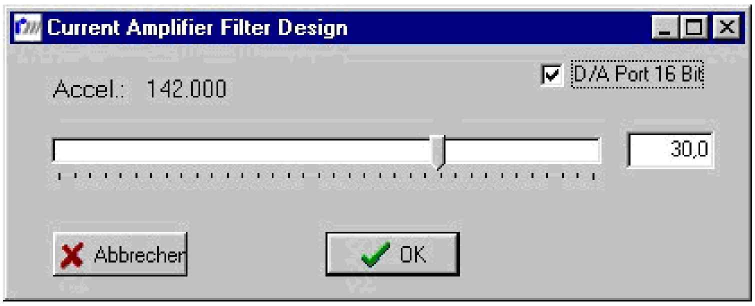

Figure 06: Filter parameter calculation

This figure shows the measured acceleration in digits/second. Furthermore, the required bandwidth (between 0.1 and approx. 300 kHz) can be selected with the shift option.
The bandwidth of the controller is a measurement for the hardness of the closed bearing control loop but cannot be selected in any size because of the stability of the closed control loop. After confirming the OK-button the calculation is started with the indicated values. The determined values will be registered in the window “Motion Tools” on the register board “digital filter”.

Important: The calculated controller parameters are only valid if the recording of the step response was realised in the *linear operation range.* You can check if you are in the linear operation range, if you double or half the output value. In these cases, the indicated acceleration also must be doubled or halved (approx.). If for example the acceleration value does not change at doubling the output voltage, the system is within the limitation. The here calculated controller parameters are not valid.

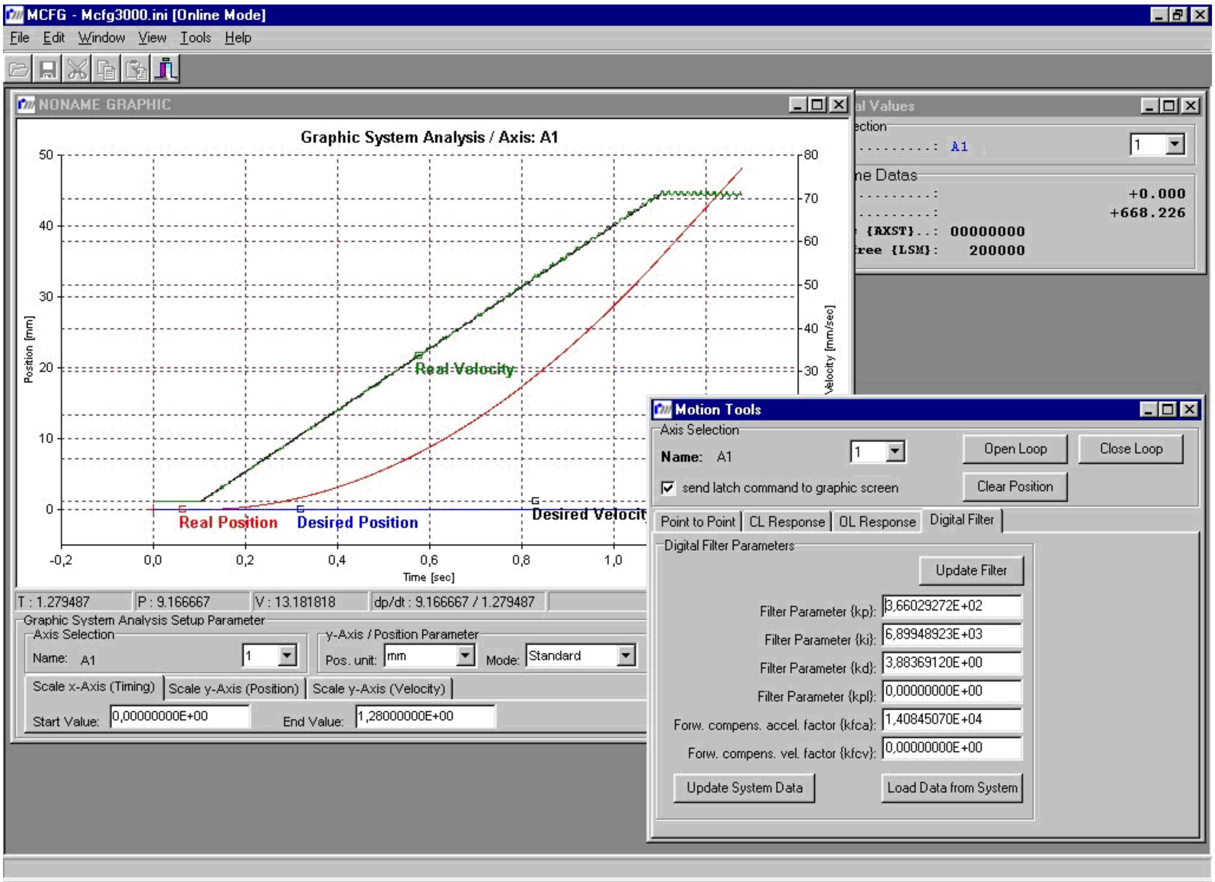

Figure 07: The calculated filter parameter were entered in the „Motion-Tools” window

- Click on the buttons “Update Filter”, “Clear Position” and “Close Loop” to close the bearing control loop with the now calculated values. Now check the behaviour of the bearing controller in respect of precision and stability.

When the system acceleration is measured on a system with angle rotation, the following message first appears instead of the window according to Figure 06:

Figure 06a: Drive system with angle rotation

- Confirm the button

After confirming the button, the window “Current Amplifier Filter Design” appears, but with disabled OK-key. In this case firstly the phase rotation must be corrected or the increase straight line must be set correctly.

Recording a traversing movement

After selecting the register board “Point to Point”, you can define a traverse profile. One example hereto is shown in Figure 08.

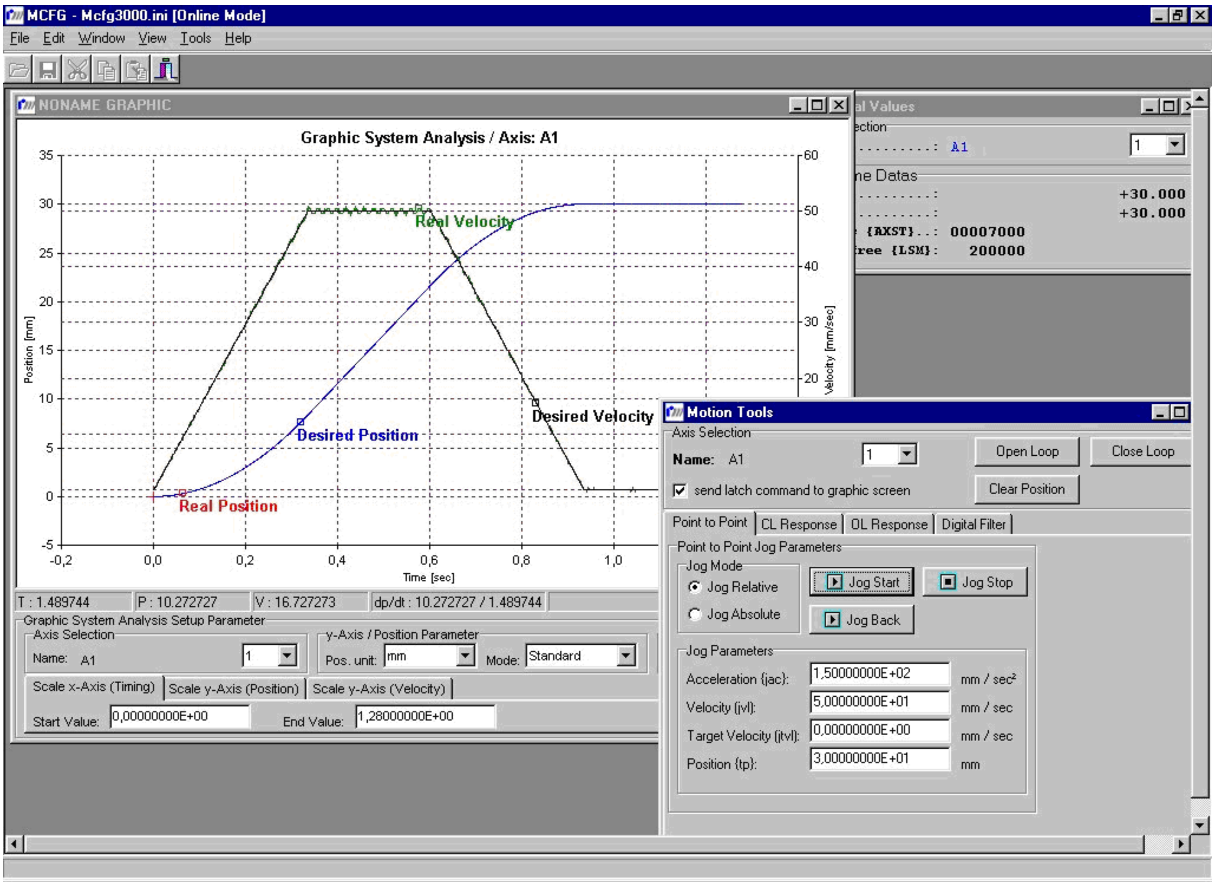

Figure 08: Trapezoidal speed profile realised

Here, please note that a profile target velocity (jtvl) is entered from 0, as otherwise the axis would not stop at the profile end.

- ➢ Click on the button “Jog Start” to start the traverse profile and the recording process.

It is recommended to return the profile after the ending immediately with “Jog Back”, so that the traversing range will not be left over the time.

- ➢ Press the right mouse key and “Update Screen” (see above) to update the graphic window.

Now the traversed traversing profile will be shown in the graphic window and now can be evaluated regarding stability and precision.

In order to improve the presentation, for example for reaching the target position, the respecting area can be zoomed.

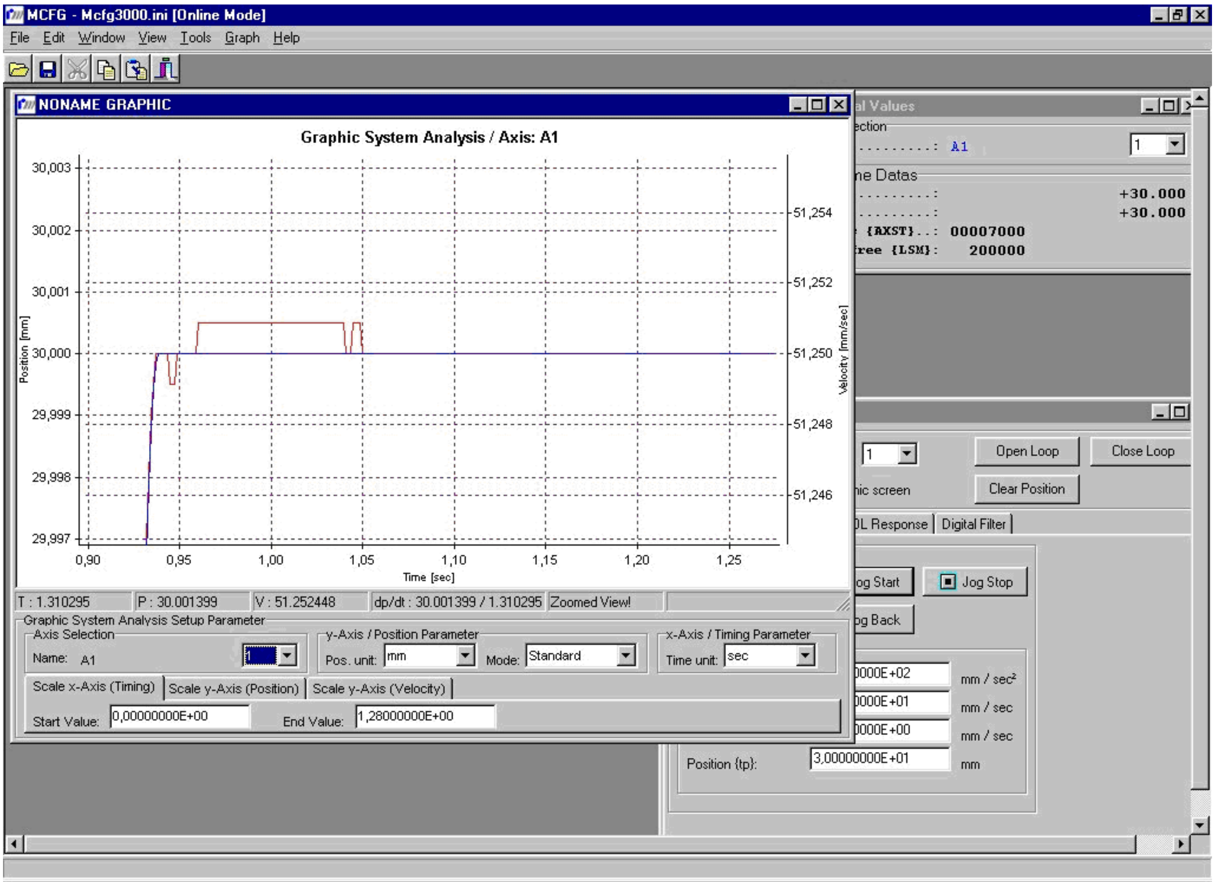

Figure 09: Reaching the target from figure 08 (zoomed out)

The figure above shows the optimal reaching of the target position. In practice, this firstly will not occur. The parameter calculation often must be repeated various times. In order not to record each time the step response of the system, for the concerned axis two windows can be opened. The recording of the step response can be realised for example in the first window only once. The evaluation of the traversing profiles can be realised in the second graphic window. If the calculation shall be started newly, in order to determine another parameter set with changed controller bandwidth, then the increase straight line is drawn newly in the first graphic window.

For the fine adjustment, afterwards, the single parameters can be adjusted manually.

- ➢ In the window “Motion Tools”, enable the button “Update Filter” in order to overtake changed parameters.

The practice shows that for example the calculated integral part Ki often can be selected double or four times higher than the calculated value.

The filter parameter Kp

The Kp value represents the proportional gain of the PID filter.

The filter parameter Kd

With the value in Kd, the D-part of the PID filter is parameterised. Kd is the derivative time of the D-part multiplied by the proportional gain Kp.

$$Tv = Kd / Kp$$

The D-part of the PID filter can be deactivated by resetting Kd to zero.

The filter parameter Ki

With the value in Ki, the I-part of the PID filter is parameterised. Ki is the reciprocal of the settling time multiplied by the proportional gain Kp. The I-part of the PID filter can be deactivated by resetting Ki to zero.

The pre-control coefficients kfcv and kfca

kfca is the acceleration pre-control coefficient and is automatically computed through the determination of parameters as described here. From the current acceleration of the axis, this value generates an output value of the manipulated value which corresponds to the desired acceleration. This value only makes sense with torque-controlled drive systems, i.e. if the voltage setpoint value of the downstream drive amplifier corresponds to an armature current or torque and thus to an acceleration. With the value 0, the acceleration pre-control is deactivated.
kfcv is the velocity pre-control coefficient (FeedForward) and is only used with speed-controlled systems. With the use described in this document, this coefficient is not used and stays with the value 0.

The filter parameter kpl

In some cases, it makes sense to use the filter parameter kpl. With this parameter, the differentiation time of the bearing controller can be increased. This is required with a short scan time or with relatively slow drive systems (high mass moment of inertia). In these cases, the control limit of the manipulated variable output is reached very quickly, namely because of a jump of the D-part. This limitation results in a non-linear system with unfavourable control characteristics (drive noises, instability). Through the time constant of the D-part, the D-jump pulse will be distributed over a longer period, thus reducing the risk of reaching the manipulated variable limit. Prevalent values for kpl are 0.0002 – 0.01. The parameter signifies a time in seconds.
In most cases, the value of kpl can be left on 0 and thus has no effect. However, if required, another controller option can also be activated with this value. The sign of the value determines which of these options is activated.

Positive values in kpl

If there are positive values in kpl, this value stands for a delay time constant for a real D-part (as described above). Especially in case of short scan times and high controller hardness, it may easily be that the manipulated value of the controller gets into override and that the controller therefore shows a non-linear behaviour. With this time constant, the period of a D-step response is extended, but the amplitude is diminished. The unit of kpl is seconds. Realistic values are between 0.0002 and 0.01 s.

Negative values in kpl

If there are negative values in kpl, this value stands for a delay time constant in the manipulated value channel. In many cases, it helps to reduce or completely prevent overshooting during the target position running-in. Firmly set drive systems in particular tend to overshooting, even if the pre-control is optimally set. However, the freedom of overshooting is “paid dearly for” by a time shift between the actual value and set value signals. The unit of kpl is seconds. Realistic values are between -0.0002 und -0.01 s.

Saving the calculated values

After finding the optimal filter parameter, these must be saved in SYSTEM.DAT:

- Hereto enable the button “Update System Data” (window “Motion Tools” register board “Digital Filter”).
- Afterwards, open the window “System Data”.

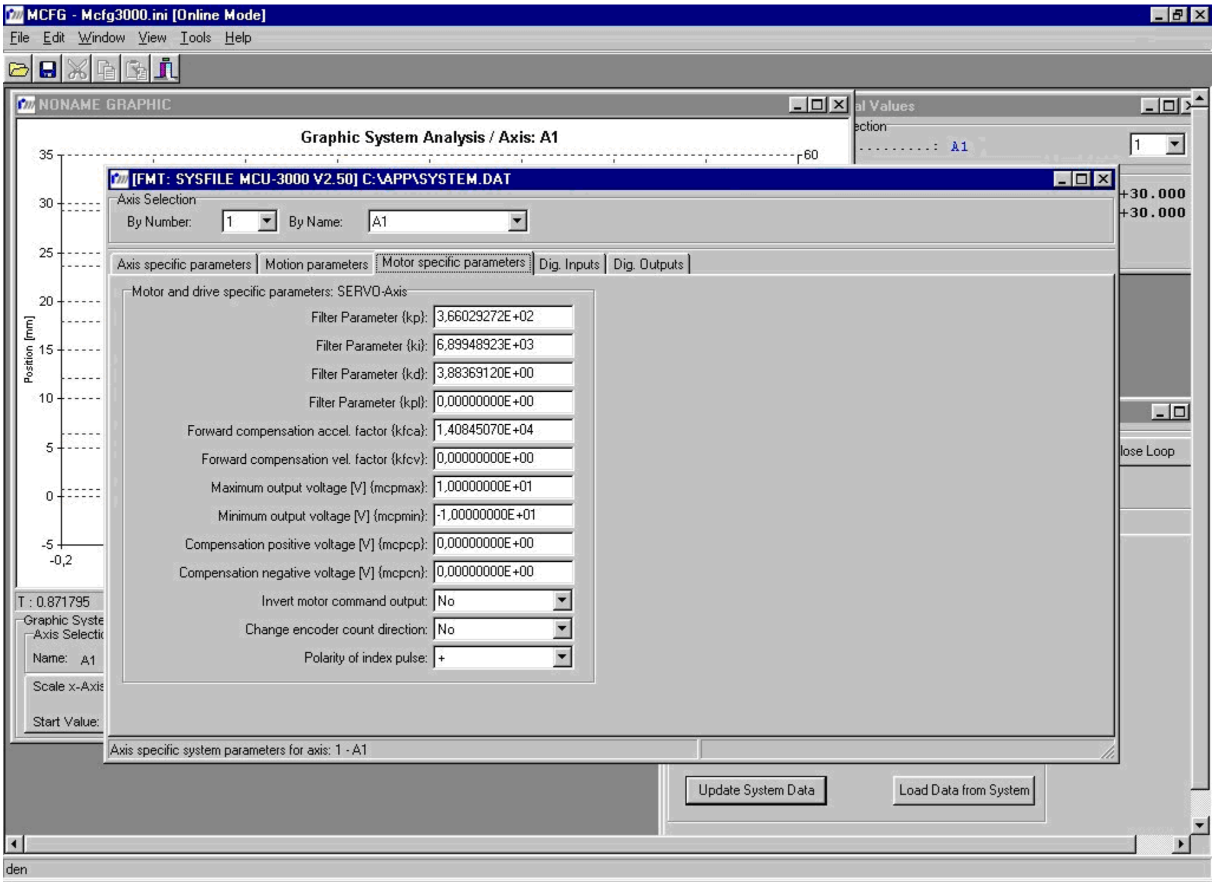

Figure 10: Window “System Data”

The filter parameters were entered at the respecting axis on the register board “Motor specific Parameters”. By saving this system data (e.g. Click on the button “Save” at booted system), the following mask appears:

Figure 11: Warning when saving

- Click on OK to confirm the message.

After confirming the message, the filter parameters will be saved in the file SYSTEM.DAT and are automatically available at the next system start with this system file.

Changing the scan time

Changing the scan time of a system affects the acceleration pre-control coefficient kfca. If this is not to be experimentally redetermined, it can also be calculated.
The kfca value has to be decreased at the square ratio of the scan time being increased or it has to be increased at the square ratio of the scan time being decreased. If, for example, the scan time is halved, kfca must be quadrupled.
Where required, the speed pre-regulation coefficient needs to be adapted as well, however using the single ratio instead of the square ratio. Generally, all other filter parameters can remain unchanged.

Furthermore, it should be noted that the calculated manipulated values for the D-part rise proportionally if the scan time is decreased. This may easily lead to an override of the manipulated value output and thus to non-linearity in the control loop and a deterioration of the control behaviour (whistling, overshooting, deteriorated transient response up to parasitic oscillation). This effect can be compensated by a real delay time constant of the D-part, which must be entered as a positive value in kpl. The unit of this value is seconds. Realistic values lie in the range from T_A up to several multiples of T_A (T_A = selected scan time in seconds).