TM450

Motion Control Concept and Configuration

PERFECTION IN AUTOMATION
A MEMBER OF THE ABB GROUP

Prerequisites and requirements

Training modules	TM410 – Working with Integrated Motion Control TM440 – Motion Control: Basic Functions
Software	Automation Studio 4.33 Automation Runtime 4.33 ACP10/ARNC0 3.16.2
Hardware	ACOPOS / ACOPOSmulti / ACOPOS P3 / ACOPOSmico / ACOPOSmotor / ACOPOSremote

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1 Introduction

The quality of motion control provided by an electric drive is crucial in determining the quality, precision and dynamic capabilities of a process. This means that the control concept as well as the controller settings are crucial factors.

The basics of the B&R drive solution are explained in this training module and then, in a step by step manner, the control concept. Calculating optimal control parameters is then covered.

Automation Studio tools are useful for determining and testing controller settings (see TM410 – Working with Integrated Motion Control).

A number of examples will help you to understand the theory.

Figure 1: ACOPOSmulti system with a B&R synchronous motor in the foreground

1.1 Training module objectives

This training module uses selected example applications and exercises to demonstrate how B&R motion control works.

- You will learn the basic concepts of closed-loop control.
- You will learn about the cascade control concept used by ACOPOS drives.
- You will learn the procedure for determining control parameters and how to use the autotuning feature.
- You will learn the procedure for manually calculating the control parameters for speed and position controllers.
- You will learn how to modify and save control parameters and then load them to the drive.

2 The basics of closed-loop control

The following question should be asked before covering the control concept in more detail in the B&R drive solution:

"*Why does a drive need a closed-loop control?*"

The goal of a drive is to reach a position as fast and as accurately as possible using a motor and various mechanics.

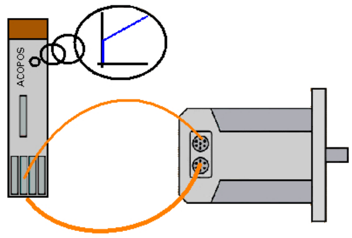


Figure 2: ACOPOS servo drive and motor

The first thing the controller must know is which position the motor should move to. This value is usually referred to as the position setpoint. In closed-loop control, a reference variable is used to do this.

The controller requires position information to find out where the motor is currently located. This information is obtained using an encoder. The encoder is a measuring element, which provides the controller with the information (actual position and speed of the motor) via feedback.

If the position setpoint and the actual position don't match then this is referred to a control deviation or a lag error.

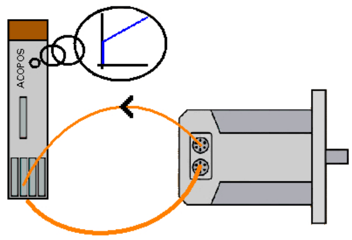


Figure 3: Encoder information is transmitted to the ACOPOS servo drive

Closed control loop

This lag error is compensated for by the servo drive. This is why the controller outputs a manipulated variable. This manipulated variable affects the controlled system (in this case, the motor and the subsequent mechanics) so that the actual position reaches the position setpoint. In our case, the actual position is the controlled variable.

All of this together is called the closed control loop.

There are also external factors that affect this system. These types of factors are called disturbance variables, and also must be compensated for by the controller. For example, a hanging load can represent a disturbance variable for the closed control loop.

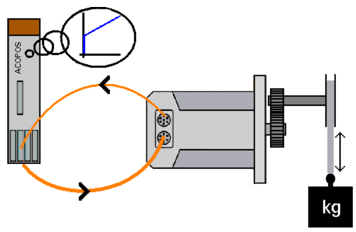


Figure 4: Closed control loop with a hanging load as a disturbance variable

Differences between closed and open loop controllers

Unlike a closed loop controller, an open loop controller does not have feedback. This means when and how the target was reached cannot be determined. An open loop controller is often used for speed control using frequency transformers.

But what happens now within a closed loop controller?

A closed loop controller can be made up of one or more parts of transfer elements. These transfer elements react differently to input values.

The controllers on the ACOPOS servo drive are generally made up of a proportional element (P element, P component) and an integral element (I element, I component).

P component

A P component immediately reacts to an input value jump with a proportional output value jump. The size of the jump on the output is determined by one factor. This gain is known as factor "kv".

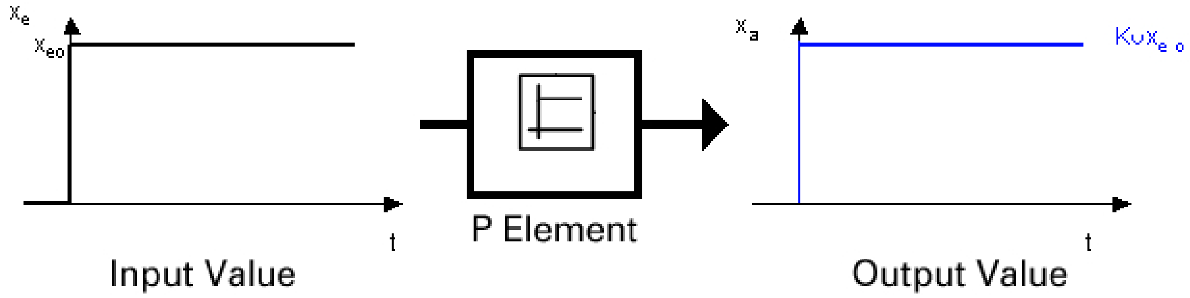


Figure 5: Reaction of a P component

I component

The output variable increases continuously in the form of a ramp if the input variable of an I component jumps. The slope of this ramp and the rate at which the output variable ascends depends on a particular time. This time is known as integral action time "tn".

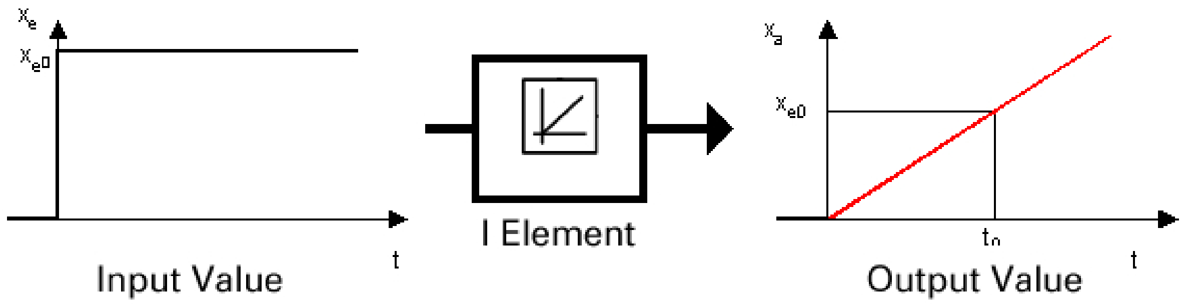


Figure 6: Reaction of an I component

PI controller characteristics

A PI controller contains a P and an I component. The output values of both components are added together. As a result, the PI controller reacts to a jump of the input value as follows: The P component allows the controller to react immediately to a change in the input value. A remaining controller deviation would occur if only one P component was used alone. The I component integrates this, thereby compensating for the deviation.

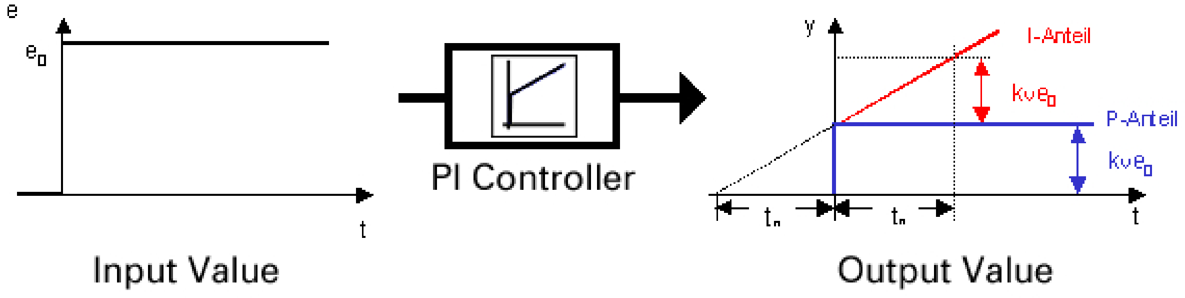


Figure 7: Reaction of a PI controller

Each of the products in the B&R servo drive family have a powerful processor. This also calculates the controller algorithms, among other things. This is why the term "digital control" is used. The difference between analog (continuous) closed-loop control and digital (discrete time) closed-loop control is that the control deviation is scanned in a corresponding time interval (cycle). The duration of this cycle should always be the same insofar as possible (= jitter-free), but should also be as short as possible to receive the changes in the controller deviation as fast as possible.

3 Cascaded control concept

The cascaded control concept is the core of the B&R servo drive. The position controller, speed controller and current controller are cascaded starting with the setpoint generator. As a result, the manipulated variable of the higher-level controller becomes the reference variable for the lower-level controllers.

For example, this means that the position controller configures the speed setpoint for the speed controller.

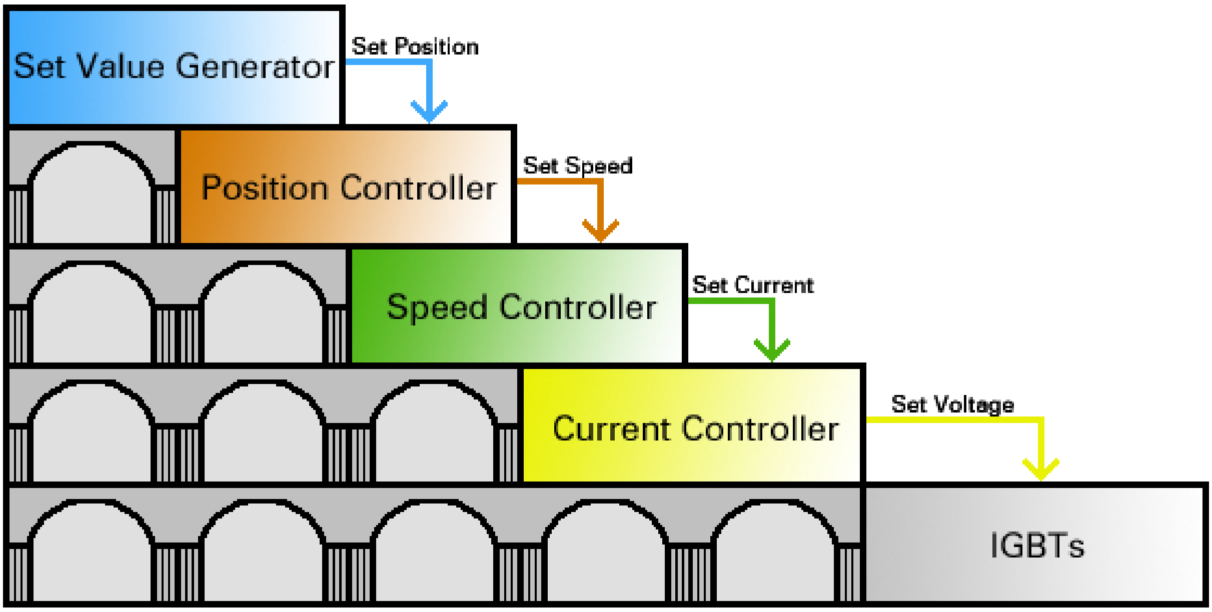


Figure 8: Cascading controller structure: The higher-level position controller generates the setpoint for the lower-level controller

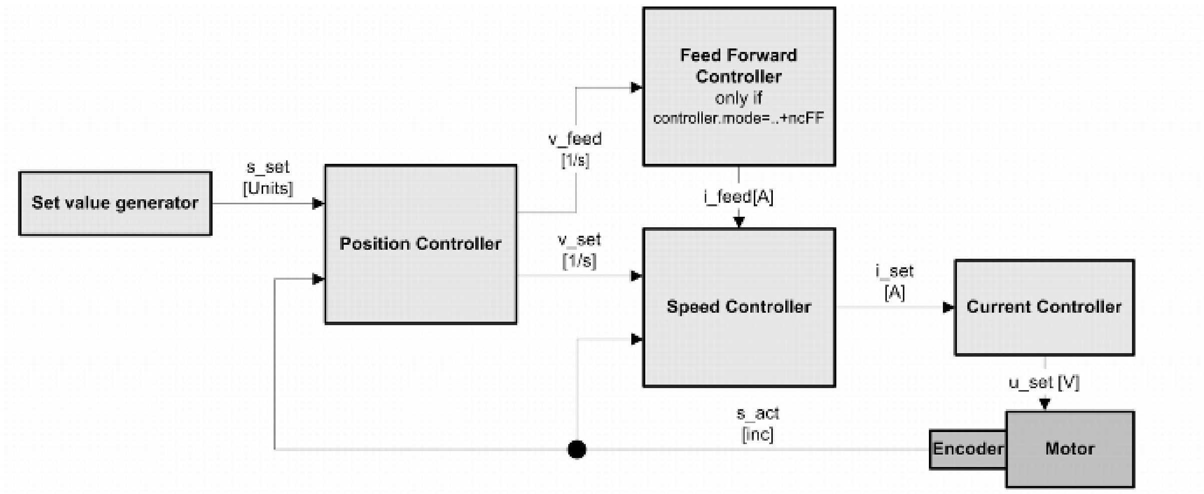


Figure 9: Controller block diagram with a setpoint generator and controller cascade

? Motion control \ ACP10/ARNC0 \ Reference manual \ ACP10 \ NC objects \ NC object "ncAXIS" \ Controller \ Controller mode "ncPOSITION"

3.1 Setpoint generator

3.1.1 Base movements

As seen earlier, the reference variable is provided for the position controller by a setpoint generator. This happens with a cycle time of 400 µs[1].

The job of this setpoint generator is to create a movement profile after a command for executing a basis movement. The path of this profile depends mostly on the base movement parameters (target position, acceleration, etc.).

Element	Data Type	Description
...		
move		**Axis movement**
...		
basis		**Basis movements**
parameter		**Parameters**
s	DINT	Target position or relative move distance [Units]
v_pos	REAL	Speed in positive direction [Units/s]
v_neg	REAL	Speed in negative direction [Units/s]
a1_pos	REAL	Acceleration in positive direction [Units/s²]]
a2_pos	REAL	Deceleration in positive direction [Units/s²]
a1_neg	REAL	Acceleration in negative direction [Units/s²]
a2_neg	REAL	Deceleration in negative direction [Units/s²]

Figure 10: Limit values for base movements

[1] The setpoint generator is calculated on the ACOPOS system with 400 µs or faster. The exact value can also be taken from the data sheet of the respective drive controller.

The following figure illustrates this type of profile and the parameter values used:

ax_par1	Value	Unit
s	10000	[Units]
v_pos	10000	[Units/s]
v_neg	10000	[Units/s]
a1_pos	100000	[Units/s²]
a2_pos	100000	[Units/s²]
a1_neg	100000	[Units/s²]
a2_neg	100000	[Units/s²]

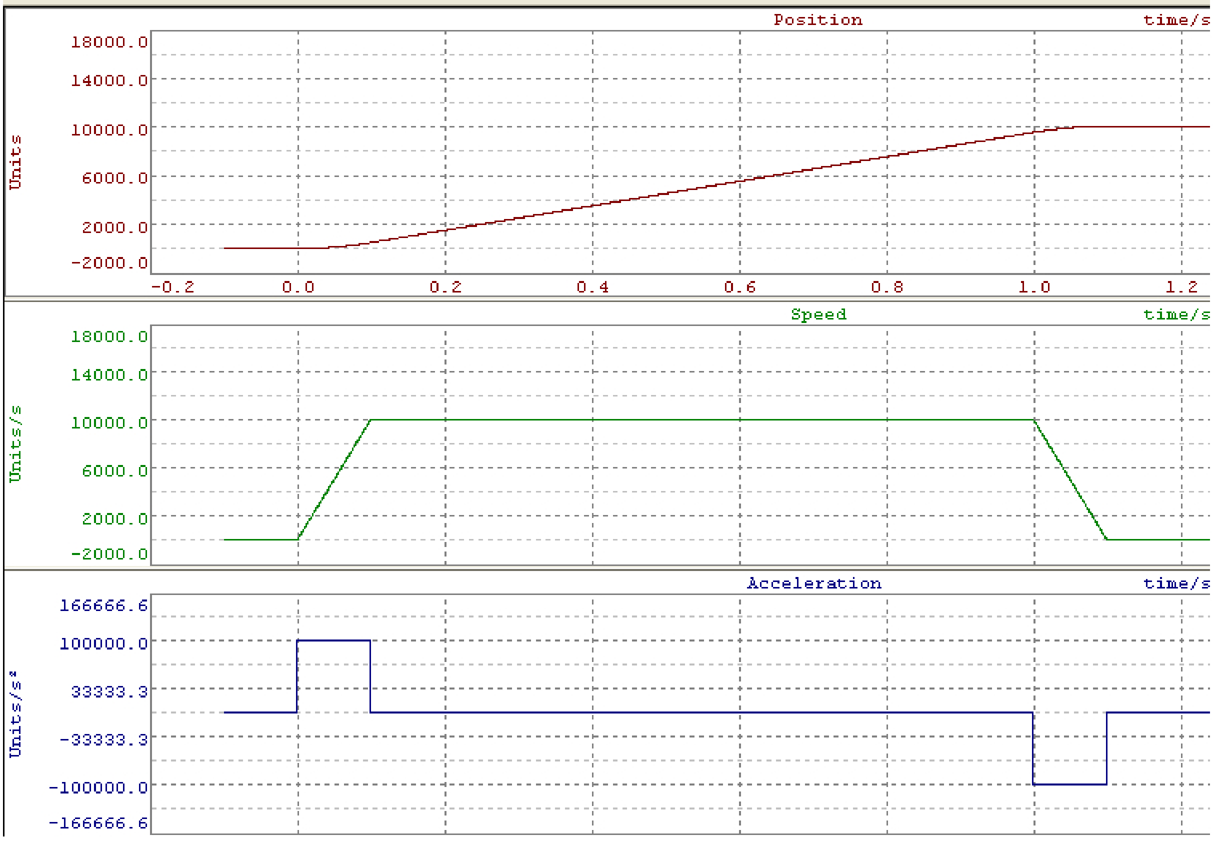


Figure 11: Trace recording of the position, speed and acceleration (first derivative of the speed)

We can see from the chart that jumps occur at each end of the acceleration. These jumps are called jolts. These occur when there is a bend in the respective speed curve.

Generally this type of behavior is not desired because the motor must generate a higher torque in this case. Furthermore, a high load is placed on the mechanics and the entire system vibrates.

This is why the setpoint generator has jerk limitation.

Motion control \ ACP10/ARNC0 Reference manual \ ACP10 \ NC objects \ NC object "ncAXIS"

- Base movements
- Limit values

3.1.2 Jerk limitation

The jolt occurs due to a change that causes a bend in the speed curve. If the speed is slowly increased at the beginning or slowly reduced at the end of the acceleration phase, the rectangular acceleration profile becomes a trapezoid. The following trace recording illustrates this:

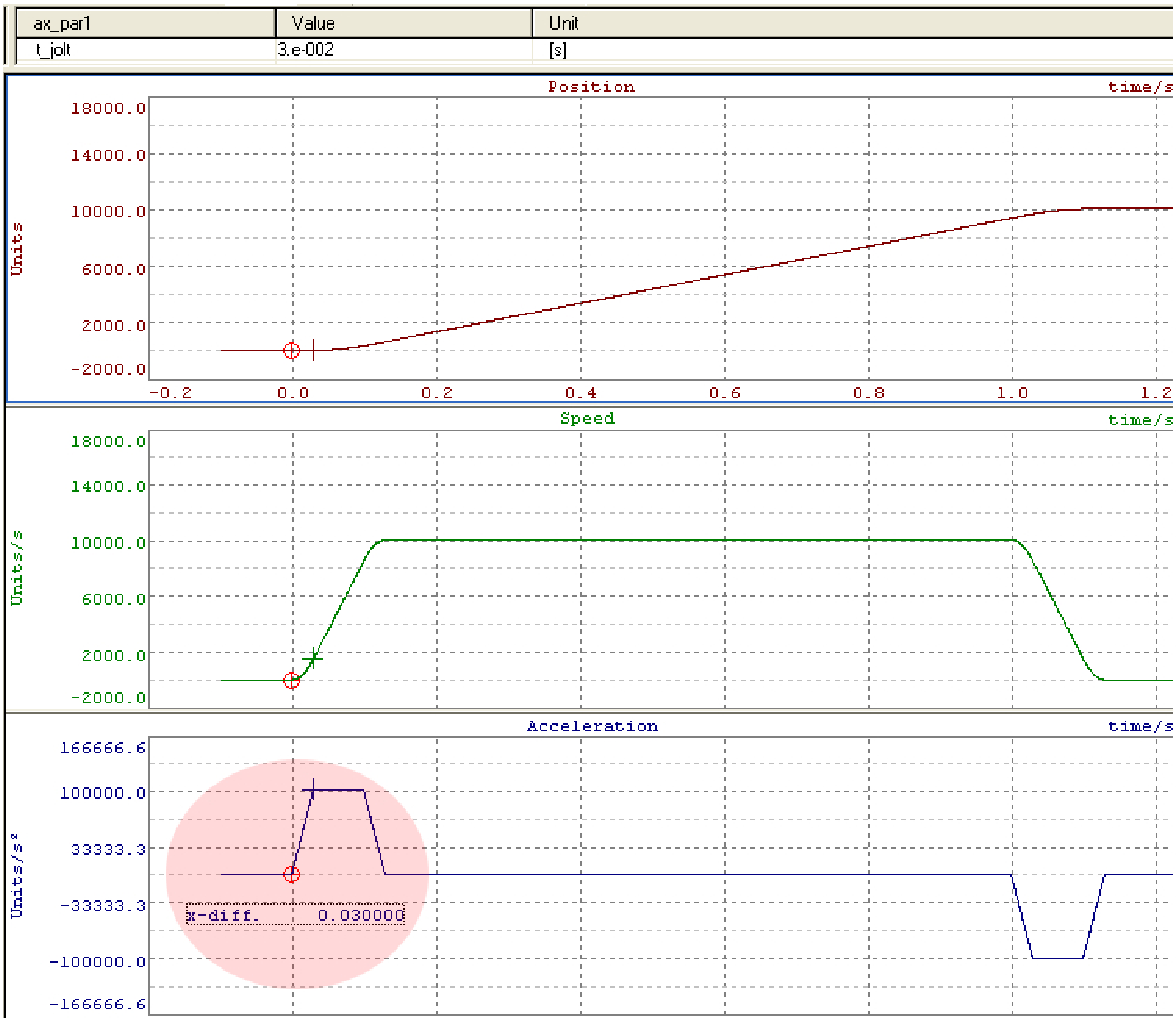


Figure 12: Trace recording of the position, speed and acceleration with active jerk filter

A jerk filter time can be set so that the servo drive generates a jerk-limited motion profile. The jerk filter time is the time required for acceleration from zero to the defined maximum value. Jerk limitation uses a linear filter during runtime. In the image you can see that the jerk filter time "t_jolt" was set to 0.03 seconds. The measurement cursors in the lower chart diagram indicate that the rise time of the acceleration is the same as the jerk filter time.

Motion control \ ACP10/ARNC0 Reference manual \ NC \ ACP10 objects \ "ncAXIS" NC object \ Base movements

Active jerk limitation extends the time for setpoint generation. However, in many cases the positioning goal can be reached sooner because the settling time of the system is shortened considerably by the lower jerk load.

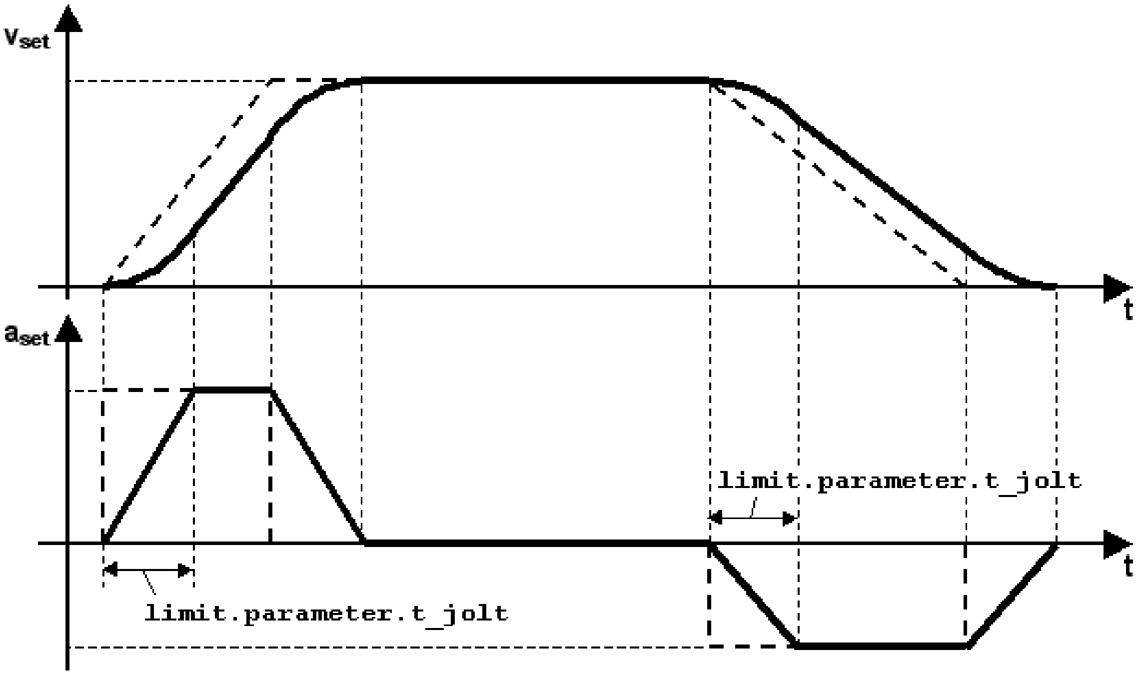


Figure 13: Timing diagram of a movement with (bold line) and without (dotted line) jerk limitation

The "t_jolt" parameter is located in the limit values just like the maximum speed and acceleration. A value between 0.0 and 0.2 seconds can be defined for "t_jolt".

3.2 Predictive position controller

The reference variable of the position controller is created by the setpoint generator. The servo drive receives the controlled variable (current motor position) via the motor's encoder system and a corresponding encoder interface card. The control deviation is determined from these two variables, which results in a new manipulated variable for the lower-level speed controller.

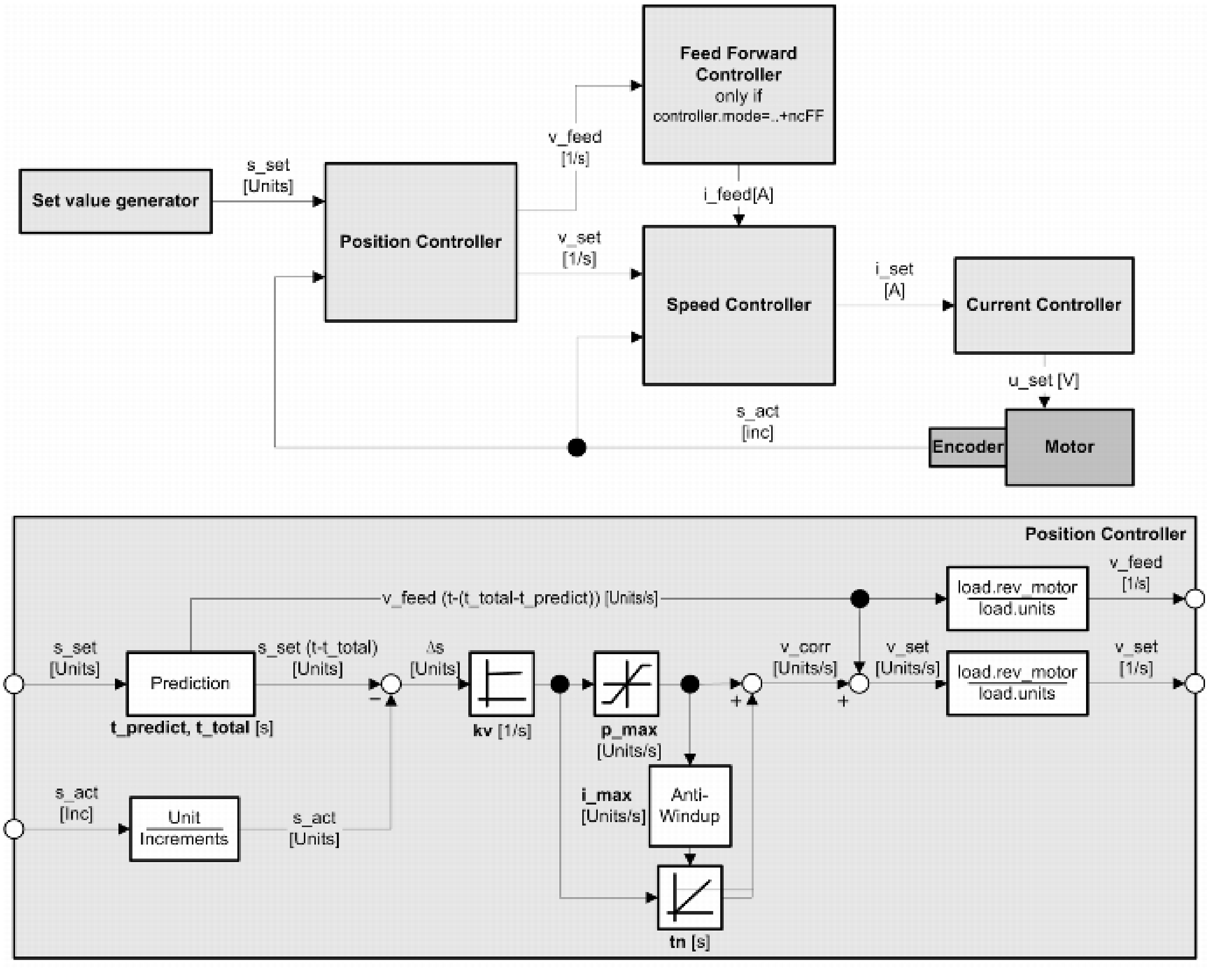


Figure 14: Overview block diagram and detail block diagram of the position controller

The position controller is implemented as a PI controller with anti-windup (manipulated variable limitation) and "predictive" feed forward.

The proportional element with the factor "kv" causes an immediate change in the speed setpoint in the event that a lag error occurs. Changes in the setpoint or disturbance variables can cause these type of control deviations.

The I component with integral action time "tn" is used to compensate for stationary disturbance quantities (e.g. suspended loads).

The manipulated variable limitation is implemented using the parameters "p_max" and "i_max". These values limit the maximum effect of the P component and the I component.

The feed forward is the predictive element of the position controller.

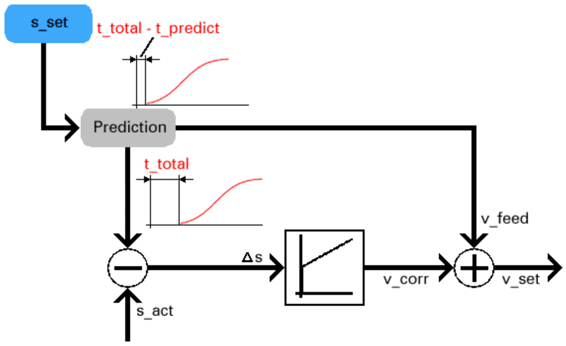


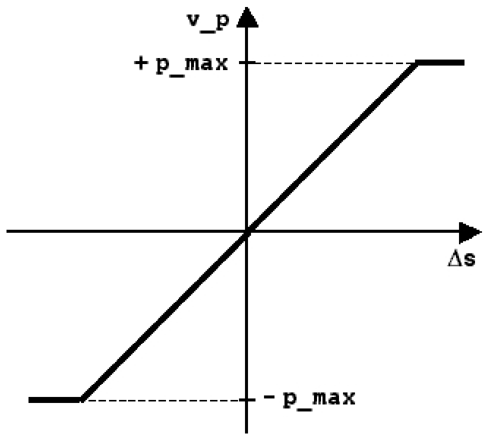
Figure 15: Prediction, feed forward

A feed forward speed ("v_feed") results from a differentiation of the position setpoint (s_set). The PI controller establishes a correction speed ("v_corr") from the lag error (Δs). These two speeds are added together to produce the speed setpoint (v_set) for the subsequent speed controller. The feed forward is then predictive if the position setpoint is sent to the PI controller with a delay (t_total). The setpoint should be delayed as long as the delay time of the controlled system. This is why the speed setpoint (t_total – t_predict) is introduced to the speed controller first. If the corresponding position setpoint of the PI controller is then accepted, the control deviation is then smaller as a result of the already fed speed setpoint. This presents a load on the PI controller because it still has to compensate for the remaining deviation. Without feed forward, the PI controller would have to take care of the speed setpoint by itself. This improves the setpoint tracking behavior and the dynamics of the drive.

Calculation of "v_corr" which results from the lag error "Δs":

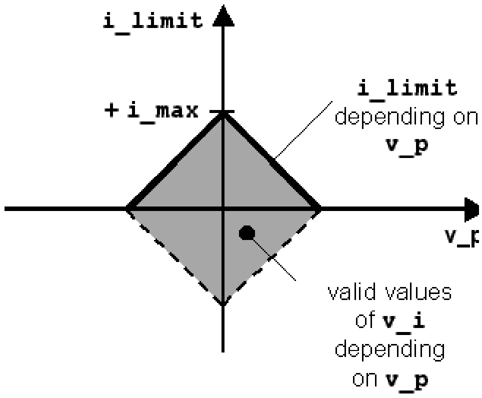
First, the speed "v_p", which results from the proportional gain, is calculated and limited to "p_max":

```
v_p = kv * Δs
if ( v_p > p_max )
    v_p = p_max
else if ( v_p < -p_max )
    v_p = -p_max
```



This value and "i_max" are used to calculate "i_limit" and the speed resulting from the integral gain "v_i" is limited to this value:

```
i_limit = i_max - |v_p|
if ( i_limit < 0 )
    i_limit = 0
    v_i = f(v_i, Δs,kv,tn)
if ( v_i > i_limit )
    v_i = i_limit
else if ( v_i < -i_limit )
    v_i = -i_limit
```



Finally "v_corr = v_p + v_i" can be calculated.

Before the speed setpoint is passed on to the speed controller, it is converted from the parameterizable unit system (unit/s) into the physical motor encoder system (rev/s).

Lag error monitoring is also performed in the position controller. An emergency stop is executed if the control deviation exceeds a parameterizable threshold value.

> ? Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions \ Drive control \ Position controller
>
> - Function \ Setpoint sources
> - Function \ Controller
> - Expansions for the PI controller

Feed-forward control

A speed and torque setpoint or a current setpoint is provided, in addition to the position setpoint, to improve the setpoint tracking behavior. This feed-forward control doesn't have any influence over the disturbance variable behavior. Additionally with an axis group, different runtimes of the position setpoints can be adjusted to each other with the POS_CTRL_T_TOTAL total delay time.

Additional information

- 5.3.3 "Compensation of delay times" on page 29

> ? Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions \ Drive control \ Position controller \ Function \ Feed forward controller
>
> - Predictive speed control
> - Speed and feed-forward torque control
>
> Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions \ Drive control \ Position controller \ Configuration guidelines for torque feed forward input control

3.3 Speed controller

The speed controller's job is to determine the difference between the manipulated variable of the higher-level position controller and the measured speed. A manipulated variable for the lower-level current controller is then generated using a PI controller with anti-windup.

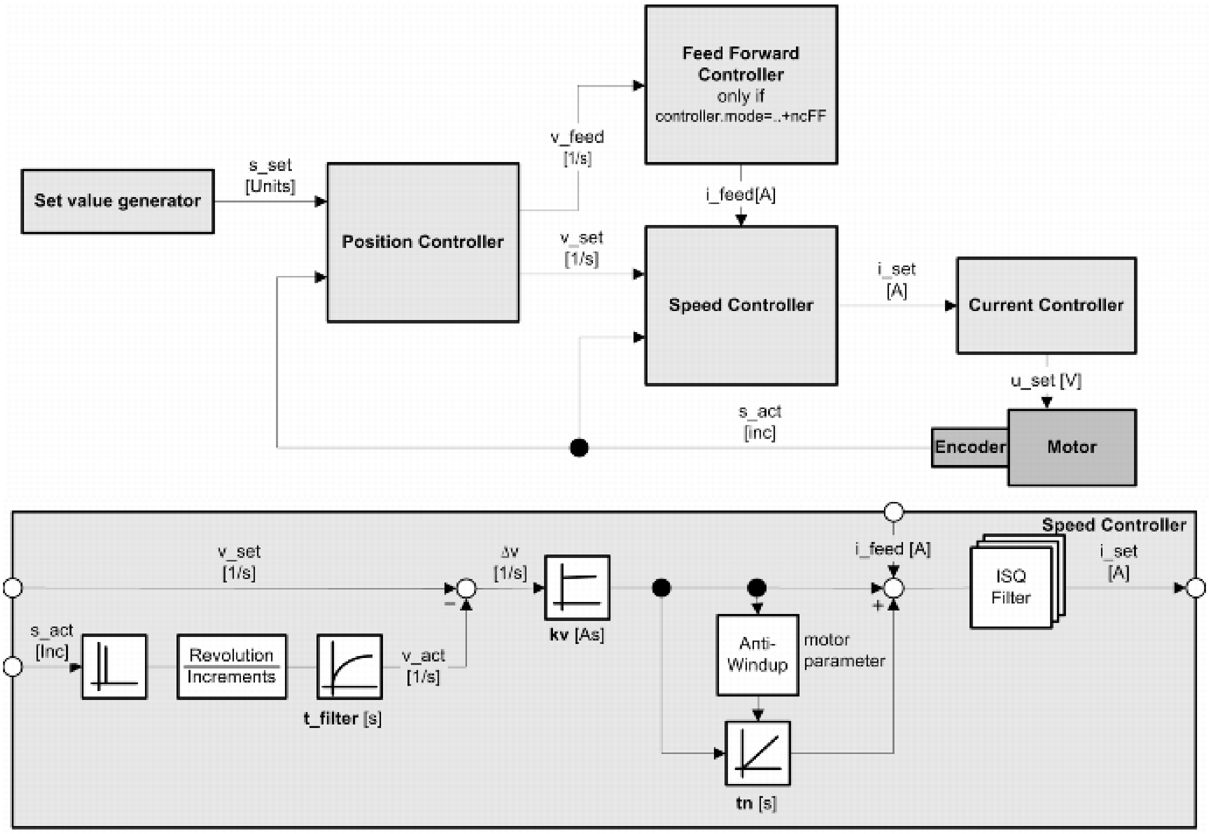


Figure 16: Overview block diagram and detail block diagram of the position controller

The speed setpoint from the position controller is first fed through an interpolator. This is necessary because the position controller runs at a cycle time of 400 µs, whereas the speed controller runs at 200 µs[2]. The value is then limited using the maximum motor speed.

The actual speed is determined by differentiating the encoder position. The value is then sent through the speed filter. The value is converted from "incr./s" to the unit "rev/s" before it can be subtracted from the speed setpoint.

The functioning of the speed filter is described in more detail.

The P component with the factor "kv" allows the controller to react immediately to any control deviation. This makes it crucial for the dynamics of the speed controller.

The I component with integral action time "tn" is used to compensate for stationary disturbance variables (e.g. load torque).

The output of the PI controller can be filtered using different current setpoint filters. The function of the filter will be explained.

[2] The sampling times are dependent on the set component.The exact data can be found in the data sheet of the respective component.

Before the current setpoint can be provided as the reference variable for the current controller, the value is limited using a torque limiter. This torque limitation also determines the anti-windup limits for the speed controller I component.

3.3.1 Torque limiting

The torque limiter is mostly used to protect the motor and the ACOPOS servo drive from the following risks:

- The ACOPOS servo drive cannot output more current than the motor can handle (motor peak current).
- The motor's stator current cannot exceed the ACOPOS peak current.

By default, the torque limiter is pre-initialized using the smaller of the following two values:

- Motor peak current (MOTOR_CURR_MAX)
- ACOPOS peak current (ACOPOS_CURR_MAX)

Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions \ Drive control \ Torque limiter

Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions \ Motor \ Synchronous motor

Motion control \ ACP10/ARNC0 \ Libraries \ ACP10_MC \ Categorized function blocks \ Torque control \ Torque limiting

3.3.2 Current setpoint filter

The current setpoint filter ISQ_FILTER is made up of a cascade of up to three different filters. The filter cascade is placed on the speed controller input and filters the quadrature current setpoint isq. For example, the filters serve to separate very frequent disturbances (e.g. signal interference) from a wanted signal or to suppress resonant frequencies (band-stop filter).

Disturbance in the encoder signal can be caused by one or more of the following:

- Coupling of disturbances on the communication path (encoder cable).
- Quantization interference when converting the analog signal to digital form. This mostly occurs when evaluating a resolver signal with low resolution.

With warp-resistant drive mechanics (e.g. direct load coupling to the motor shaft using fastening devices), the mechanical system can be subject to oscillations due to closed control loop ("two-mass oscillation"). These types of systems generally have a resonance frequency in the range from 700 to 1500 Hz. Furthermore, this is dependent on the following factors:

- Rigidity of the mechanical system
- Mass inertia of the mechanical system
- Physical layout of the system

Speed filter

The actual speed is filtered before it is processed further in the speed controller. This filter is known as a "speed filter" and functions like a low pass. High-frequency disturbances can be filtered out from the speed signal using this low pass behavior. This makes it possible to achieve higher controller quality.

Parts of the desired signal will also be filtered out if the limit frequency of the low pass filter is set too low.

Band-stop filter

Using the notch filter, the frequency range of the current setpoint can filter for the current controller.

A band-stop filter should only be used on mechanics with a rigid coupling (e.g. direct drive). This filter should not be used for connections such as belts or gears!

Furthermore, it can only be used if the existing moments of inertia are always constant!

The resonance frequency of the system could shift as a result of mechanical wear. This means that over time the defined filter can lose its effectiveness.

The notch filter is only effective when the resonance frequency is in the range from 700 to 1500 Hz.

The filter has the highest amount of damping at the "notch frequency" entered (= resonant frequency of the mechanical system). There is a range (bandwidth) around this notch frequency in which the damping is lower than 3 dB. The smaller the bandwidth is set, the stronger the damping is in the notch frequency.

The band-stop filter can be used (once all of the requirements for use have been met) to increase the controller gain factors, without causing the entire system to become unstable.

All the rest of the 9 available current setpoint filter are described in the reference manual.

Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions \ Drive control \ Current setpoint filter

3.4 Current controller

The current controller is made up of PI controllers (like the position and speed controllers). The corresponding parameters are automatically determined by the servo drive using the motor parameters and the specific ACOPOS parameters.

The current controller uses its manipulated variable to control the IGBTs (Insulated Gate Bipolar Transistor). These then output a pulse width modulated (PWM) current signal to the motor. The current controller works with different cycle times depending on the PWM switching frequency[3].

[3] For example, a switching frequency of 20 kHz results in a current controller cycle time of 50 µs. The possible switching frequencies can always be found in the data sheet of the servo drive or inverter module.

4 Theoretically determining control parameters

In the previous sections we learned how the ACOPOS servo drive controllers are structured and interrelated. Now we want to find the corresponding values for the control parameters. These values can be calculated or determined empirically if some of the requirements have not been met.

We can use the following formulas to determine good starting values for the control parameters if we already know the system's total moment of inertia and if the load is fixed to the motor. In most cases, we will achieve even better controller behavior by making fine adjustments to the parameter values manually.

?

Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions

- Drive identification \ Control parameters (autotuning) \ Procedure to auto-tune the speed and position controller \ Approximate parametrization
- Drive control \ Cycle time of the controller cascade

4.1 Speed controller

Replacement time constant T_I of the current control loop:

$$T_I = 2 \times \left(0{,}000075 + \frac{1}{2 \times switching\_frequency}\right)$$

Summation of the individual time constants to a replacement time constant T_{σ_v}:

$$T_{\sigma\_v} = T_I + T_{tot\_v} + T_{filter}$$

T_{tot_v} = 0.000175 s (encoder interface dead time, speed determination and sampling)

T_{filter} ("t_filter" parameter) = Filter time constant of the speed filter

Proportional gain of the speed controller:

$$kv = \frac{J \times \sqrt{2} \times \pi}{T_{\sigma\_v} \times k_t}$$

J = Total moment of inertia (J_{motor} + J_{brake} + J_{load})

k_t = Torque constant of the motor being used [Nm/A]

Integral action time of the speed controller:

$$tn = 4 \times T_{\sigma\_v}$$

4.2 Position controller

Summation of the individual time constants to a replacement time constant T_{σ_p}:

$$T_{\sigma\_p} = T_{\mathrm{interpol}} + 4 \times T_{\sigma\_v} + T_{tot\_p}$$

Tinterpol = Dead time resulting from interpolator (0.0001 s)

4 x T_{σ_v} = Replacement time constant of the speed control loop

T_{tot_p} = Dead time resulting from sampling (0.0002 s)

Proportional gain of the position controller:

$$kv = \frac{1}{2 \times T_{\sigma\_p}}$$

Integral action time of the position controller:

$$tn = 4 \times T_{\sigma\_p}$$

Parametrization of the motor "8LSA23.ee060ffgg-3" without a load

k_t = 0.73 Nm/A

J = 0.07 kgcm²

Switching frequency = 10 kHz

Speed controller:

$$T_I = 2 \times \left(0{,}000075 + \frac{1}{2 \times switching\_frequency}\right) = 2 \times \left(0{,}000075 + \frac{1}{2 \times 10000}\right) = \underline{0{,}00025\,s}$$

$$T_{\sigma\_v} = T_I + T_{tot\_v} + T_{filter} = 0.00025 + 0.000175 + 0 = \underline{0.000425\,s}$$

$$kv = \frac{J \times \sqrt{2} \times \pi}{T_{\sigma\_v} \times k_t} = \frac{0.000007 \times \sqrt{2} \times \pi}{0.000425 \times 0.73} = \underline{0.100\,As/\mathrm{rev}}$$

$$tn = 4 \times T_{\sigma\_v} = 4 \times 0.000425 = \underline{0.0017\,s}$$

Position controller:

$$T_{\sigma\_p} = T_{\mathrm{interpol}} + 4 \times T_{\sigma\_v} + T_{tot\_p} = 0.0001 + 4 \times 0.000425 + 0.0002 = \underline{0.002\,s}$$

$$kv = \frac{1}{2 \times T_{\sigma\_p}} = \frac{1}{2 \times 0.002} = \underline{250\frac{1}{s}}$$

$$tn = 4 \times T_{\sigma\_p} = 4 \times 0.002 = \underline{0.008\,s}$$

5 Procedure for tuning the controller

In this section we will learn about a possibility for determining control parameters, which has been proven time and time again in the field. This will allow you to check and make fine adjustments to values that have already been calculated. If this is not possible, suitable values can be determined empirically. In this case, the values specified in the corresponding notes can be used as start values.

The autotuning functions can be used to ease the calculation of the controller settings (see 6 "Determining control settings using autotuning" on page 38).

Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions \ Drive identification \ Controller parameters (autotuning) \ Sequence autotuning speed and position controller

- Approximate parameter settings

Motion control \ ACP10/ARNC0 \ Commissioning \ Autotuning

5.1 General information

The control parameters only really have to be determined when the mechanics are already put together. When dealing with a machine where the axis is loaded with different masses, the parameters must be tested both without a load and with the highest load. The parameters should also be tested at different speeds and accelerations.

These tests could result in the need for a compromise.

Globally valid values for the control parameters cannot be used because all mechanics have different features.

To determine parameters of cascaded controllers, it is best to start from the bottom (last) controller and work up. In our case, this means that we would start by setting the speed controller first followed by the position controller. The current controller is automatically parametrized by the ACOPOS servo drive.

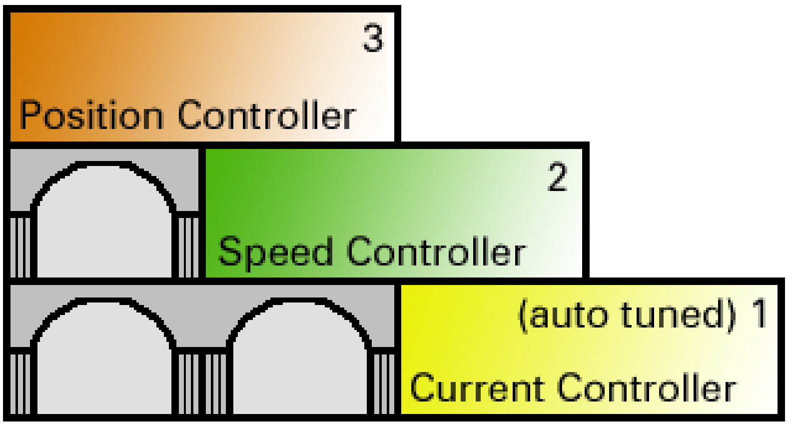


Figure 17: Order for setting the controllers

It is usually the goal to set the controller as "hard" as possible. A controller can be considered "hard" when a disturbance variable is compensated for as quickly and perfectly as possible.

Procedure for tuning the controller

We want to manually rotate a flywheel mass which is mounted to the motor shaft.

- The controllers are set "soft" if the flywheel mass can be easily rotated.
- The controllers are set "hard" if the flywheel mass is difficult to rotate or cannot be rotated at all.

However, sometimes it is not the goal to set the controller as hard as possible. This is because a hard closed-loop control can cause quick heating, a higher load on the mechanics and therefore more wear. This is the reason why a compromise must often be found when determining the parameters.

We will be using the NC test window to help us set the control parameters. This allows us to change and initialize the control parameters online. This also makes it possible to start positioning movements using any base motion parameters. We can also configure, start and evaluate the trace in the NC test window.

The behavior of the controller during a typical movement can be estimated very accurately by selecting suitable parameters for tracing. Therefore, a base movement (e.g. relative or absolute movement) is usually started and the corresponding parameters are recorded.

Furthermore, the control parameters should be selected so that oscillation in the recorded values is kept to a minimum.

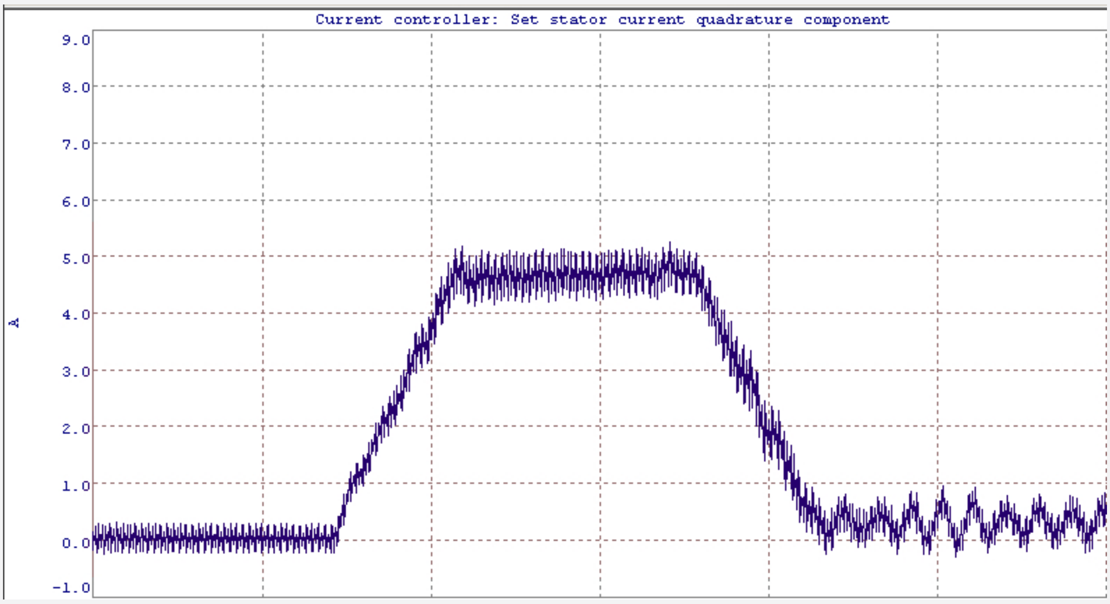


Figure 18: Stark oscillation – Optimization of settings required

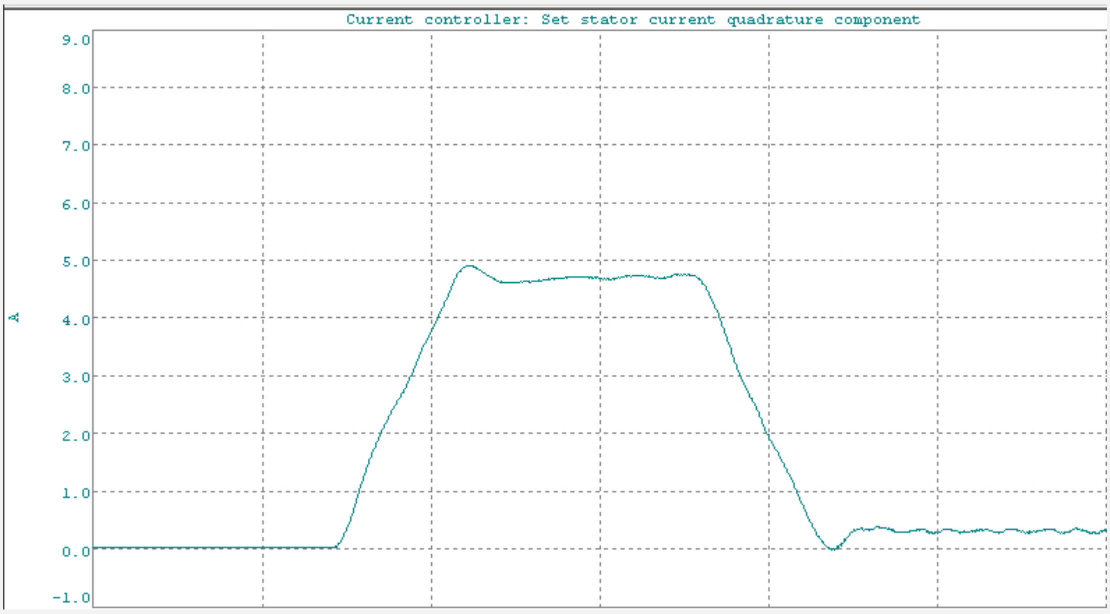


Figure 19: Almost no oscillation

The user must then check to make sure that all of the requirements have been met (e.g. lag error within the tolerance) once all parameters have been set.

If this is the case, make sure that there are reserves for the gain factors because the system can behave differently due to mechanical wear. Therefore, a corresponding reserve (approx. 1/3) should be taken from the determined values.

5.2 Speed controller

The following parameters are provided in the data structure of the speed controller. The following three parameters as well as up to three current setpoint filters can be set for the speed controller. These parameters are located in a subgroup of the control parameters:

Element	Data Type	Description	
...			
speed		**Speed Controller**	
kv	REAL	Proportional amplification [A sec / Revolutions]	
tn	REAL	Integral action time [sec]	
t_filter	REAL	Filter time constant [sec] (from V1.12 on)	
isq_filter1		**ISQ Filter1 (from V1.24 on)**	
type	UINT	Type (default setting: ncOFF):	
		ncOFF:	Filter switched off
		ncLOW_PASS:	Low pass
		ncNOTCH:	Notch
		ncZ_TRANS:	z transfer function
		ncISQF_LIM:	Limitation (from V2.06 on)
		ncISQF_LIM2:	Limitation 2 (from V2.06 on)
		ncISQF_LIM3:	Limitation 3 (from V2.06 on)
		ncISQF_COMP:	Compensation (from V2.06 on)
		ncISQF_TRQ_ADDLIM:	Torque ADDLIM function (from V2.37 on)
		ncBIQUAD:	Biquad (from V2.19 on)
a0	REAL	Coefficient a0	
a1	REAL	Coefficient a1	
b0	REAL	Coefficient b0	
b1	REAL	Coefficient b1	
b2	REAL	Coefficient b2	
c0_par_id	UINT	Parameter ID for coefficient c0 (from V2.06 on)	
c1_par_id	UINT	Parameter ID for coefficient c1 (from V2.06 on)	
isq_filter2		**ISQ Filter2 (from V1.24 on)**	
type	UINT	Type (default setting: ncOFF):	

Figure 20: Control parameters - Speed controller

When setting the speed controller, the following parameters can be configured in the NC Trace for recording:

- Speed setpoint: SCTRL_SPEED_REF (ID 250) [1/s]
- Actual speed: SCTRL_SPEED_ACT (ID 251) [1/s]
- Current controller: Stator current setpoint of quadrature component ICTRL_ISQ_REF (ID213) [A]

The scan rate should be set as low as possible (approx. 0.2 to 4 ms).

A trigger event can be used to start the NC Trace as accurately as possible (further information can be found in the Automation Studio help system).

The "kv" and "tn" parameters of the position controller should be initialized with the value "0" so that only the speed controller is active.

The value from "current controller: stator current setpoint of the quadrature component" is the torque generating component of the current setpoint.

The peak value of the current is displayed in the NC Trace. This value must be divided by the factor √2 (≈1.414) to compare it with the specifications of the motor parameters and the ACOPOS servo drive parameters.

Motion control \ ACP10/ARNC0 \ Reference manual \ ACP10 \ ACOPOS parameter IDs \

- CTRL speed
- CTRL current

Motion control \ ACP10/ARNC0 Reference manual \ NC \ ACP10 objects \ "ncAXIS" NC object \ Closed-loop controller \ Data structure

Motion control \ ACP10/ARNC0 \ NC Diagnose \ NC Trace \ Configuration

5.2.1 Proportional gain "kv"

The most important parameter of the speed controller parameters is the gain factor "kv". This parameter significantly determines the dynamic properties of this controller. The goal is to set the value as large as possible without causing the system to oscillate.

1/5 to 1/10 of the nominal motor current (I_n) can be used as starting value for this factor.

Example:

Difference between the speed setpoint and the actual speed:	1 rev/s
Value of the factor "kv":	2 As/rev
Output value of the P component:	2 A

5.2.2 Integral action time "tn"

For most applications it is not necessary to use an integral action time in the speed controller ("tn" = 0 s). However, this time value should not be set too low if an application does require an I component (e.g. to compensate for load-side disturbances, poor (soft) load coupling, high speed precision). Otherwise, the tendency for oscillation is increased in the speed controller.

100 ms (0.1 s) can be used as starting value for the integral action time if you want to use the I component. The value can then be gradually reduced.

5.2.3 Speed filter

The filter time constant "t_filter" for the speed filter is the last parameter in the speed control parameters. It can be used to set the limit frequency with the unit [s] (e.g. 1 kHz equals 0.001 s).

Improvement to the controller behavior using the speed filter can only be achieved in systems with a high mass moment of inertia and encoder systems with a low resolution (e.g. resolver). Whereas if encoder systems with a high resolution are used, the speed filter generally cannot create any improvements in the controller behavior.

You can start with a value of 0.8 ms (0.0008 s). This value can be then be gradually increased until the controller behavior (reduced oscillation) has improved. Generally, the usable values are in the range from 0.8 ms to 2 ms.

5.2.4 Motion control \ ACP10/ARNC0 Current setpoint filter

The current setpoint filters (e.g. band-stop filter) also work in the speed controller.

Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions \ Drive control \ Current setpoint filter

Determining parameters for band-stop filter

The resonance frequency of the system can be determined using the following steps:

- Initialize the position controller parameters with the value "0", deactivate the speed filter (t_filter = 0) and deactivate the current setpoint filter.
- Switch on controller.
- The proportional gain of the speed controller is increased until the mechanics oscillate.
- Record the actual speed using the trace (scan rate = 200 µs). Switch the controller off again when the trace has finished.
- Analyze the frequency spectrum in the trace using FFT (Fast Fourier Transformation).
- Set the most notable frequency occurring in the trace as notch frequency for the band-stop filter.
- Enter a minimum bandwidth (e.g. 25 Hz).
- Switch the controller on again and determine a critical proportional gain for the speed controller.
- If the critical value has increased, determine if the behavior has further improved due to variation in the bandwidth and the notch frequency. Otherwise, determine a characteristic natural frequency again.
- If further improvement is no longer possible, the determined values can be entered in, for example, the NC Init module or the mapp configuration for the MpAxisBasic component.

The band-stop filter cannot be used if a distinct resonant frequency cannot be determined.

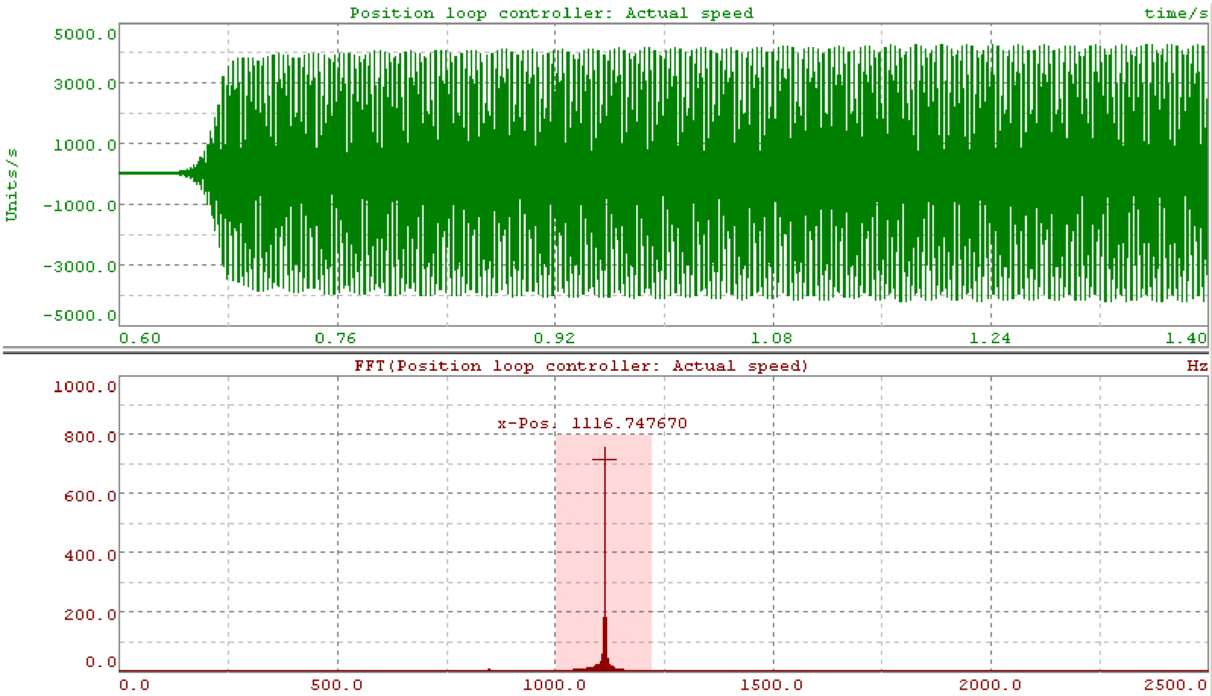


Figure 21: Analyzing the frequency spectrum in the NC Trace - Determining resonant frequency with FFT

? Motion control \ ACP10/ARNC0 \ NC Diagnose \ NC Trace \ Calculations \ Special functions

Servo Loop Optimizer

The Servo Loop Optimizer (SLO) provides a way to configure a servo drive's controller with the aid of frequency responses. SLO is based on autotuning but offers the ability to fine-tune the calculated settings and examine their effects through measurement.

? Motion control \ ACP10/ARNC0 \ NC Diagnose \ Servo Loop \ Optimizer \ Controller configuration range

- Plant
- Speed controller
- Position controller

Exercise: Manually determine the controller settings and filter settings for the speed controller

The base movement parameters to be used are already predefined in the NC Init module.

The positioning path is "s" = ± 50000 units

A stationary manipulated variable is simulated in the example project using an additive torque setpoint.

Parameters for the NC Trace:

Maximum trace duration:	2 seconds

Sampling rate:	0.0008 seconds

Use the flow chart (see 5.5 "Overview for setting control parameters") to set the speed controller in steps.

1) What happens in this case if the value "0" is entered for the position control parameter "kv"?
2) Can a band-stop filter be used/set as a current setpoint filter?
3) Can the speed filter be used/set?
4) Would you set an integral action time "tn" for the speed controller?

5.3 Position controller

The parameters for setting the position controller are located in a subgroup of the control parameters:

Element	Data Type	Description
...		
position		**Position controller**
kv	REAL	Proportional amplification [1/sec]
tn	REAL	Integral action time [sec]
t_predict	REAL	Prediction time [sec]
t_total	REAL	Total delay time [sec]
p_max	REAL	Max. proportional action [Units/sec]
i_max	REAL	Max. integral action [Units/sec]

Figure 22: Control parameters - Position controller

The following parameters can be configured for recording with the NC Trace when setting the position controller:

- Actual speed of the position controller: PCTRL_V_ACT (ID 92) [units/s]
- Lag error of the position controller: PCTRL_LAG_ERROR (ID112) [units]
- Quadrature component of the current controller stator current setpoint: ICTR-L_ISQ_ACT (ID214) [A]

The sampling rate should be set as low as possible in this case as well.

Motion control \ ACP10/ARNC0 \ Reference manual \ ACP10 \ ACOPOS parameter IDs

- CTRL position controller
- CTRL current

Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions \ Drive control \ Position controller

5.3.1 Proportional gain "kv"

The value of the "kv" factor should also be set as large as possible for the position controller without causing the controller to oscillate.

You can start with a value of 50/s and increase it gradually.

Lag error:	15 units
Value of the factor "kv":	100/s
Output value of the P component:	1,500 Units/sec

5.3.2 Integral action time "tn"

Similar conditions also apply for this value as for the integral action time of the speed controller. For some applications it is sufficient to just use just one P controller. An I component must be used if an axis has to compensate for a stationary disturbance variable (e.g. hanging load). Furthermore, it may be necessary to use the I component of the position controller if the speed controller was only able to be set soft.

The integral action time does not have to be set for the position controller if already set for the speed controller.

You can also use a starting value of 100 ms if necessary in this case.

An I component in the position controller causes oscillation when the target position is reached and therefore should only be used in special cases.

5.3.3 Compensation of delay times

Transferring data from a coupling master to a coupling slave via a network results in a delay. This can be compensated on the coupling master using the position controller parameter for total delay time ("t_total"). Details regarding the compensation of delay times and how they are calculated can be found in the **"Calculation of delay times" table**. The table is provided in Automation Help as a download.

It is necessary to configure a broadcast channel in order to couple an axis to setpoints that originate from outside of the network.

Motion control \ ACP10/ARNC0 \ Libraries \ ACP10_MC \ Categorized function blocks \ Important points \ Axis coupling

- Compensation of delay times
- Coupling axes to different networks

Position controller total delay time ("t_total") in the controller block diagram

The ACOPOS block diagram is shown in the upper part of the figure. In it, the setpoint generator supplies the position controller with the position setpoint. In the lower part, the position controller is shown in detail. Here you can see, among other things, how the value of "t_total" is applied in the position controller.

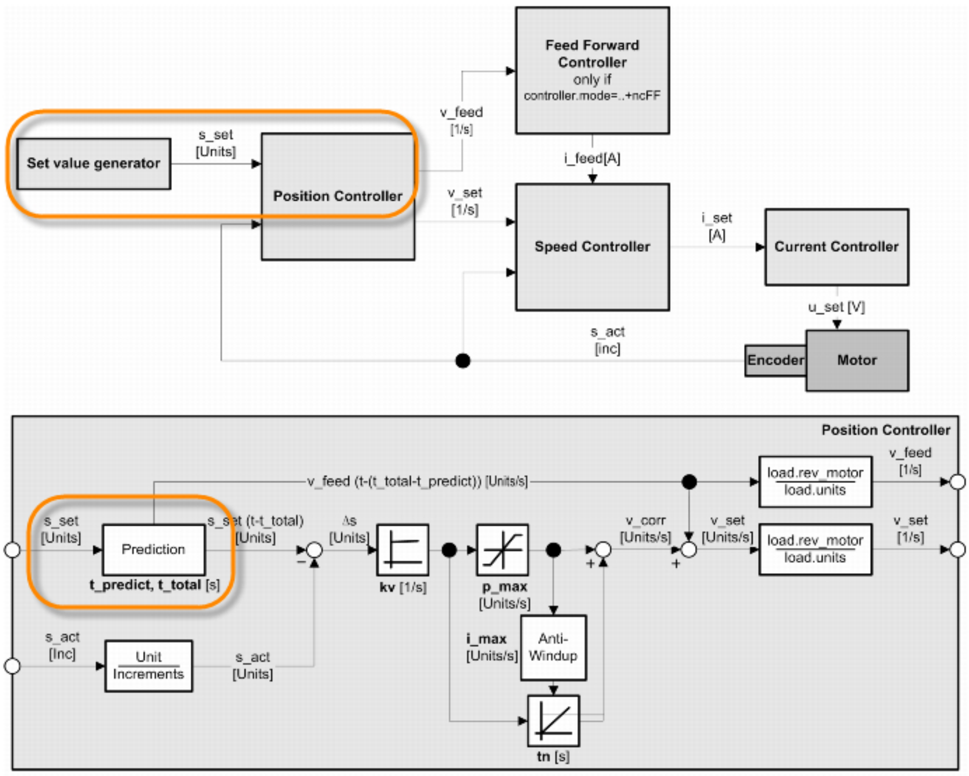
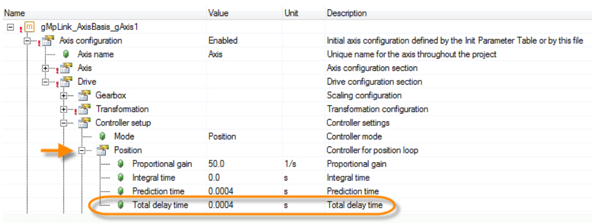


Figure 23: "ncPOSITION" block diagram controller mode

Motion control \ ACP10/ARNC0 \ Reference manual \ ACP10 \ NC objects \ NC object "ncAXIS" \ Controller \ Controller mode "ncPOSITION"



Name	Value	Unit	Description
gMpLink_AxisBasis_gAxis1			
Axis configuration	Enabled		Initial axis configuration defined by the Init Parameter Table or by this file
Axis name	Axis		Unique name for the axis throughout the project
Axis			Axis configuration section
Drive			Drive configuration section
Gearbox			Scaling configuration
Transformation			Transformation configuration
Controller setup			Controller settings
Mode	Position		Controller mode
Position			Controller for position loop
Proportional gain	50.0	1/s	Proportional gain
Integral time	0.0	s	Integral time
Prediction time	0.0004	s	Prediction time
Total delay time	0.0004	s	Total delay time

Figure 24: Configuration of "t_total" in the mapp configuration for MpAxisBasic

The "t_total" parameter is configured in the mapp configuration with the parameters for the position controller.

"t_total" monitoring

It's necessary to configure this properly so that the compensation of the delay times on the network works. CTRL position controller: The effect of the compensation can be determined by plotting the "PCTRL_V_SET" parameter: Parameter ID 114: CTRL position controller: Velocity setpoint" with the NC Trace on all coupling axes. In the NC Trace, the setpoint for the velocity setpoint must be changed simultaneously on all coupling axes when a set-point is changed on the coupling master.

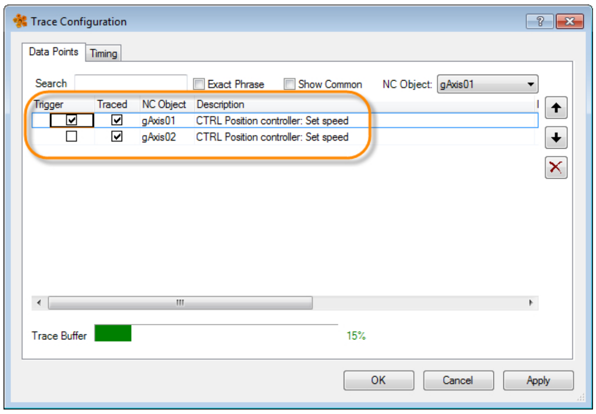


Figure 25: Trace configuration for plotting the velocity setpoint of the position controller for all coupling axes

The following figure shows an NC Trace recording in which the value for the velocity setpoint of the position controller for two coupling axes has been plotted. The recording interval for this NC Trace has been configured with 400 µs. Placing the measurement cursor at a random position results in the same setpoint for both curves. If a deviation is recognized, then the configuration of the "t_total" parameter is unsuitable.

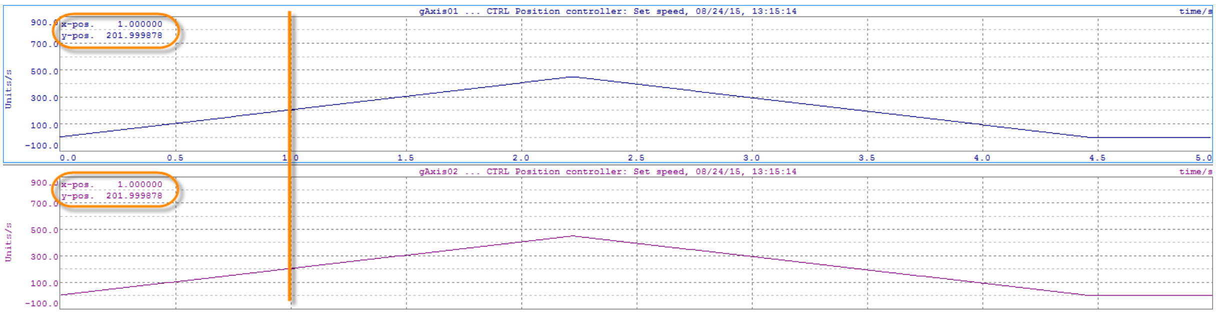


Figure 26: Recording PCTRL_V_SET: Parameter ID 114 on all coupling axes

Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions \

- Driver controller \ Position controller
- Controller identification \ Controller parameters (autotuning)

Additional information

Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions \ Network, position coupling and axis cross-link

- Network coupling
- Axis cross-link

Motion control \ ACP10/ARNC0 \ Reference manual \ ACP10SDC

- Feed forward and delay compensation
- Setpoint / position setpoint calculation - SDC internal

5.3.3.1 Total delay time "t_total"

In a single-axis application, this parameter should be initialized with the same value as the prediction time.

The delay via the network can be compensated using the "t_total" in multi-axis applications.

The potential value range is also as large as in the parameter "t_predict".

5.3.3.2 Prediction time "t_predict"

This parameter is required for the feed forward. A value "t_predict = 0 s" disables the feed forward.

The prediction time makes it possible to compensate for the lag error during the acceleration and deceleration phase to approximately "0". This parameter is generally set after correct values have been determined for "kv" and "tn".

> The potential value range of the "t_predict" parameter is 0.0 to 0.06 seconds.
>
> Generally, a large prediction time is not really necessary if the speed controller could be set hard.

Definition rule:

$$t\_predict = \frac{4 \times \pi \times J}{(kv_{speed\_controller} \times k_t)} + 0{,}0002$$

J = Moment of inertia on the motor [kgm²]

$kv_{speed\ controller}$ = Proportional gain of the speed controller [As/rev.]

k_t = Torque constant of the motor being used [Nm/A]

The following charts display the lag error for different prediction time values.

Corresponding speed profile:

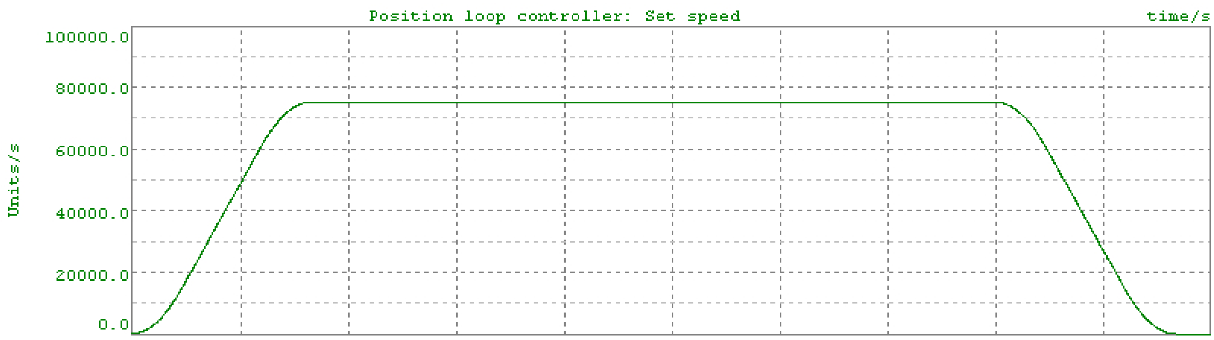


Figure 27: Speed curve for the following lag error curves

"t_predict" set too low:

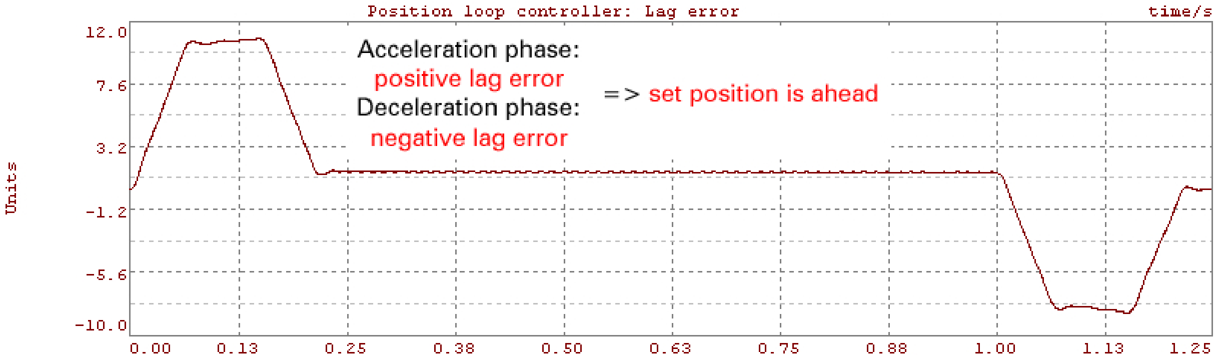


Figure 28: "t_predict" prediction time too low

"t_predict" set too high:

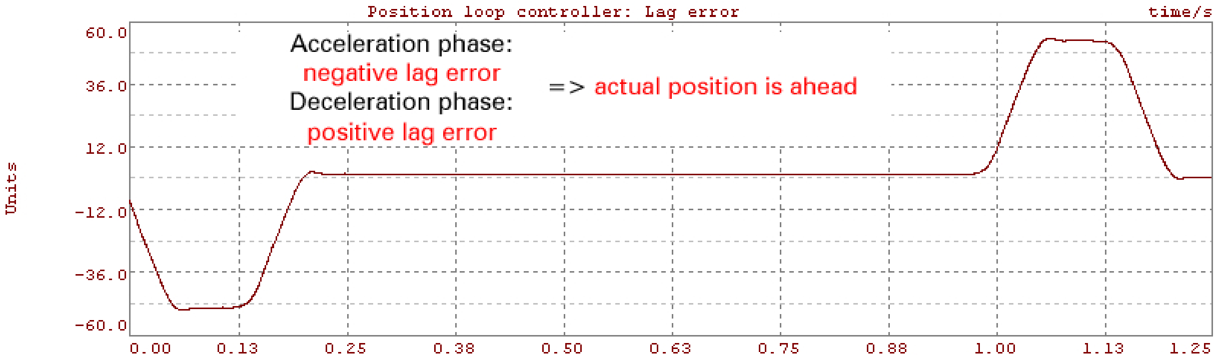


Figure 29: "t_predict" prediction time too high

"t_predict" set appropriately:

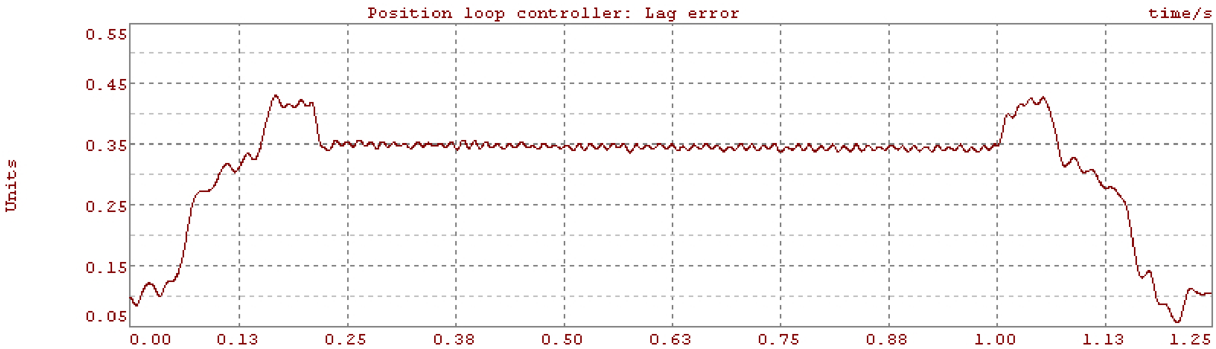


Figure 30: "t_predict" prediction time appropriate

5.3.4 Maximum proportional action "p_max"

The influence of the proportional gain can be limited using the "p_max" parameter. This can be done to prevent manipulated variables that are too large.

The value for this parameter can be calculated using the following formulas:

$$p\_max = \frac{I_{max} \times 2}{kv_{speed\_controller}} \times unit\_factor$$

I_{max} = Motor peak current [A]

$kv_{speed\ controller}$ = Proportional gain of the speed controller [As/rev.]

Unit factor = Unit scaling [units/rev.]

5.3.5 Maximum integral action "i_max"

The maximum influence of the integral element can be limited using the "i_max" parameter. This can be done to prevent a "windup".

The value for this parameter can be calculated using the following formula to achieve a required holding torque:

$$i\_max = \frac{\frac{M}{k_t} \times 1,1}{kv_{speed\_controller}} \times unit\_factor$$

M = Required holding torque [Nm]

k_t = Torque constant of the motor being used [Nm/A]

$kv_{speed\ controller}$ = Proportional gain of the speed controller [As/rev.]

Unit factor = Unit scaling [units/rev.]

Exercise: Manually determine the controller settings for the position controller

The same project and same hardware are used for this exercise as before.

The base movement parameters to be used are already defined in the NC Init module.

Positioning path "s" = ± 50000 units

A stationary manipulated variable is simulated in the example project using an additive torque setpoint.

Parameters for the trace:

Max. trace duration:	2 seconds
Sampling rate:	0.0008 seconds

Use the flow chart (see 5.5 "Overview for setting control parameters") to set the position controller step by step. The values of the speed controller obtained in the previous exercise form the basis.

1) What happens if you don't use an integral action time "tn" for the position controller?

? Motion control \ ACP10/ARNC0 \ Reference manual \ ACOPOS drive functions \ Drive control \ Position controller \ Function \ Closed-loop controller

5.4 Limit value parameter

When the control parameters are optimized, two parameters must still be set for the limit values.

5.4.1 "t_jolt” jerk time filter

The value for the parameter can be determined by recording the lag error during a positioning movement without jerk filter time. At the end of this movement, it will become evident that the system must first "settle down". After being determined from the trace, the settling time (time until oscillation levels out) can now be used as jerk filter time "t_jolt".

Figure 31: Calculating "t_jolt" jerk time by observing the lag error in the position controller

5.4.2 Lag error cancellation limit

The two limits "ds_warning" and "ds_stop" are defined for lag error monitoring (difference between actual position and position setpoint in position controller).

Element	Data Type	Description
...		
limit		**Limit values**
...		
parameter		**Parameters**
...		
ds_warning	REAL	If the lag error exceeds "ds_warning", a warning will be indicated
ds_stop	REAL	If the lag error exceeds "ds_stop", an active movement will be stopped
...		

Figure 32: Limit value parameter - Lag error cancellation limit

A warning is output if the current lag error value set for the "ds_warning" parameter is exceeded. An emergency stop is executed if the value of the "ds_stop" parameter is also exceeded.

A controlled emergency stop ramp is generated when an emergency stop occurs. The speed setpoint is decelerated to "0" using the current initialized limit values. The controller is then switched off.

The value for "ds_stop" can be determined using the following calculation:

$$\frac{I_{max}}{kv_{speed\_controller} \times kv_{position\_controller}} \times 2 \times unit\_factor$$

I_{max} = Motor peak current [A]

$kv_{speed\ controller}$ = Proportional gain of the speed controller [As/rev.]

$kv_{position\ controller}$ = Proportional gain of the position controller [1/sec]

Unit factor = Unit scaling [units/rev.]

Motion control \ ACP10/ARNC0 Reference manual \ ACP10 \ NC objects \ NC object "ncAXIS" \ Limit values

Motion control \ ACP10/ARNC0 Reference manual \ ACP10 \ NC object "ncAXIS" \ Aborting a movement

Exercise: Determining the limit value parameter

The same project and same hardware are used for this exercise as in the previous exercises.

The base movement parameters to be used are already defined in the NC Init module.

Positioning path "s" = ± 50000 units

A stationary manipulated variable is simulated in the example project using an additive torque setpoint.

Parameters for the trace:

Maximum trace duration:	2 seconds
Sampling rate:	0.0008 seconds

Set the limit value parameters correctly and check the result.

5.5 Overview for setting control parameters

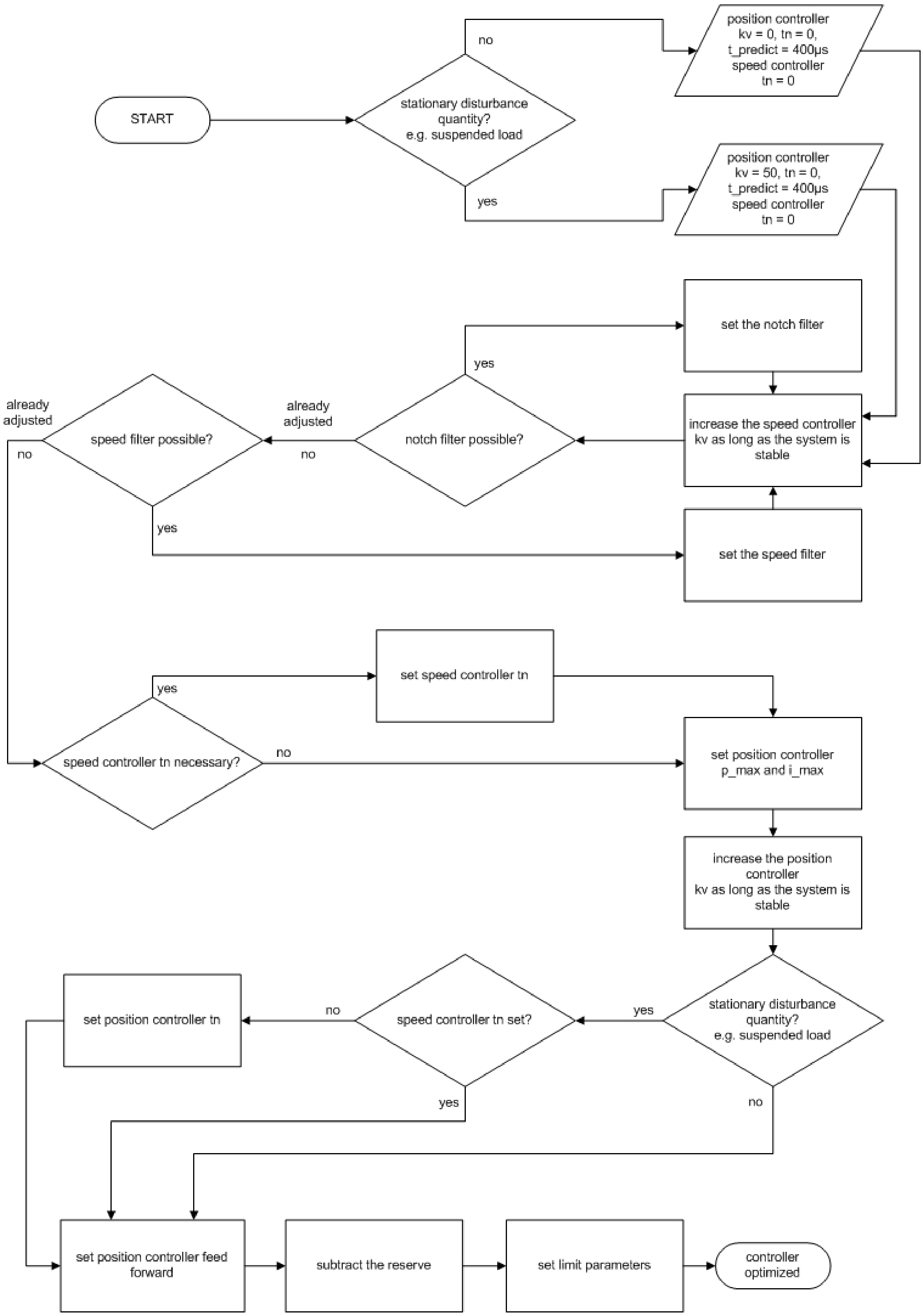


Figure 33: Overview of the process for setting the control parameters

6 Determining control settings using autotuning

B&R drive software is based on a cascaded control concept. A position setpoint is provided to the position controller by a setpoint generator that calculates a path profile upon receiving a positioning command. To achieve this position setpoint, the position controller specifies a speed profile. The task of the speed controller is to maintain the speed setpoint as closely as possible.

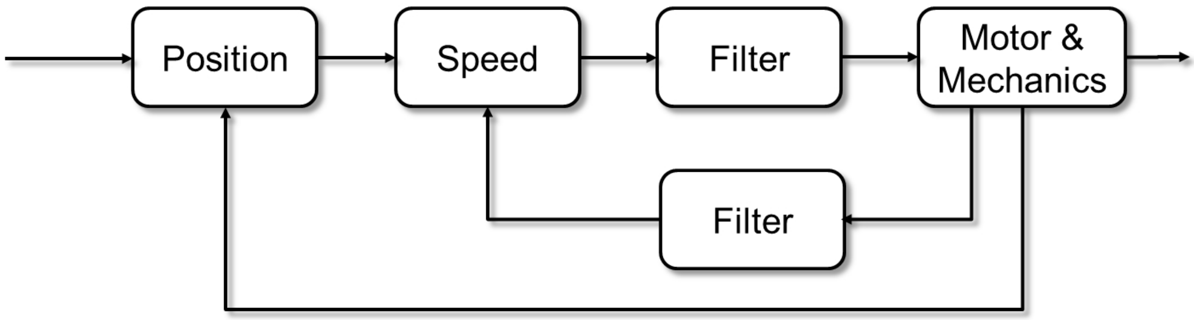


Figure 34: Simplified illustration of the cascaded control concept

The integrated autotuning procedure makes it possible to calculate the control parameters automatically. It is recommended that the parameters for closed-loop control be calculated in the following order: speed controller, followed by position controller. The control settings should then be tested before determining the parameters for the feed forward.

Preparing autotuning

The drive must be operational before autotuning can be carried out. The functionality of the holding brake must then be checked. It is also necessary to check the measured direction of rotation and distance of the encoder. If any deviations are observed, or if another malfunction of the encoder is detected, the encoder must be checked both mechanically and electrically. The encoder should then be phased [4]. The tuning parameters can now be entered:

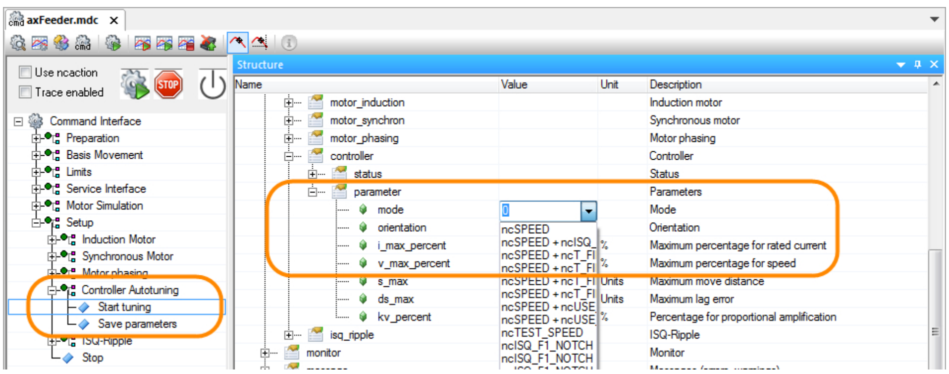


Figure 35: commands for autotuning in the command interface; tuning parameters in the parameter window of the NC Test window.

[4] Phasing is not normally required for B&R motors. Phasing is necessary, for example, if the encoder has been installed at a later time. Motor commissioning is described in detail in "TM460 – Initial Commissioning of Motors".

A suitable NC Trace configuration for analyzing each phase of the autotuning procedure is available in the "Motion control \ ACP10/ARNC0 \ Commissioning \ Autotuning" section of Automation Help.

Tune the cooling output

The speed controller's job is to determine the difference between the manipulated variable of the position controller (to which it is subordinate) and the measured speed. This calculates a manipulated variable for the subordinate current controller that works against a deviation in the speed by accelerating.

Selecting the "ncSPEED" autotuning mode[5] and restarting the tuning procedure from the command interface will determine the parameters for the speed controller.

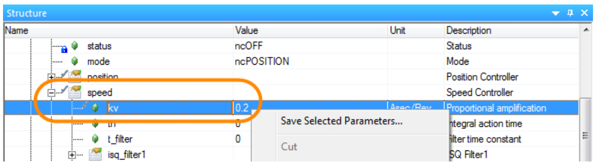


Figure 36: Viewing and saving the parameters in the parameter window

These parameters are displayed in the parameter window in the settings for the speed controller. They can be saved by selecting **<Save selected parameters>** from the shortcut menu.

Tuning the position controller

The purpose of the position controller is to compare the position provided by the setpoint generator to the actual position and to generate a manipulated variable for the subordinate speed controller that works against a position change by changing the speed.

Selecting the "ncPOSITION" autotuning mode and restarting the tuning procedure from the command interface will determine the parameters for the position controller.

This requires that the underlying speed controller is stable.

These parameters are displayed in the parameter window in the settings for the position controller. They can be saved by selecting **<Save selected parameters>** from the shortcut menu.

Testing the controller settings

Before a movement is executed with the new controller parameters, the control loop should be checked for stability. For this purpose, the system has the option of applying a short disturbance signal to the control loop ("ncTEST" autotuning mode). If the controller parameters are set correctly, the disturbance will decay. The images shown are only a guideline. The key factor is that the current or the speed should exhibit decay.

[5] Various filters (e.g. "ncSPEED + ncISQ_F1_NOTCH") are available when tuning the speed controller to stabilize the system.

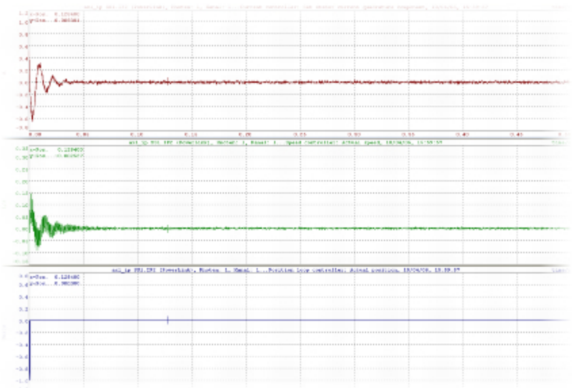


Figure 37: Example: Satisfactory controller parameters

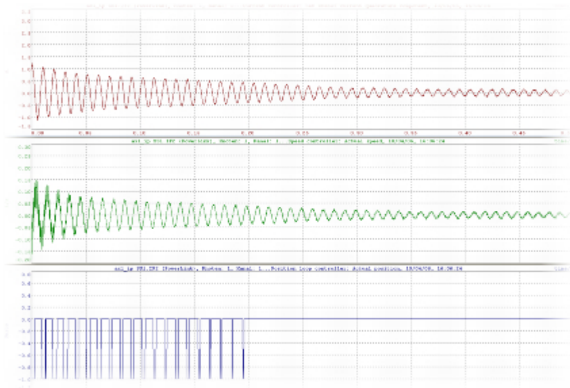


Figure 38: Example: Unsatisfactory controller parameters

It is a good idea to record several parameters to test the controller parameters. More information regarding how this can be configured is available in the Automation Studio help system.

Traced	Trigger	Description	ID
x		CTRL current: Stator current setpoint of the quadrature component	213
x		CTRL speed: Actual speed	251
x		CTRL position controller: Actual position	111
	x	Status: Controller	465

Table 1: Overview of parameters recorded in "ncTEST" tuning mode

Motion control \ ACP10/ARNC0 \ Reference manual \ ACP10 \

- NC objects \ NC object "ncAXIS" \ Setup \ Setup for controller (autotuning) \ Example: Setup for controller in NC Test
- Overview of ACOPOS parameter IDs

Feed-forward components

The purpose of the feed-forward component is to reduce the load on the controller when the speed changes. The values used by the feed-forward component take the system's moment of inertia into consideration and are determined during auto-tuning.

This requires that the underlying speed and position controllers are stable. To do so, the axis is put into motion and must be referenced.

Motion control \ ACP10/ARNC0 \ Commissioning

- Testing the holding brake
- Encoder phasing

Motion control \ ACP10/ARNC0 \ Commissioning \ Autotuning

- Preparing autotuning
- Speed controller
- Position controller
- Feed-forward components
- Testing controller settings

Motion control \ ACP10/ARNC0 \ Reference manual \ ACP10 \ NC objects \ NC object "ncAXIS" \ Setup \ Setup for controller (autotuning)

- Function
- Data structure
- Example: Setup for controller in NC Test

Exercise: Determining control parameters using autotuning

Use the autotuning procedure to determine the controller parameters for an axis. To do so, proceed as follows:

1) Open the NC Test window
2) Check the holding brake and encoder signal.
3) Perform autotuning for the speed controller.
4) Perform autotuning for the position controller.
5) Test the controller parameters.

7 Saving the controller settings

The data that has been determined must be saved to the controller so that it is available whenever the machine is started. All parameters available in the axis structure can be saved in an NC Init module or in the mapp configuration. Additional values can be recorded in a ACOPOS drive parameter table.

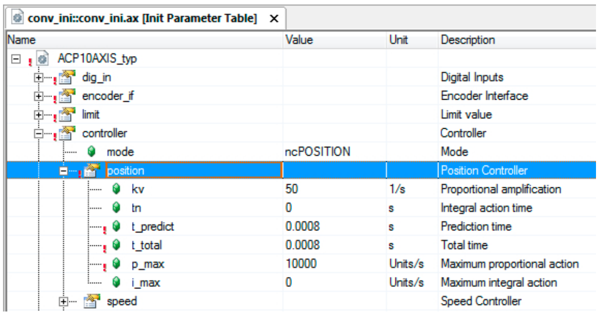


Figure 39: Controller settings in the NC Init module

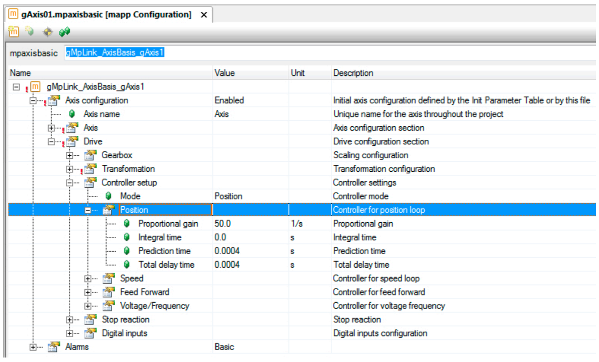


Figure 40: Controller settings in the mapp configuration

8 Summary

All relevant control parameters were explained and their effect was shown using the controller cascade. Knowledge about the theoretical determining of control parameters, about the approximate parametrization of the controller cascade, is just as important as the step-by-step procedure for manually setting the controller or using the integrated autotuning procedure. Additional current setpoint filters are provided in the speed controller for adjusting to the behavior of the drive mechanics. The NC Trace, the integrated autotuning procedure as well as the servo loop optimizer serve as a tool for parameterizing the drive solution.

The determined parameters display different values according to the application. However, the procedure for obtaining these values is always the same.

Figure 41: ACOPOSmulti system and synchronous motor

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