

Drive Optimization Guide

V3.0, 08/2023

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1 Advices before beginning



WARNING

Some of the functions and measurements described in this document trigger an axis movement.

The user bears the responsibility and must ensure that no persons or parts of the mechanics are harmed by carrying out the respective function / measurement.

Before starting, it must therefore be ensured that the working area is free and mechanical parts connected to the motor are fixed and sufficiently covered.

Comment traces

Comment all measured traces to be able to compare and evaluate changes later. It can be also used as a report!

Example:

Axis_1_speedCtrl_Kp=10_Tn=20_Filter_550_500_-20_0

Axis_1_posCtrl_ Kp=10_Tn=20_Filter_550_500_-20_0_Kv=150

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Manual optimization using frequency responses

Many of the measuring functions which are described in this document can only be used for TIA-Portal/Startdrive

For other drives or engineering systems like Scout/Starter other methods are available. These measuring functions were explicitly

Third-party motors

See "SINAMICS S120/S150: Requirements placed on third-party motors"

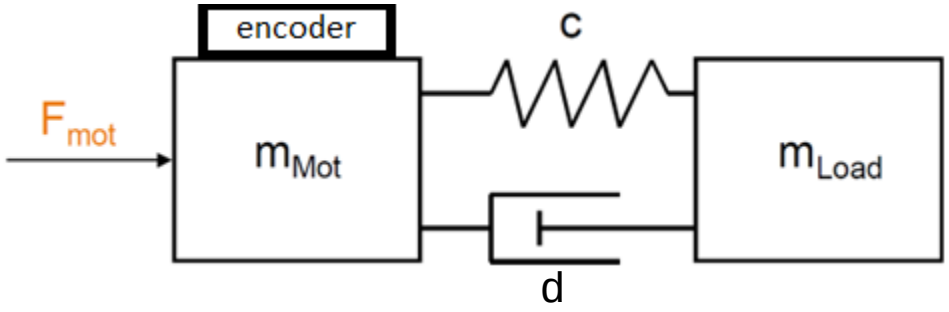
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2 Fundamentals & general information

2.1 Ideal two-mass-system

A mechanical system which is driven by a motor can be simplified by a so called two-mass-system.

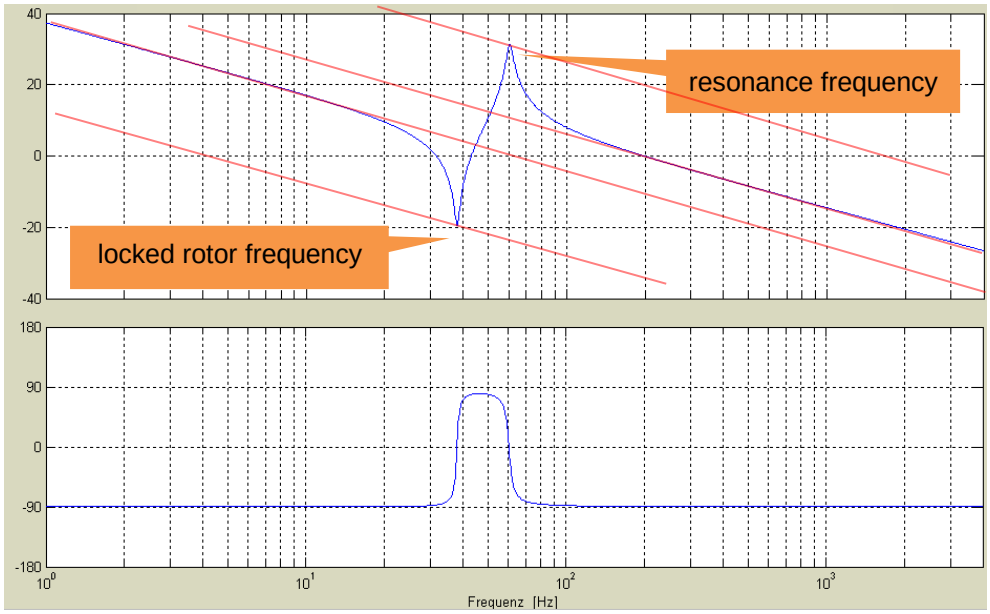
The connection between these two loads, the coupling, is described by stiffness (c) and a damping (d).



In the frequency domain the system has the following frequency response:

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Figure 2-1 Simulated speed-controlled system frequency response



This transfer function is the speed control system. The input is a PRBS-Torque-Signal, the output is the actual speed.

The two distinctive frequencies

- Locked-rotor-frequency (f_T) (zero)
- Resonance frequency (f_R) (pole)

define a load coupled to a motor.

The two frequencies are defined by the following formulas:

$$f_T = \frac{1}{2\pi} \cdot \sqrt{\frac{c}{J_{Load}}} \qquad f_R = \frac{1}{2\pi} \cdot \sqrt{c \cdot \left(\frac{1}{J_{Motor}} + \frac{1}{J_{Load}}\right)}$$

With the frequency pair locked-rotor-frequency/resonance frequency the load-mass gets decoupled from the system/motor. That implies, that an excitation of the load with frequency higher than locked-rotor-frequency is no longer possible. The energy transmission from motor to load is disconnected.

The amplitude drops with 20db/ decade. The level of the red parallel lines represents the inertia that exists in the system (see chapter 4.1). A lower level line means more inertia compared to a higher-level line.

For the ideal two-mass-system, the total inertia of the system can be read to the left of the locked rotor frequency, where the transfer function drops with 20dB/dec. Right of the resonance frequency, the load inertia has decoupled - only the motor inertia is visible.

The line through the zero point shows that at this frequency even a much higher inertia appears to be present. The movement of the load appears to be very energy consuming - it eliminates the movement of the engine.

In contrary, the line through the pole implies, there seems to be little inertia in the system. In this scenario the motor does not have to use that much energy in order to move the load - the load pushes the motor. It can lead to a resonance disaster.

Stiffness and damping are reflected in the frequency response in the expression of the amplitude overshoot and how fast the phase rises from -90 ° to 90 ° with the locked-rotor-frequency and tilts from 90 ° to -90 ° with the resonance frequency . Large overshoot and fast turn off phase corresponds to a poorly damped system (see Figure 2-1with Figure 2-2).

The frequency at -90 ° phase is also the peak of the amplitude overshoot. This is constant regardless of the attenuation.

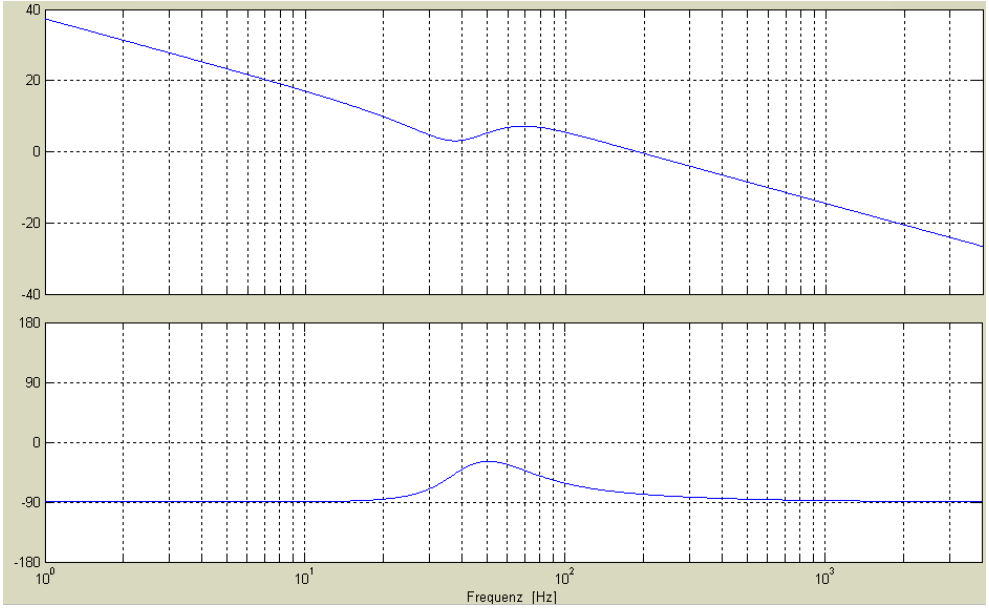
In a better damped system, the amplitudes of the pole and zero are much smaller. The phase does not tilt so fast.

In the real system, the damping corresponds to the friction.

In the time domain, the damping affects only the amplitude of an oscillation, but not the frequency. (A certain mass with a specific stiff compound oscillates in air at the same frequency as in oil, but with a different amplitude.)

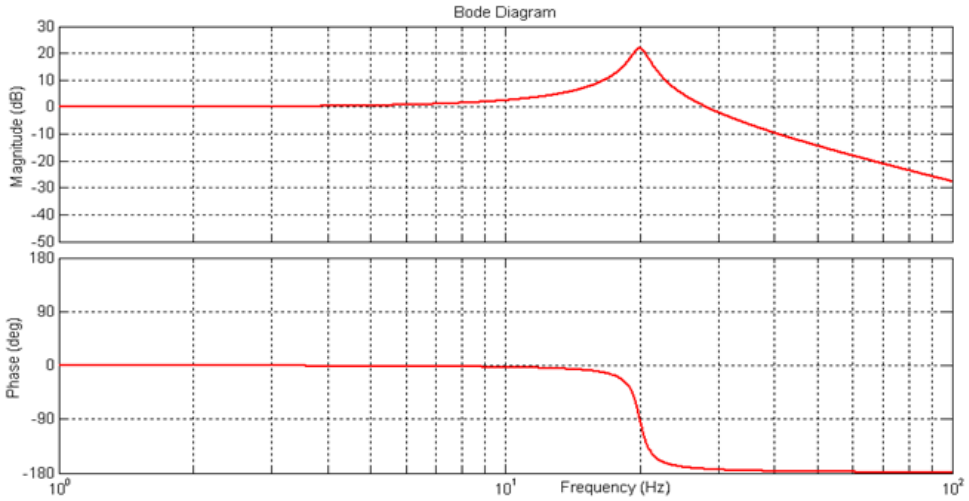
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Figure 2-2 Speed-controlled system with higher damping



The following "mechanics frequency response" describes the decoupling of the load in a better way. The input is the motor-rpm, the output the load-rpm.

Figure 2-3 Simulated mechanics frequency response



NOTE

The pole frequency in this frequency response corresponds to the locked-rotor-frequency (zero) in the speed-controlled system!

The amplitude for f < f_T equals 0dB. This corresponds to an amplification of 1.

The phase equals to 0° → no phase shift of the load in relation to the motor. The movement of the motor corresponds to the movement of the load.

If the load gets excited with f_T, the phase starts to tilt. The load follows with increasing phase shift up to -180°.

Furthermore, the amplification is bigger than 0dB. The load is excited more than intended.

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If the load gets excited with f > f_T, the load starts to decouple from the motor. The energy transmission from motor to load reduces, while the phase shift is -180°.

The formulas which are shown above for calculating the locked rotor and resonance frequencies illustrate the requirements of the mechanical system in combination with the motor to reach a dynamic control loop with a wide bandwidth.

- The motor : load inertia ratio should be as small as possible.

  However, this depends on the type of mechanical system (e.g. stiffness of the coupling), since it can lead into a high motor price.

Table 2-1 Recommended motor : load inertia ratio

Axis type	Motor : load inertia ratio
Winder	< 1 : 600 still ok!
Rotary Knife	< 1 : 5 recommended!
Web transportation axes (printing, coating, laminating, etc.)	< 1 : 20 recommended!

- The coupling between motor and load should be stiff enough.

  However, this can't be generalized. A very stiff coupling also means a hard connection of the mechanics to the motor. Impacts on load side are transferred to the motor/encoder with less damping effect.

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2.2 Multi-mass-system

In reality, a mechanical system consists several pole and zero frequency combinations, resulting from different parts of the mechanics, e.g. through a gear, belt, motor encoder, etc.

To get a easier understanding of the system, it can be summarized in masses / inertias which are connected by certain stiff connections (couplings).

Figure 2-4 Masses and stiffness distribution in a machine with linear axis and ball screw

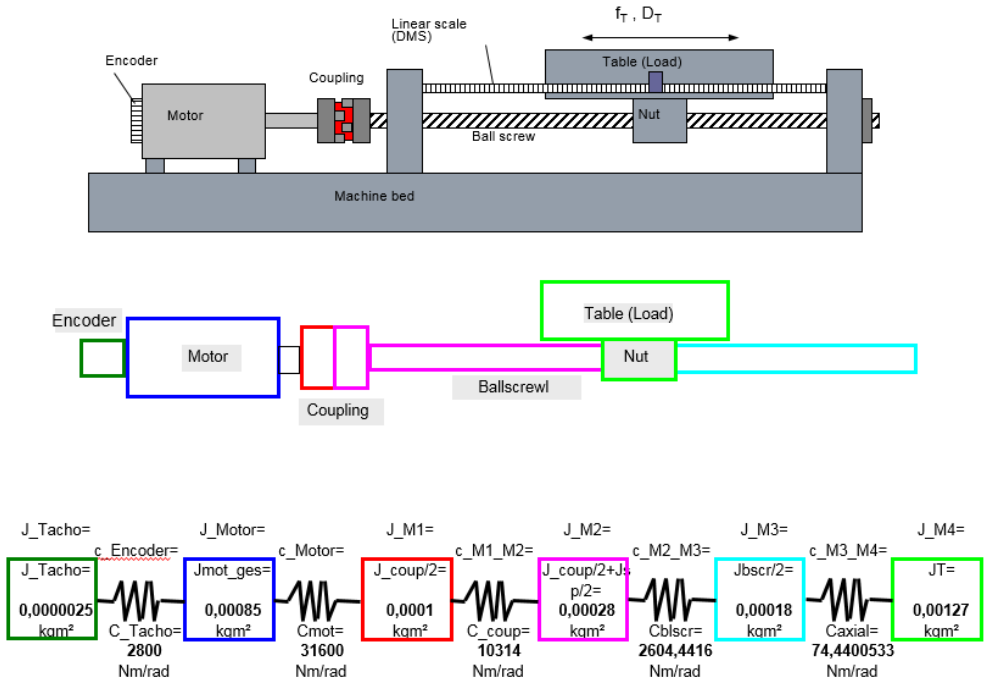
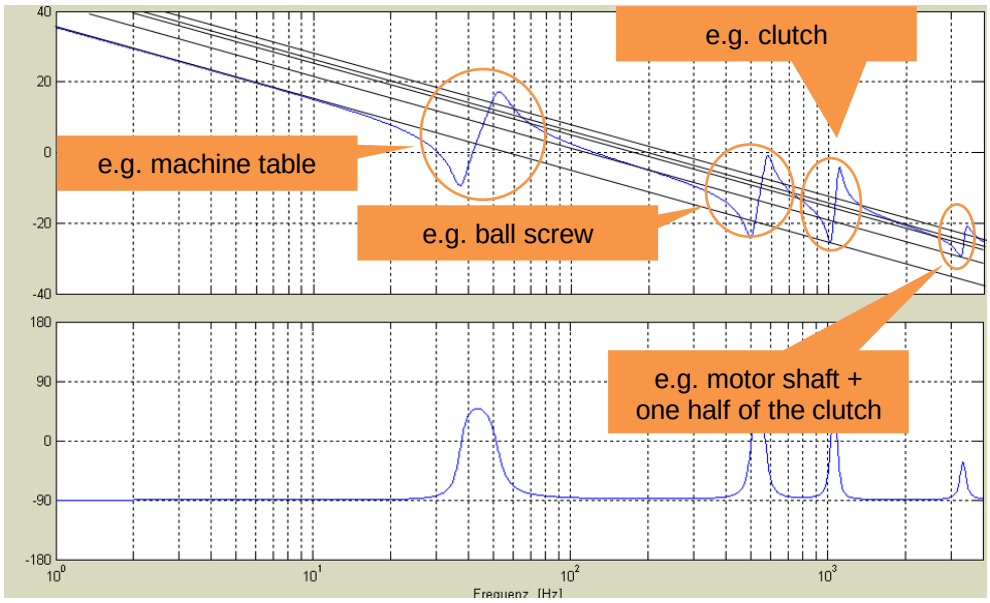


Figure 2-5 Speed-controlled system of a multi-mass-system



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Even if the assignment of the frequencies to the respective part of the mechanics requires some experience, it may still be helpful to know them.

In particular, when specific frequencies must be damped by a current setpoint filter. In case the filtered frequency can move its position can shift depending on the situation, one would have to choose a filter with a larger bandwidth.



CAUTION

Touching moving parts can cause severe injury!

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3 Measurement of the mechanical system

The measuring function can be used to determine the number and location of locked rotor frequencies and resonance frequencies.

Advantages compared to measuring the closed speed control loop:

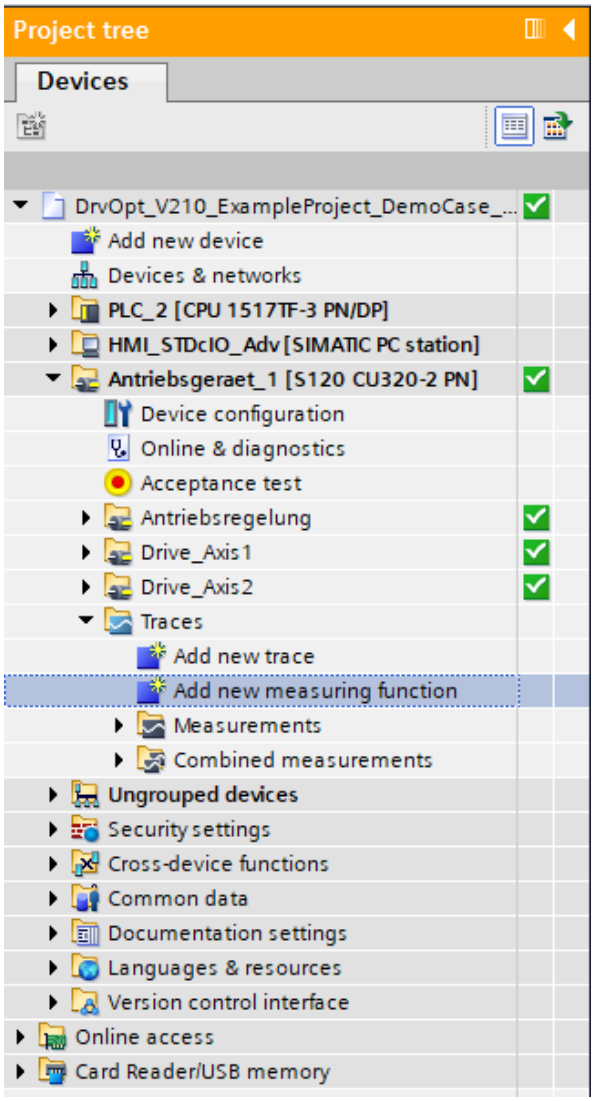
- Drive doesn't have to be optimized
- Resonance frequencies in the closed loop are usually damped by current setpoint filters

3.1 Speed-controlled system frequency response

The frequency response of the speed-controlled system is traced with the "Measuring function" integrated into TIA/Startdrive.

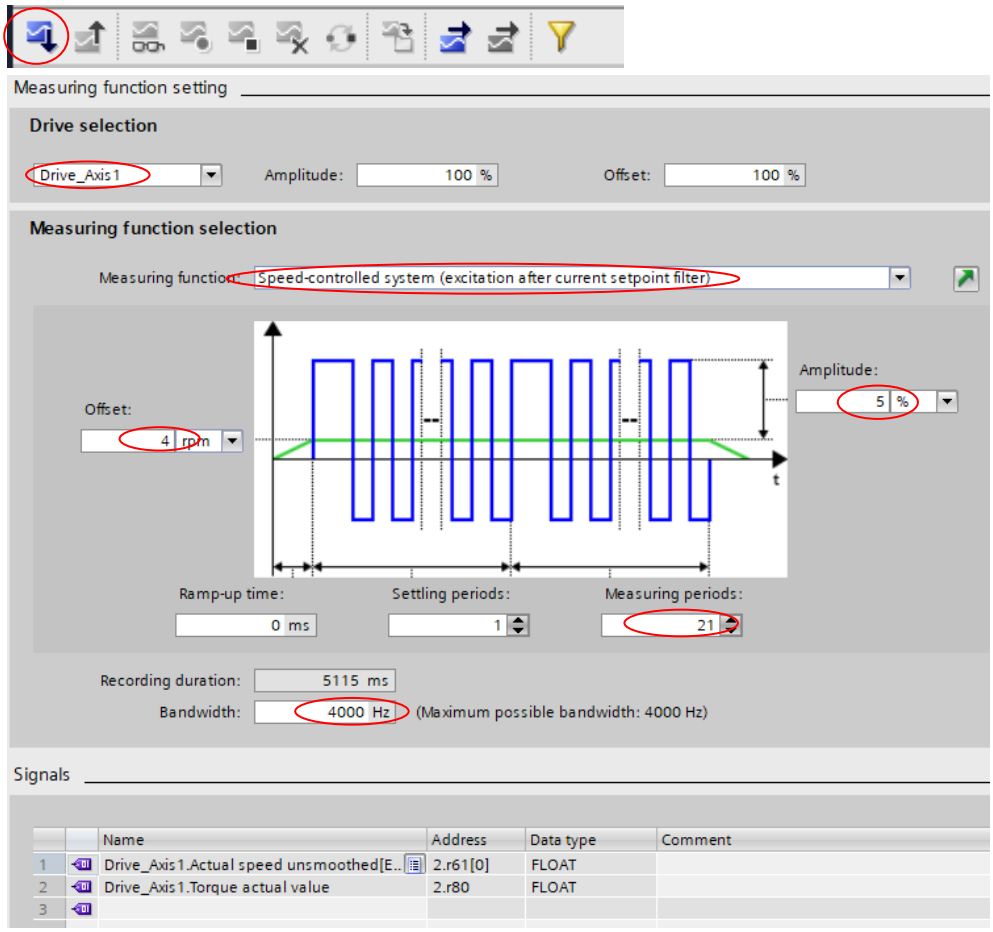
To open the Measuring function, press the following button (online-mode):

Figure 3-1 Project tree in TIA/Startdriv



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Figure 3-2 measuring function speed-controlled system



Drive selection:	Select the device on which the drive you want to measure is located (e.g. Drive_Axis_1).
Measuring function:	“Speed controlled system (excitation after current setpoint filter)”
Amplitude:	ca. 3% - 5% of reference torque (Default-settings) → Too big amplitude may affect the measuring result negatively! (Limitations can be reached – non-linear behavior) → Too small amplitude excites the system insufficiently → Check sound during measurement: audible but not abnormal
Offset:	**unequal 0** (Default-settings) → To avoid movement around standstill (stick-slip-effect = static friction to sliding friction change) → The offset should be just as big to lift the negative amplitude above zero speed (avoid reversing of the motor)
Ramp-up time:	duration till offset-speed is reached to start the measuring out of movement.

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Measuring periods:	ca. 20 → More measuring periods increases the accuracy (averaging) → Affects the measuring time (shorten dependent on bandwidth)
Bandwidth:	4000Hz → Distribution of the measuring points about the frequency range

NOTE

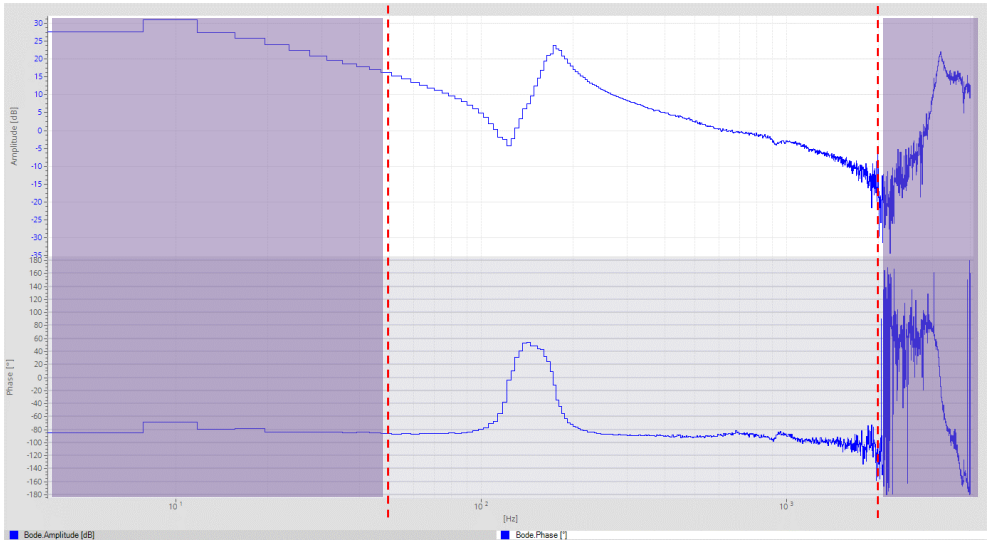
The speed controller must not be set too dynamically for the measurement since it will then "fight" against the noise signal (measurement signal). If it is too weak, the measurement will be negatively affected by the controller reaching to the offset speed level.

For an already optimized speed controller, the reset time should **first** be increased by a factor of 10 **and then** the Kp reduced by a factor of 10.

ATTENTION: If a position controller is active when changing the speed controller parameter, e.g. because control priority in drive has not yet been fetched, the position controller gain must first be reduced!

ATTENTION: hanging axes can fall down when the speed controller is too weak!

Figure 3-3 speed-controlled system frequency response of a two-mass-system with 4kHz bandwidth



The measurement shows the exemplary result of a speed-controlled system frequency response of a two-mass system. Locked-rotor frequency and resonance frequency of the two-mass-system are clearly visible.

Attention: The measurement provides only **accurate values in the middle range.**

The lower 50% of the trace window and the upper 50% of the bandwidth should be neglected (red dashed lines).

In the lower frequency range, the sampling is not good enough. In the upper part, amplitude and phase could be displayed in a wrong way due to aliasing effects.

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The noise signal used for the measurement contains 1023 frequencies, linear distributed over the selected bandwidth. With a bandwidth of 4000Hz, the resulting gird is 3.9Hz.

NOTE

To increase the resolution in the lower frequency range, repeat the measurement with reduced bandwidth (ca. 600Hz).

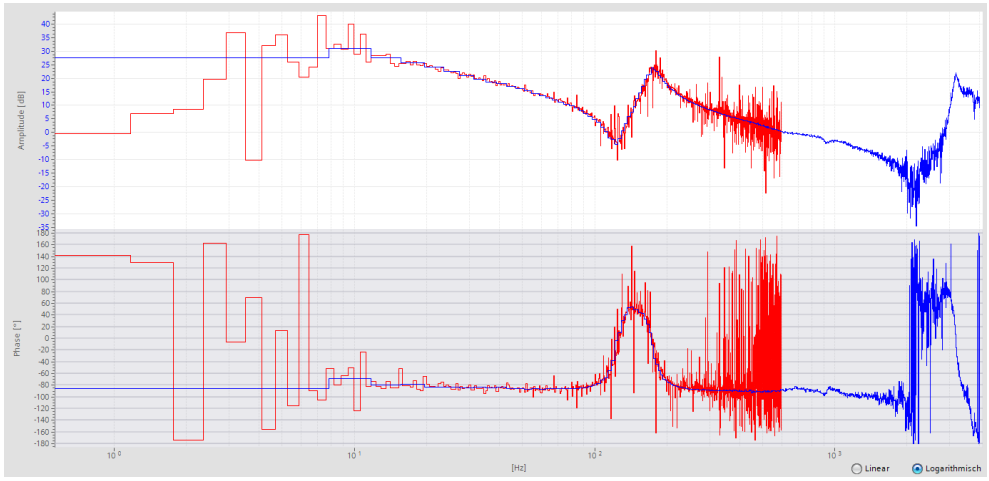
Both measurements can be displayed in a superimposed mode.

By reduction of the bandwidth you achieve a dispersion of the measuring points in a smaller area. This way the resolution is increased.

NOTE

Reduce the number of measuring periods to keep the previous measuring time.

Figure 3-4 speed-controlled system frequency response with reduced bandwidth (600Hz)



Attention

Same in this measurement, only the middle range is significant!

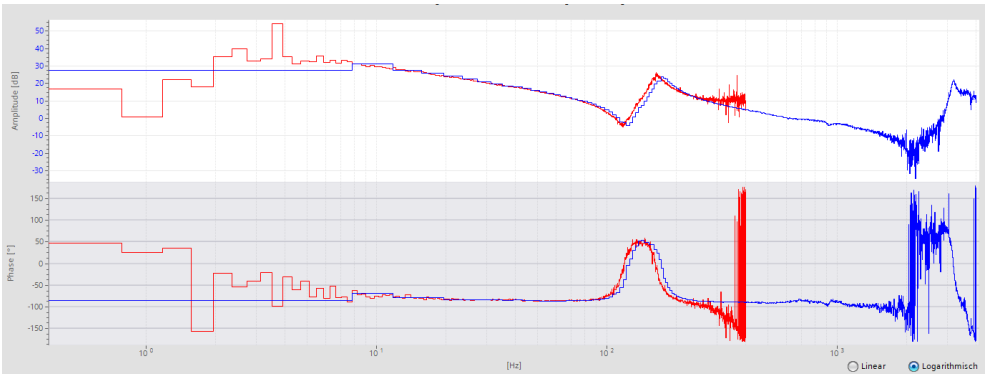
The locked rotor frequency is located in the significant area. Both frequency responses are congruent.

In the low frequency range, the resolution has improved.

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The following figure shows a measurement with once more reduced bandwidth:

Figure 3-5 speed-controlled system frequency response with reduced bandwidth (400Hz)



The locked rotor frequency is located on the verge of the significant area. The frequency responses are not congruent anymore.

Note

Choose the bandwidth twice as big as the frequency you want to have correctly measured/displayed! (Nyquist–Shannon sampling theorem)

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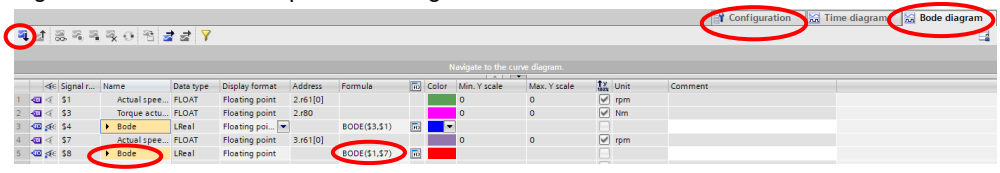
3.2 Mechanics frequency response

Attention **The trace is possible only if encoder on the load side exists!**

The mechanics frequency response can't be found as a built-in measuring function. But you can create the frequency response manually by using the mathematics function. Trace the motor-encoder's and load-encoder's actual speed [r61] and link them by a transfer function: **Transfer = ([r61]_motor ; [r61]_load).**

For that the measuring function "speed-controlled system" could be extended as follows:

Figure 3-6 add new bode-plot in existing measurement function



1) add the signal DriveAxis2_r61 in the window "configuration"
2) go to the window "Bode diagram"
3) add new Bode Diagram (transfer function)
4) choose signals and build formula (in the figure 3-6: $1 and $7)
5) load trace configuration in the device and activate the trace

Note Name/label the new measuring functions in the comment field.

Note

Change the direction of rotation of the load motor to "Counter-clockwise".

Expert-List: p1821

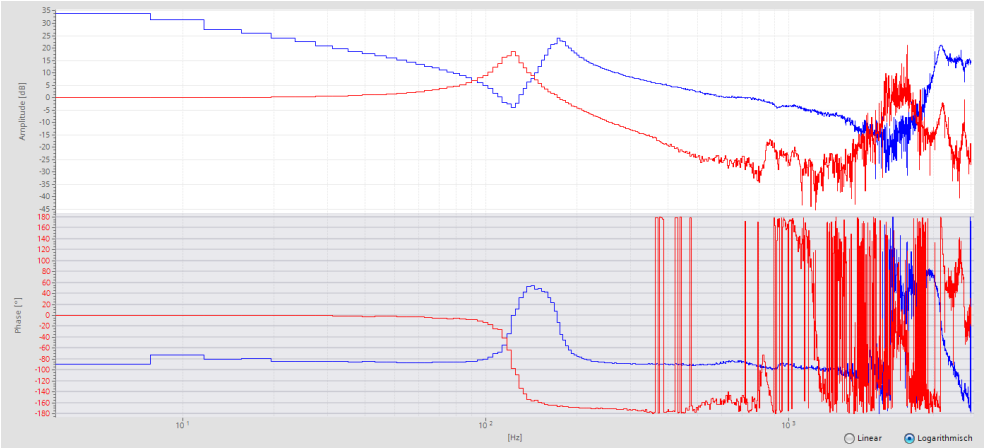
With a load encoder, pay attention to encoder inversion.

Expert-List: p410

Otherwise the mechanics frequency response phase will not be 0° in the front area.

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Figure 3-7 mechanics frequency response (red) superimposed speed-controlled system frequency response (blue)



The mechanics frequency response explains the locked rotor frequency. According to the speed controlled system, there is little movement at the locked rotor frequency, because it is based on the motor encoder. By looking at the mechanics frequency response and therefore looking at the load encoder, it can be seen that the load movement is amplified for this frequency.

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3.3 Image frequencies

So-called image frequencies can occur when the sampling frequency of the measurement is too small relative to the frequency of the signal to be sampled.

A sine wave sampled at 500Hz in 2ms clock (1 / 0.002s is also 500Hz) would result in a zero line. This handling would injure Nyquist-Shannon theorem.

If you scan a vibration of example 535Hz in 2ms clock, however, creates a image frequency at 475 Hz.

To avoid this, the sampling frequency must be at least twice as high as the highest frequency component in the signal to be sampled.

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4 Inertia determination of a mechanical system

In most cases the motor inertia is known (data sheets or expert list p341). In contrary the load inertia is often unknown. Different methods can be used to determine the inertia.

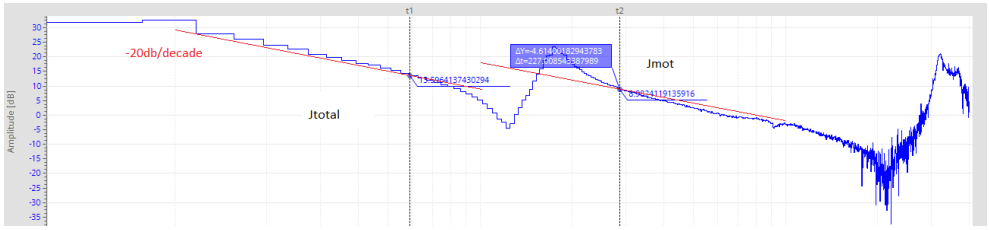
4.1 Frequency response

NOTICE	**This method is less accurate in respect to the accuracy!**

With the speed-controlled system frequency response inertia components and torsion stiffness can be calculated.

The below displayed curve can be measured with the measuring function “Speed controlled system (excitation after current set-point filter)”.

Figure 4-1 identification of inertia and torsion stiffness from the frequency response



The displayed frequency response is the typical speed-controlled system of a two-mass-system (motor vibratory coupled with a load). Typical is the frequency pair locked-rotor-frequency (zero-point) and resonance frequency (pole).

With this frequency pair the mass is decoupled from the system. That implies, that an excitation of the load with frequency higher than locked-rotor-frequency is no longer possible.

Formula to calculate the inertia components:

$$J = \frac{10^{\frac{-y[dB]}{20dB}} \cdot 60}{4 \cdot \pi^2 \cdot f} = \frac{1}{(2\pi \cdot f) \cdot \frac{2\pi}{60} \cdot 10^{\frac{y[dB]}{20dB}}}$$

This reflects a pair of values consisting of amplitude y [dB] and frequency f [Hz] in a gradient area of **-20 dB/decade**!

The values to calculate the **total inertial** of the system must be determined out of the area below the first locked-rotor-frequency.

After the first frequency-pair the load has been decoupled. The value of inertia, which can be calculated out of the area after the resonance frequency, corresponds to the remaining inertia of the system, the inertia of the motor.

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NOTE For determination of the amplitude for the total inertia calculation, trace the frequency response with lower bandwidth to be able to determine the value precisely.

Example:

The pair of values y = 14.00dB and f_1 = 59Hz results in the total inertia of the system J_total = 0.005140kgm².

The pair of values y = 8.98dB and f_2 = 286Hz results in the motor inertia J_M = 0.001890kgm².

To calculate the torsion stiffness between two masses, the locked rotor frequency, the resonance frequency and the inertia of the masses has to be known.

Depending on the known values you can use the following equations:

$$c_T = 4 \cdot \pi^2 \cdot J_M \cdot (f_R{}^2 - f_T{}^2)$$

$$c_T = \frac{(f_R \cdot 2\pi)^2}{\frac{1}{J_L} + \frac{1}{J_M}}$$

$$c_T = (f_T \cdot 2\pi)^2 \cdot J_L$$

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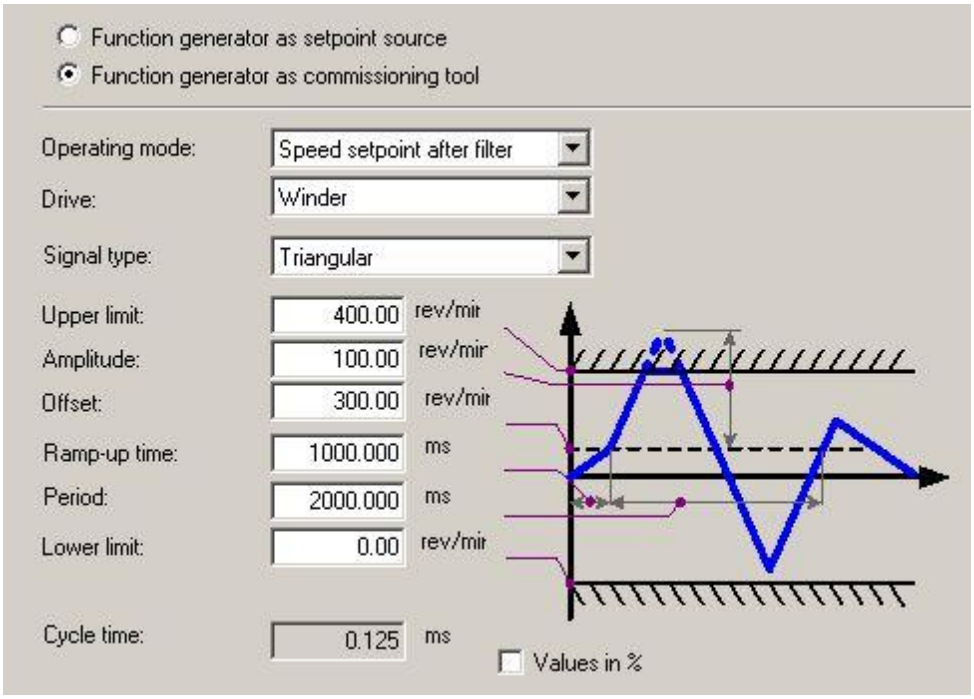
4.2 Velocity profile using the ramp function generator

This feature is only available in Scout/Starter.

1. Friction curve is detected and active
2. The axis can be rotated freely. SIMOTION is in STOP (drive is not enabled)
3. Go to the Comissioning menu in the drive and open the Function Generator



4. Exemplary settings of function generator:



NOTE The settings of the function generator needs to be adapted to the mechanics!

5. Start function generator:

   The axis is moving with a period of 2000ms between 200 and 400 rotations per minute (after ramp-up time). During the acceleration and deceleration phase the controller output (r1480) should have the shape of a rectangle. Trace the parameter r1480, r80, r62 und r3841 with the endless trace.

6. Calculation of the moment of inertia:

   The set acceleration (angular acceleration) is the result of the amplitude (rev/min) and the period time (ms):

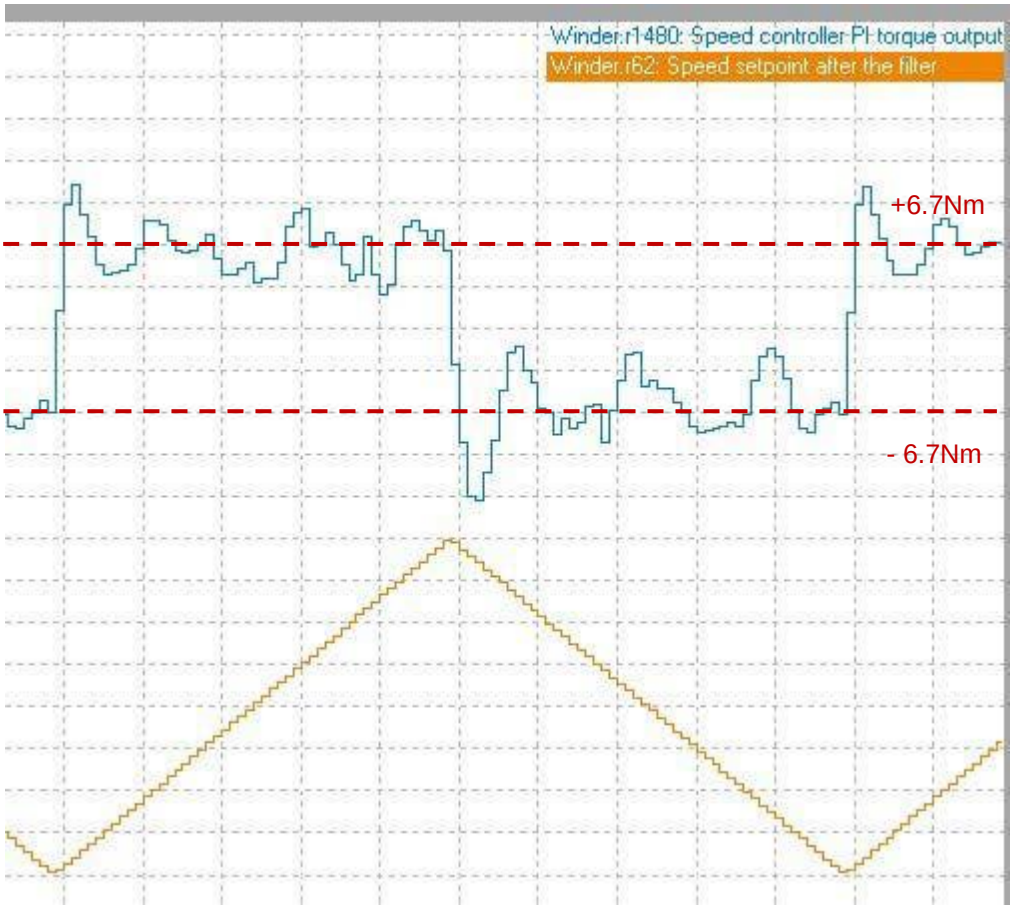
   α = Amplitude / Periodendauer * 8.0 * PI * 1000 / 60

   α ist in rad/s^2 definiert!

   With the settings above, αis approximately 21 rad/s^2.

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In case of a too small signal of r1480 the time of the period could be decreased. The acceleration-based torque (r1480) is shown in the measurement; the shape should be similar to a rectangle. Take the average value, in this case 6.7Nm.



The total inertia can be calculated from the torque during acceleration and the angular acceleration α.

$$J = \frac{M}{\propto}$$

In this example, the total moment of inertia is J = 6.7 / 21 = 0.319 kgm^2.

This value is calculated for the motor side.

The load inertia can be calculated by deducting the motor inertia which is known form the motor data sheet.

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5 Mot-ID (Motor-Identification)

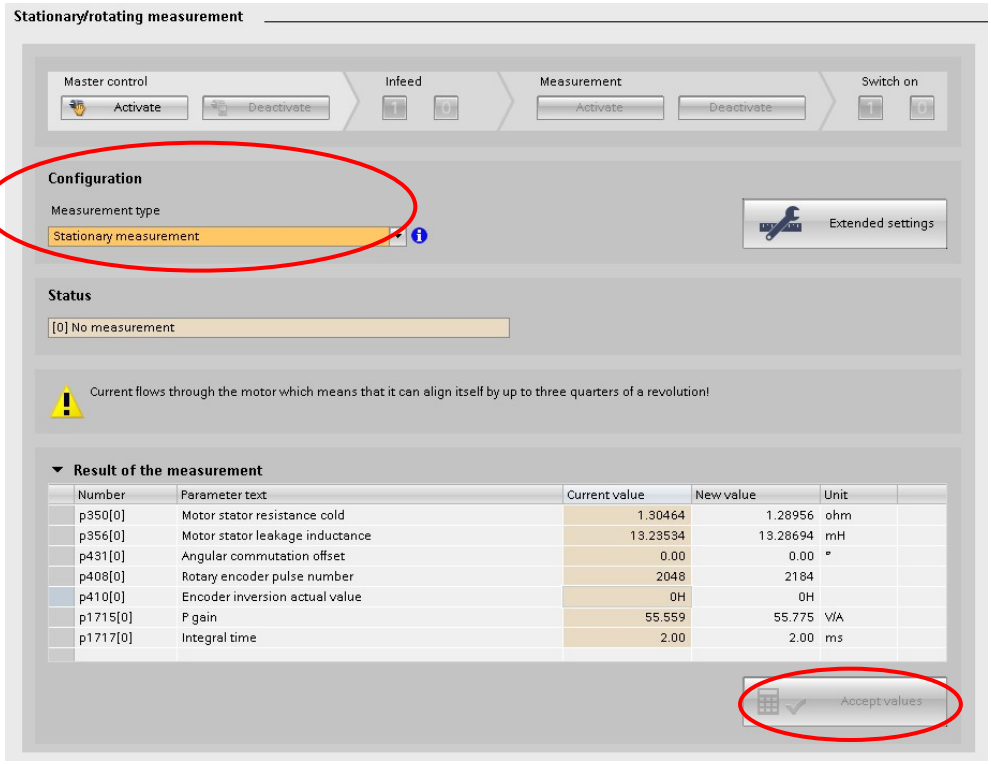
The Mot-ID can be used to adapt motor- and control parameters which are based on data sheet data to the real, motor specific data. The default values which are preset by inserting a drive can differ from the real motor values.

Using third-party motors, it might be the case that not all motor parameters are available. In this case the Mot-ID is mandatory.

Furthermore, some motor parameter can only be set correctly if other data are known. These data must be set by the user before starting the measurement.

The figure below shows the menu of the motor identification. It can be opened in the project tree under the respective drive in "Rotate & Optimize".

Figure 5-1



At first, choose the desired measurement.

In the lower area parameter are listed, which will be set/adapted by the measurement.

NOTICE	**After the measurement, the calculated values must be accepted by pressing the button “Accept values”.**

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Complete calculation of the motor/control parameters (p340)

- Parameters will be calculated based on entered motor data
- For third-party-motors and SIMOTICS entered by motor data
- Performed immediately by clicking on “Activate measurement”

Stationary measurement (Mot-ID) (p1910)

- For third-party-motors, SIMOTICS entered by motor data and in general for motors with a long supply cable (higher cable resistance and inductivity)

  Not required for DRIVE-CLiQ motors or catalog motors!
- Execute the complete calculation of the motor/control parameters first
- During the stationary measurement, parameter will be measured and calculated (the pulses of the drive getting enabled!)
- The commutation angle and the direction of rotation are determined as well
- Performed after drive is enabled

Rotating measurement (Mot-ID with additional parameter) (p1960)

- For third-party-motors, SIMOTICS entered by motor data and in general for motors with a long supply cable (higher cable resistance and inductivity)

  Not required for DRIVE-CLiQ motors or catalog motors!
- Mainly for motors in VECTOR mode
- Execute the complete calculation of the motor/control parameters and the stationary measurement first
- Load moment of inertia is determined, and speed controller is set
- Saturation characteristic and rated magnetization current of induction motors are measured
- The commutation angle and the direction of rotation are determined as well
- Perform the turning measurement for a motor without load to prevent damage to sensitive mechanical system
- Performed after drive is enable

NOTICE	**If the motor has a holding brake, it must be opened before executing stationary and turning measurement (p1215 = 2).** **Before doing so, make absolutely sure that opening the holding brake will not cause any unwanted movements (for example falling down of a lifting table).**

Encoder adjustment (p1990)

- This function is only required for synchronous motors and can be started when commissioning for the first time or after replacing the motor encoder
- Determines the angular commutation offset and transfers it into p0431

  (angular commutation offset = angular difference between electrical position of encoder and flux position)

  Performed after drive enable

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6 Current Controller optimization

6.1 Siemens drives & motors

Using Siemens-drives & motors the motor data and controller settings (proportional gain factor Kp, integral time Tn and Kp adaption) are preset automatically. This is done by the auto-configuration of DRIVE-CLiQ drives or by entering the motor code number.

The proportional gain factor is proportional to the inductance of the motor winding, the integral time on the current controller clock cycle:

62.5µs →Tn = 1ms
125µs → Tn = 2ms
250µs → Tn = 4ms

Normally the current controller optimization of Siemens-drives & motors is not necessary!

If there are problems with the behavior of the overall control system, start the fault analysis with a check of the current controller setpoint frequency response.

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NOTE

Motor- and control parameter which are set by inserting a drive with the drive-wizard or automatic configuration are based on the motor data sheet.

Because of production tolerance it is possible that these data differ to the real motor data.

Remedy: see chapter Mot-ID (Motor-Identification).

6.2 Third-party drives & motors

There are several possibilities to set the controller characteristic parameter of third-party drives & motors:

- By entering the motor nominal data, a calculation of the motor model starts to determine proportional gain and integral time.
- Entering the motor model data manually.

Attention

Pay attention to all physical units of the motor data!

Manufacturer's specification can be different (units, frequency or angular frequency etc.)!

Note

It is recommended to always check the current controller setpoint frequency response when third-party drives & motors are used.

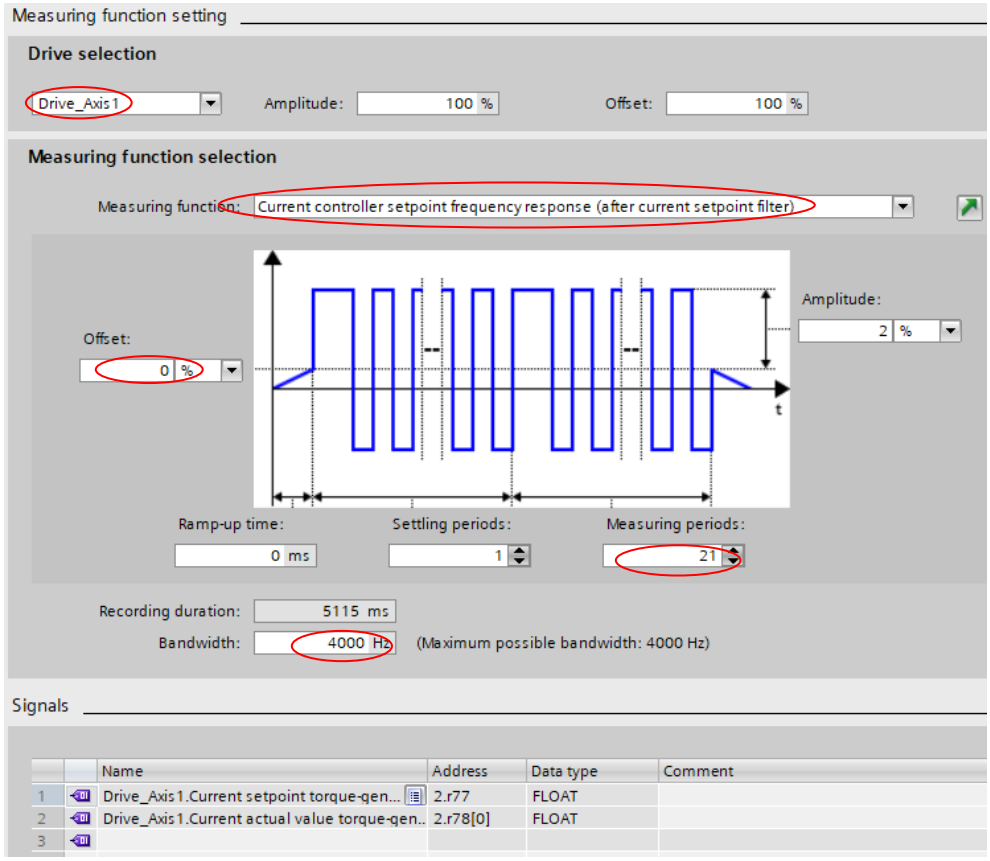
The current controller is often set too high due to the stator leakage inductance (p356). Keep in mind, that the terminal-neutral variable is required here!

NOTE

Please pay attention to chapter 9.1 Current controller adaption!

6.3 Current controller setpoint frequency response

Figure 6-1 measuring function Current controller setpoint frequency response



Device selection: Select the device on which the drive you want to measure is located (e.g. SINAMICS_Integrated).

Measuring function: “Current controller setpoint frequency response (after current setpoint filter)”

Amplitude: - default -

→ Too big amplitude may affect the measuring result negatively! (Limitations can be reached – non-linear behavior)

→ Too small amplitude excites the system insufficiently

→ Check sound during measurement: audible but not abnormal

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Offset:	0 Aeff (if the value is unequal to zero, the motor accelerates!)
Measuring periods:	ca. 20
	→ More measuring periods increases the accuracy (averaging)
	→ affects the measuring time (shorten dependent on bandwidth)
Bandwidth:	4000Hz
	→ Distribution of the measuring points about the frequency range
Current controller settings:	Do not change the current controller proportional gain factor (Kp) and integral time (Tn)

Note Activated current setpoint filter(s) have no effects on the measurement.

Figure 6-2 current controller setpoint frequency response (Kp, Tn: default-values)



The amplitude should stay close to the 0dB line till phase tilt.

NOTE In the curve above, the slight reduction in the amplitude curve is not a too weak controller gain. The cause here is the locking time of the transistors in the frequency converters. The time is longer at low voltage modulation. If the measurement would be executed with higher measurement amplitude, this effect is no longer visible.

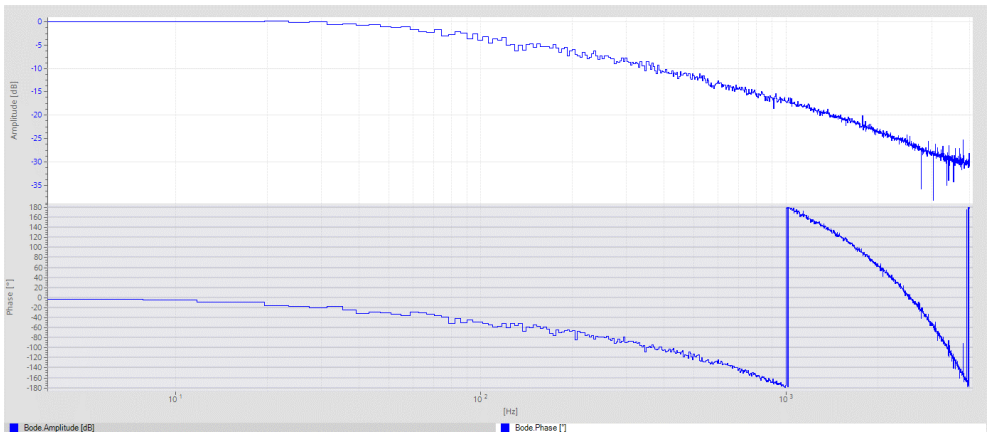
Note As of firmware V4.4 of the SINAMICS CU and supporting hardware version, parts of the current controller are calculated on the power unit. Due to the available computing resources, higher dynamics can be achieved (the phase tilts later).

If a corresponding CU is created in the project, bit 11 of parameter p1810 is TRUE, and p118 = 20.5µs. If you upgrade an older firmware version, you must set the parameters manually to use the function.

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The following trace shows the result of a too low proportional gain factor:

Figure 6-3 current controller proportional gain factor undersized



Because of the too low proportional gain factor, the magnitude is only up to 40Hz close to 0dB.

→ Increase Kp!

Note

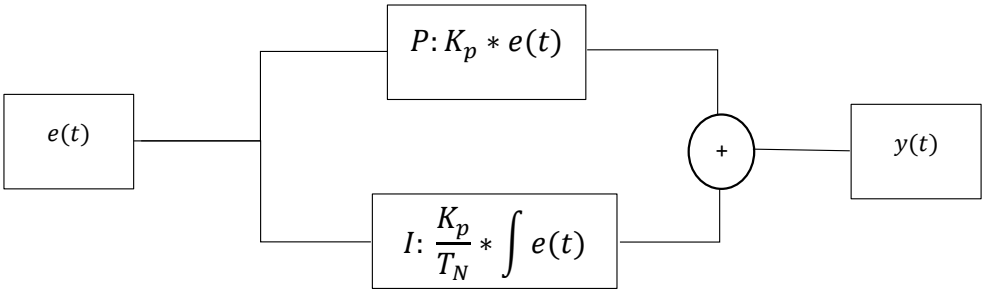
The integral time results from the current controller sample time. Because of this the integral time shouldn't be adapted manually.

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7 Speed controller optimization

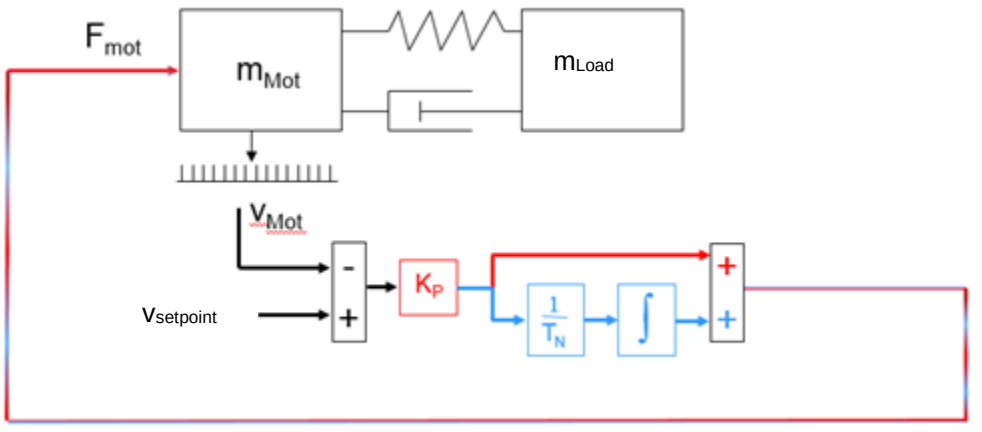
The speed-controller is also a PI controller. The controller parameters of the current controller are depending on the motor and its sampling time. With the speed-controller, these parameters are selectable. The speed controller of a rotary axis (regulates the roles per minute) corresponds to the speed-controller of a linear axis (regulates the speed of the axis). Since a linear axis is easier to display, the speed controller of a linear axis is explained in the following figures. The block diagram of a PI controller in the parallel structure looks like this:

Figure 7-1 block-diagram PI controller



The variable y(t) for the motor of the speed-controlled axis (output of the speed controller) is made up of the sum of the P and I components of the PI controller. The P component is the product of the proportional gain Kp and the control difference e(t). The I component is the quotient of Kp and the integral time constant Tn multiplied by the integral of the control difference e(t). Thus, the following equivalent circuit can be derived for the velocity control:

Figure 7-2 Equivalent circuit diagram speed control of a linear axis



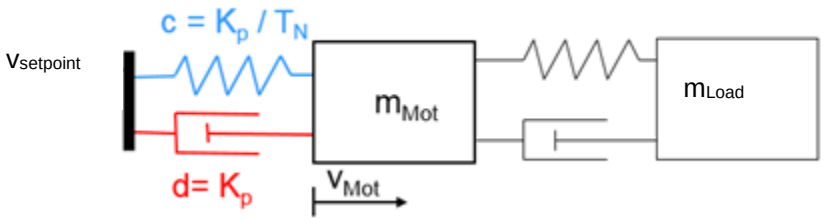
The control difference is formed from the setpoint velocity $v_{setpoint}$ and the negative return of the actual velocity v_{Mot}. This control difference is then multiplied on the one hand by the Kp factor and on the other hand integrated over time and multiplied by the prefactor Kp/Tn. The sum of these two operations then results in the manipulated variable Fmot, which has a direct influence on the motor.

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The P component of the speed controller generates a force proportional to a speed difference. The unit of the gain is N*s/m (Nm*s/rad for rotary axes). A force proportional to a speed corresponds in mechanics to the element of the damper. The I component is formed from the gain Kp/Tn and the integral of the velocity difference. The integral of the velocity is the displacement. The output of the integral component is therefore a force corresponding to a position deviation. The unit of amplification of the I component is N/m and corresponds to the mechanical element of a spring.

If the two properties of the components of the velocity controller are combined, they can be represented in the following equivalent mechanical circuit:

Figure 7-3 equivalent mechanical circuit of speed control



According to this figure, the setpoint speed is specified by moving the left vertical bar (mechanical speed setpoint) horizontally with the desired setpoint speed. The speed and position deviation between the mechanical speed setpoint and the motor mass results in a force on the motor mass, which is caused by the damper and the spring of the speed controller. This force corresponds to the output of the controller.

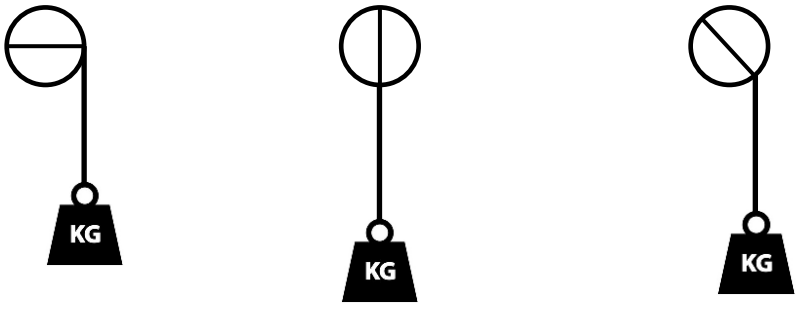
NOTE

Thought experiment for the speed-controller of a rotatory axis:

By hanging a mass on the side of the motor shaft, this generates a torque when falling. The motor shaft rotates until the mass is hanging on the bottom of the shaft.

If only the P-part of the controller would be effective, the mass would still fall down (radially), but will be dampened as it would fall, in a viscous liquid. A larger Kp increases the damping effect.

With an active integral component, the weight only falls to a certain angle before it stops. One can imagine that a spring is getting compressed, which decelerates the falling mass (standstill reached when spring force = torque of the weight). The shorter the reset time and the greater the Kp-value, the sooner the weight will be stopped. If you remove the weight, the motor "springs back" to the initial position.



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The speed controller can be optimized in two strategies:

- Interference optimum

  High controller gain and Tn very short. The motor follows the setpoint very well. Disturbances on the motor side are optimally compensated, with the disadvantage that a soft connection of the load is sensitive to oscillation.

  The encoder on the motor side does not see what happens on the load side, if it is not connected stiff enough.

- Damping optimum

  The controller is set weak on purpose so that the "spring" of the controller oscillates instead of the motor : load coupling.

  However, disturbances on the motor side (e.g. gear or cogs) can have negative effects on the load side because the controller does not completely suppress them.

7.1 Stability criteria

The control system is stable, if its step response approaches a finite value for t -> ∞.



Stable unstable

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Attention

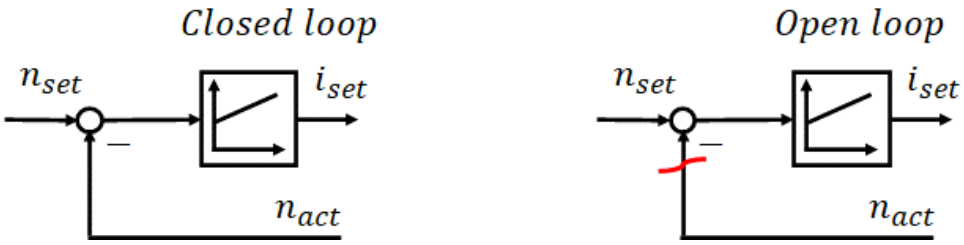
The correct stability has to be evaluated with the open speed control loop!

In SINAMICS trace there is a measuring function for the closed speed control loop (“Speed controller setpoint frequency response (after speed setpoint filter)”).

The open speed control loop must be created manually with the mathematics function.

An open speed control loop means that, in contrast to a closed loop, the negative return of the actual speed value from the motor encoder is disconnected.

Figure 7-4 open and closed speed-control loop



To create the open speed control loop, the speed controller setpoint frequency response has to be extended with the transfer function.

Transfer = system deviation [r64] ; actual speed [r61]

(For more information about mathematics function see chapter 3.2)

The coherence between the closed control loop and the open control loop is characterized by the following formula.

$$F_{cl} = \frac{Fo}{1+Fo}$$

If the denominator (of the characteristic equation) equals 0 (Fo = -1), the closed control loop is instable.

This occurs if the actual value |Fo| = 1 and the phase amounts -180°.
(in logarithmic description: 0dB and -180° phase)

Reverse: to guarantee stability an adequate phase margin φ_R is required while amplitude amounts 0dB.

If the phase is near -180°, a distance to 0dB is required (amplitude margin).

The bode-diagram of the open speed-control loop looks like this:

Figure 7-5 open speed control loop

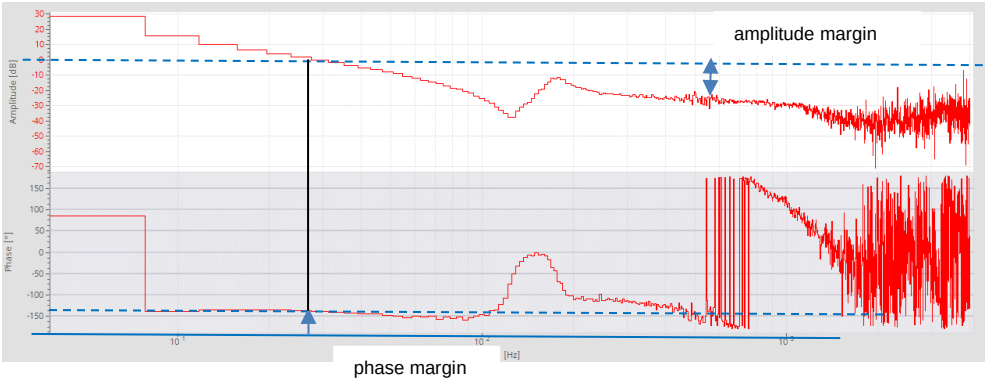


Table 7-1 Stability criteria of the open speed control loop

The following criteria must be read in the open speed control loop	
Amplitude margin	Distance to the 0 dB line in the amplitude response where the phase is crossing -180°. Determines the damping behavior of the control loop in conjunction with the phase reserve.
Phase margin	Distance to the -180° line in the phase response where the magnitude crosses the 0dB-line in amplitude diagram for the first time. Determines the damping behavior of the control loop in conjunction with the amplitude reserve.
Critical points	If the phase reaches -180°, the amplitude reserve should be approx. 6dB - 10dB. If the amplitude reserve is less than 6dB - 10dB, the phase reserve should be approx. 40°.

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There are also important criteria for the closed speed control loop:

Figure 7-6 closed speed control loop

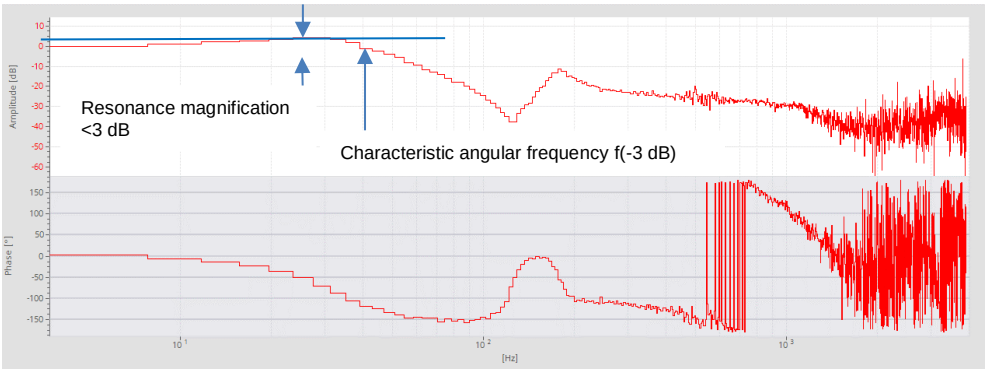


Table 7-2 criteria of the closed speed-control loop

The following criteria should be observed for the closed speed control loop:	
Resonance magnification	Overshoot in the low frequency range. Overshoot up to max. 3dB permissible. Corresponds to an overshoot of max. 43% in the time domain. Influenced by a short integral time constant or too large P-gain.
Characteristic angular frequency (= bandwidth of closed contol loop)	Frequency is determined in the amplitude response at -3dB. The characteristic frequency should be as high as possible in order to obtain a high dynamic range and a short response time.

NOTE

In summary, it can be said that the stability-critical points such as amplitude and phase reserve must be read in the open speed control loop. The dynamics of the speed controller are assessed with the characteristic angular frequency and the resonance magnification at the closed speed control circuit.

7.2 Proportional gain factor (Kp)

Premise: optimized current controller

The optimization is done in two steps:

- Proportional gain factor optimization (Kp)
- Integral time optimization (Tn)

NOTE

To optimize the speed controller gain, the integral component of the PI controller must be deactivated.

This is done by selecting by setting a very long reset time, e.g. 1000ms.

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NOTE The reset time is optimized after the speed controller gain Kp has been determined.

The typical goal is to set the proportional gain factor high enough to obtain the required machine dynamic, but at the same time maintain the stability of the control loop.

The reachable Kp factor is related to the total system inertia (motor + load).

The bigger the total inertia, the higher the reachable/necessary Kp.

NOTE However, the stiffness of the load connection is important as well. The reachable speed controller gain is directly related to the motor-near inertia, if the locked rotor frequency and resonance frequency are in the lower frequency aerea..

NOTE Thought experiment:

With a small motor A, a Kp of 0.3 can be set without load. After connecting a load with a certain stiffness c to this motor, this system can become unstable at a specific frequency, even though the total inertia is bigger than before. However, due to the stiffness of the coupling, a resonance frequency may appear in which the inertia which the motor faces, is substantially smaller than the motor inertia itself (see Chapter 2.1). The load "pushes" the motor at this point, whereby the Kp is too large. Remedy can be a current setpoint filter (see chapter 7.3).

By inserting a new drive to a project, the Kp factor gets pre-assigned depending on the motor inertia and an additional factor of 1/3:

$$Kp \approx 1000 \cdot J_M \cdot \frac{1}{3}$$

The factor 1/3 is a preventive reserve to avoid mechanical oscillating at first use of the machine.

The maximum reachable Kp factor without coupled load (inertia close to the motor) can be approximated by the following equation:

$$Kp \approx 1000 \cdot J_M$$

Depending on additional load inertia, the ideal Kp factor can be determined by following measurements.

Depending on the load connection (characteristic of the locked-rotor frequency / resonance frequency), the amplitude and phase margin might be too small, which means the Kp would have to be reduced or current setpoint filters must be set.

To get a first reference of the speed control loop, start a measurement with default Kp setting.

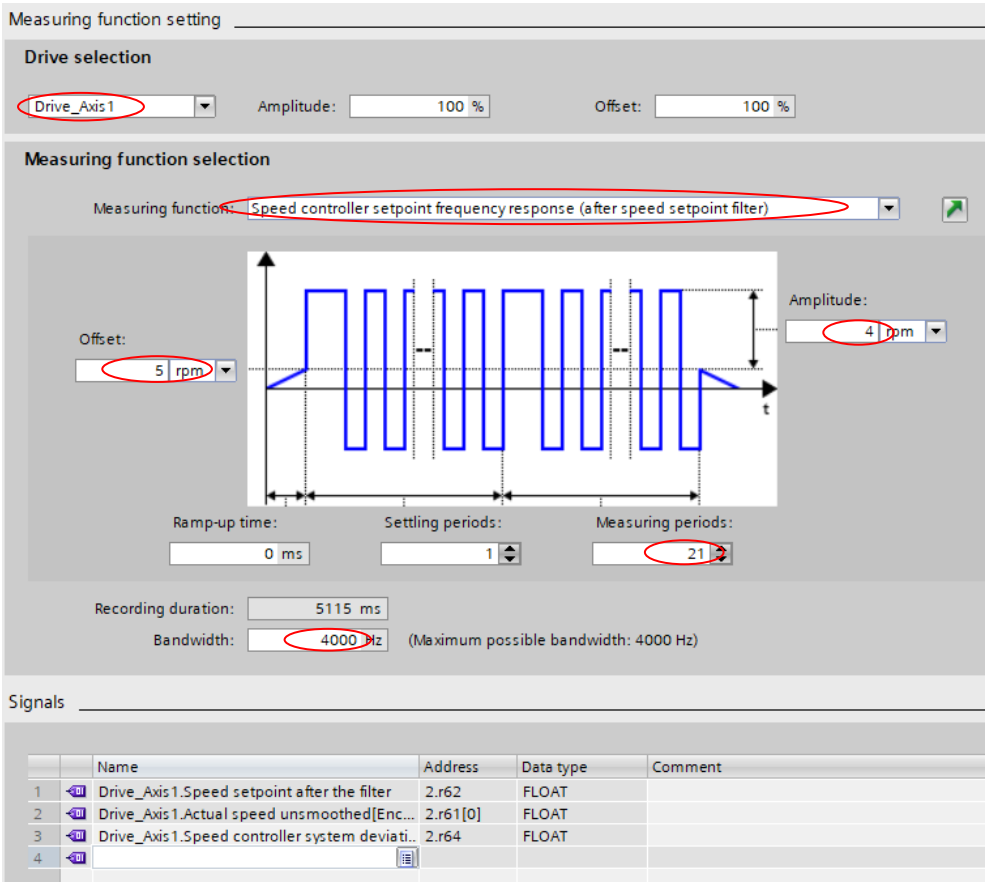
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For that, the measuring function “Speed controller setpoint frequency response” (closed control loop) can be used.

NOTE

It is recommended to add the transfer function of the open speed control loop to evaluate the stability criteria! (see chapter 7.1 and 3.2 (creation of a new bode function))

Figure 7-7 Measuring function “speed controller setpoint frequency response”



Drive selection: Select the device on which the drive you want to measure is located (e.g. Drive_Axis1/ Drive_Axis2).

Measuring function: “Speed controller setpoint frequency response (after speed setpoint filter)”

→ Additionally: **transfer function of open speed control loop** (see chapter 7.1 and 3.2)

Amplitude: -default-

→ Too big amplitude may affect the measuring result negatively! (Limitations can be reached – non-linear behavior)

→ Too small amplitude excites the system insufficiently

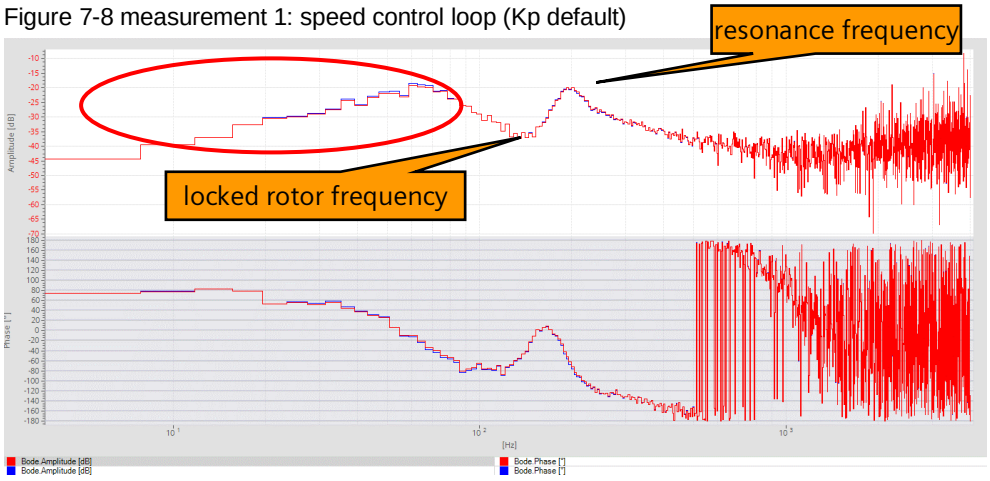
→ Check sound during measurement: audible but not abnormal

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Offset:	**unequal 0** (Default-settings) → To avoid movement around standstill (stick-slip-effect: static friction to sliding friction change) → The offset should be just as big to lift the negative amplitude above zero speed (avoid reversing of the motor)
Measuring periods:	ca. 20 → More measuring periods increases the accuracy (averaging) → Affects the measuring time (shorten dependent on bandwidth)
Bandwidth:	4000Hz → Distribution of the measuring points about the frequency range
Proportional gain:	Kp = 1000 x J_M x 1/3 (default value)
Integral time:	1000ms

Note If the Kp is getting increased much during optimization, the amplitude might need to be reduced.

Figure 7-8 measurement 1: speed control loop (Kp default)



(red curve: closed speed control loop, blue curve: open speed control loop)

In this trace both curves are congruent, because of the low proportional gain (feedback loop is interrupted)

The locked rotor frequency (zero) has no effect on the stability of the control loop, but it affects the reachable system dynamic.

The excitation with resonance frequency (pole) in conjunction with a high proportional gain (peak near 0dB or above) and low phase margin can lead into an unstable condition.

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From the course of the magnitude in front of the locked rotor frequency, it can be seen that the proportional gain is way too long.

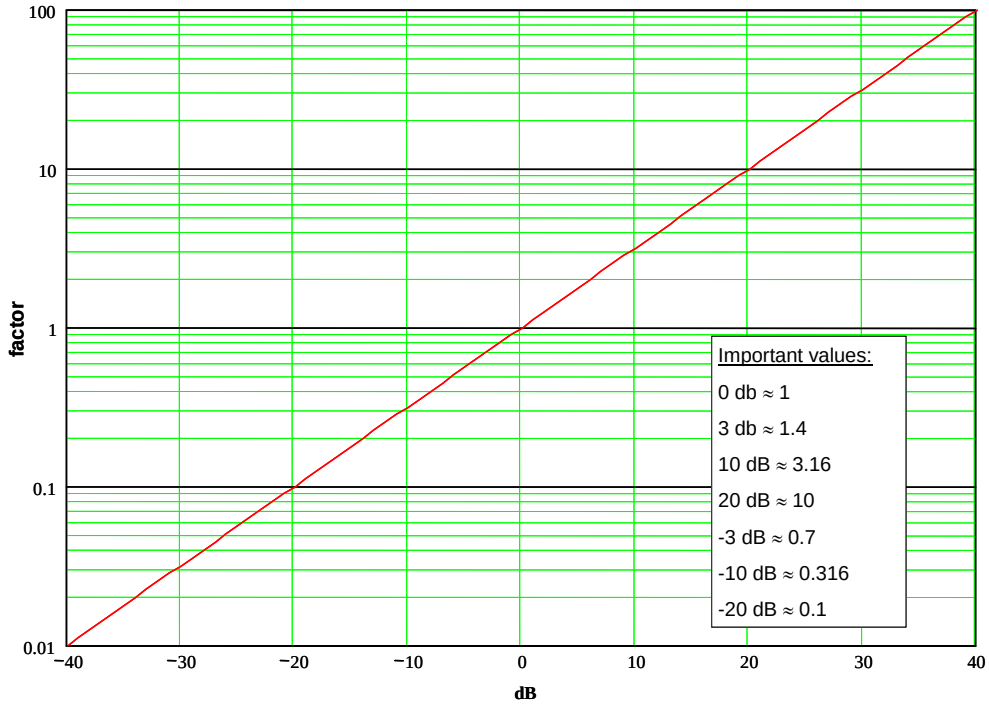
The closed loop magnitude should stay on the 0dB line up to the locked rotor frequency.

The big amplitude margin above the resonance frequency shows the possibility to raise the proportional gain factor as well.

Rule of thumb for Kp increase:
Factor 1.4 (40%) corresponds to 3dB amplitude amplification

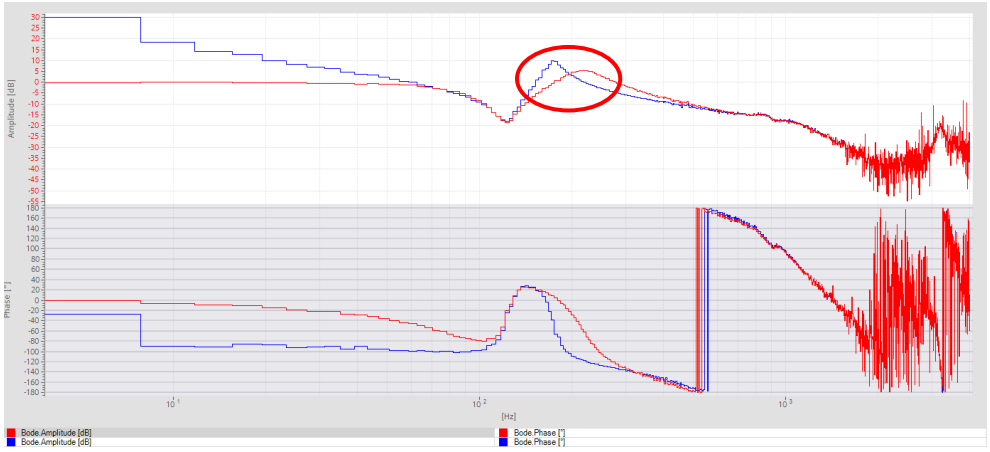
If the factor for the gain increase is displayed over the amplitude in db in logarithmic representation, the correlation is a straight line. The factor for gain increasing can be easily determined from the diagram.

Figure 7-9 conversion logarithmic <-> linear



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Figure 7-10 measurement 2: speed control loop



The open control loop magnitude (blue) reaches the 0dB line. At this point there is still phase margin left.

Therefore, there is no instability in this case.

In order to reduce this resonance anyway, you could set current setpoint filters.

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7.3 Current Setpoint Filter

Alternatively, the critical resonance spot can be damped by a filter. In this way, the Kp factor can be kept, perhaps even another Kp raise is possible.

So to say, the filter effects a Kp reduction in certain areas.

Use the measuring cursor to determine the exact frequency of the resonance spot.

Attention **It's not necessary to use a filter at all resonance frequencies.**

See chapter Current setpoint filters in multi-mass-systems

There are four current setpoint filters available to damp disturbing oscillations/resonances. One of these filters is active by default to mask out the encoder noise. It's configured as a low-pass filter with the characteristic frequency of 2000Hz and a damping of 0.7 (70%).

NOTE

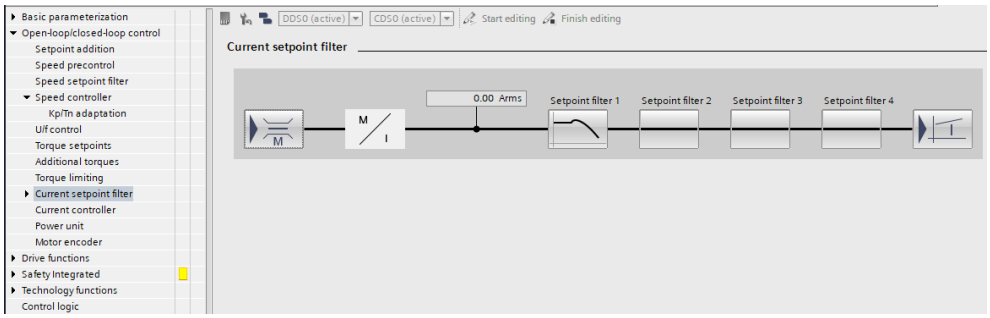
The current setpoint filters 1 to 4 are available as standard. You can activate the current setpoint filters 5 to 10 offline in the object properties of the drive.

Select the desired servo drive in the project navigator and open the "Properties" menu. Click the "Function modules" tab. Activate the "Extended current setpoint filters" function module in the function modules selection. Download the data to the target system.

The extended current setpoint filters 5-10 can be activated via the parameter p5200[0] and configured with p5201-p5230.

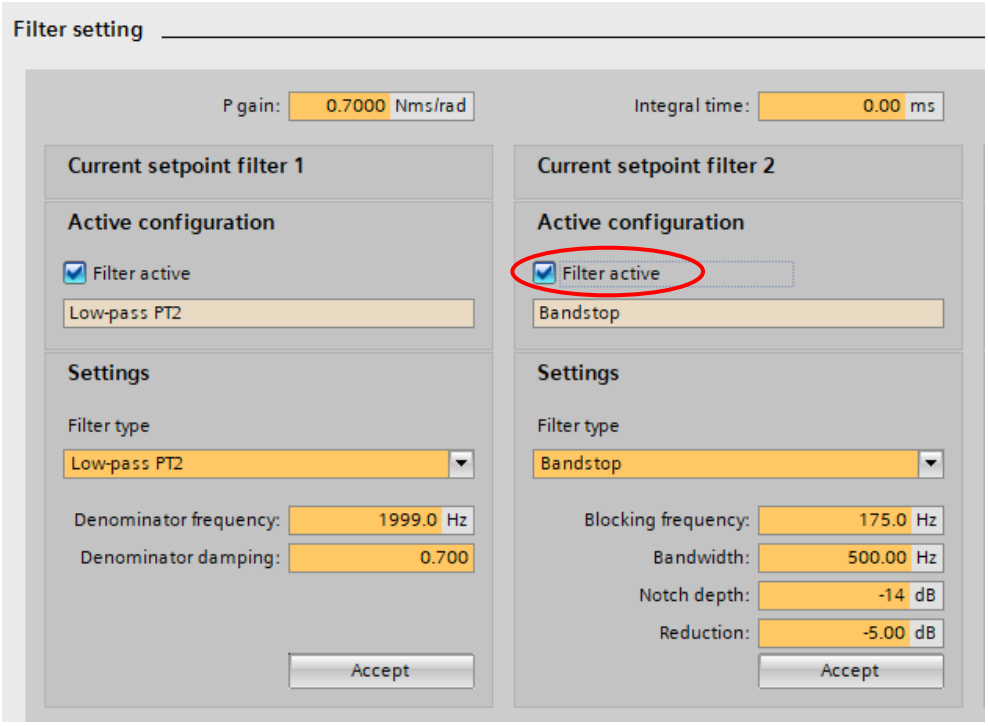
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Figure 7-11 current setpoint filters in TIA/Startdrive



By clicking on the buttons, the filter can be parameterized.

Figure 7-12 settings of the current setpoint filter



To activate a filter check the checkbox „filter active“

First, the filter type must be chosen. Select low-pass filter, band-stop, low-pass filter with reduction or general filter 2nd order.

Note

If you want to see the effects and transfer functions of the filters, you can also set the current setpoint filters in Starter. The amplitude and phase frequency responses of the filters are shown there.

Note

While low-pass filters have a better filter efficiency, band stop filters cause less phase tilt (see graphic above). This has less bad influence on the dynamics of the speed loop.

For single resonance frequencies, a band-stop filter is recommended. If there are several closely spaced resonance frequencies, a single low-pass filter could be better.

Band-stop filter parameter:

Notch frequency:	resonance frequency (pole) determined with measurement cursor
Bandwidth:	Not smaller than half notch frequency!
	The filter must be robust in case of a shift of the resonance frequency!
Notch depth:	ca. 50% of magnitude difference between pole and zero
	Set notch depth as deep as necessary only.
	Notch depth causes phase tilt!

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Reduction:	Effects a permanent reduction of the magnitude after the notch. Set only if required and as deep as necessary, as it causes phase tilt!

To have a look on the filter results, repeat the last measuring (without any changes at the controller parameter) after setting the filter.

Figure 7-13 measurement 3: speed control loop (current setpoint filter active)



Because the filter the resonance frequency is damped, the trace shows an adequate amplitude margin. At the open speed control loop without filter (Figure 7-10 measurement 2: speed control loop) the resonance is at +10 dB.

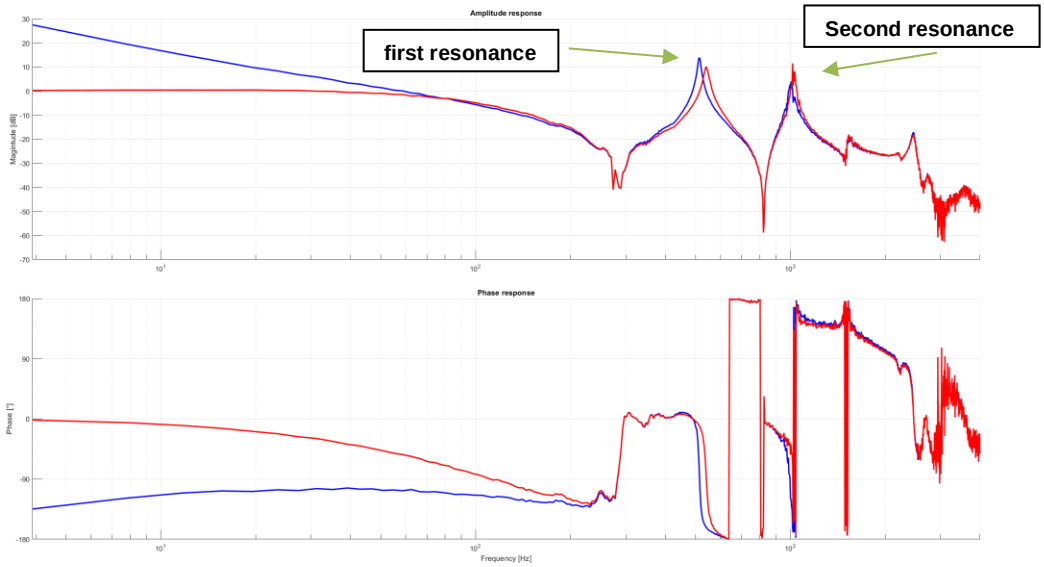
Now the proportional gain factor Kp can be increased.

In this control loop, the phase reserve is always too large at the resonance points, which is why no instability can occur.

In the following, a critical speed control loop will be considered, in which the the setting of the filters is more relevant.

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Figure 7-14 open (blue) and closed (red) speed control loop without filters

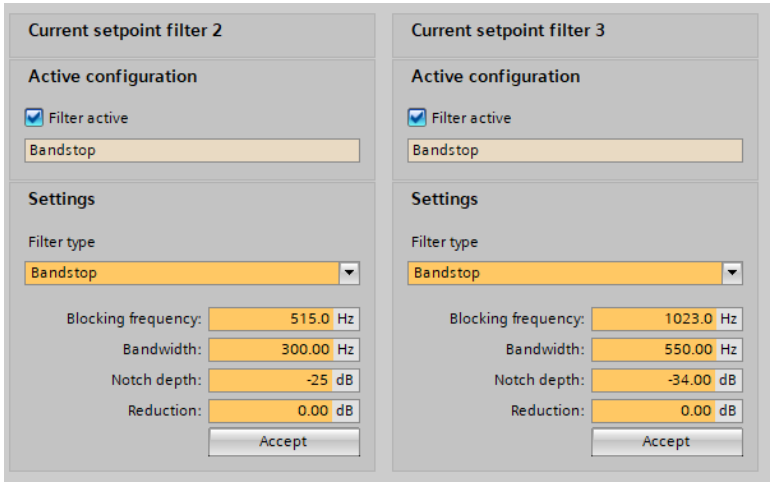


First resonance (approx. 500Hz): The pole is above 0dB and the phase reaches -180°. A filter must be set.

Second resonance (approx. 1000Hz): There is no phase reserve at this pole. A filter must be set here and the resonance damped to prevent instability.

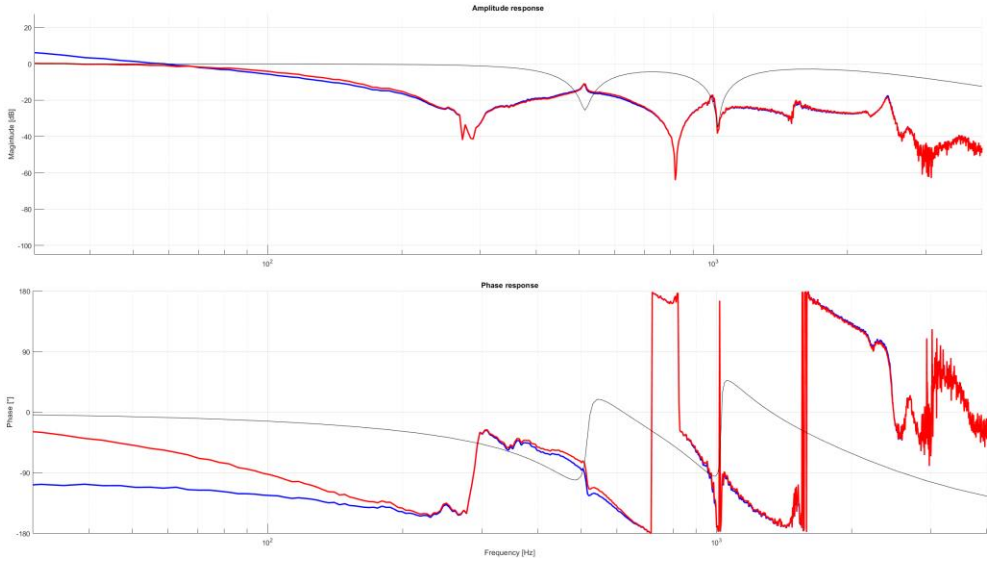
The poles are damped with these bandstops:

Figure 7-15 filter configuration



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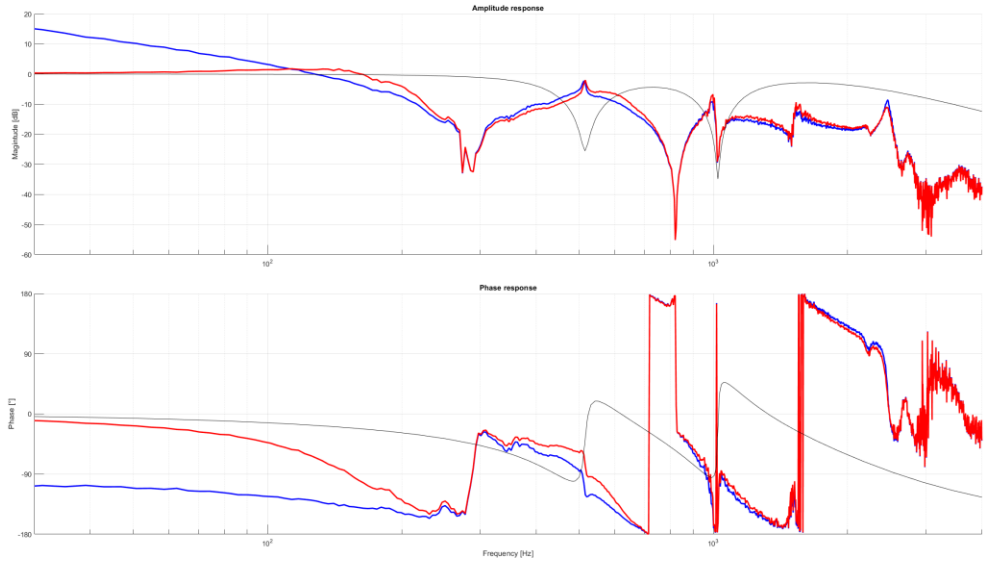
Figure 7-16 open (blue) and closed (red) speed controlled loop with both filters



The black graph shows the impact of both bandstops. Their notch in the magnitude leads to damping of the poles in the open speed-control loop. The first resonance point is now at -10dB, the second at -17dB. Due to the amplitude reserve in the open speed-control loop that has now been created, the closed speed control loop is no longer instable.

To increase the dynamics of the speed control loop again, the Kp value can now be further enlarged.

Figure 7-17 speed control loops with enlarged Kp



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7.4 Integral time (Tn)

After the speed controller proportional gain factor Kp is optimized, the integral component of the PI controller can be activated with the integral time Tn.

Reducing the integral time affects a shortening of the integral-action time. As a result of this, the amplification in the lower frequency domain of the closed speed control loop rises.

This can be seen at the amplitude increase of the closed speed control loop (red) in the front area of the frequency response.

NOTE

Optimized for the symmetrical optimum, the resonance peak should not be higher than 3dB.

In the step response, this corresponds to an overshoot of approx. 43% over the stationary end value. The reset time then corresponds to the rise time of the purely P-controlled system.

Figure 7-18 speed control loop



By reducing the integral time, the controller bandwidth got higher again (characteristic angular frequency f(-3dB) = 48Hz, without Tn: f(-3dB) = 40Hz).

NOTE

The characteristic angular frequency is the frequency at which the amplitude response falls below -3dB. The characteristic angular frequency is a measure of the achievable dynamics and control bandwith.

- **The stability criteria are still complied.**

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7.5 Current setpoint filters in multi-mass-systems

Besides the desired damping effects of the current setpoint filters, there are also negative effects:

Depending on the filter type and the adjusted parameter, a phase tilt is the negative result. This effects the dynamic and the stability of the control loop.

Be careful with the number of filters and the choice of the filter parameters.

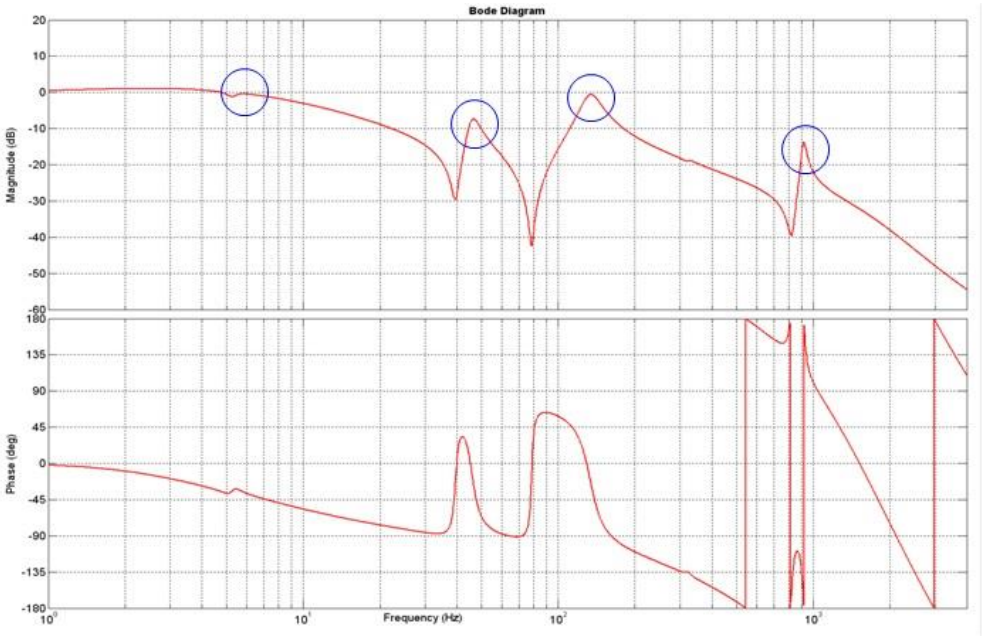
Not every resonance frequency has to be damped by a current setpoint filter.

Resonances in the area of the controller bandwidth of the speed controller (in this area the controller reacts dynamically), are responded by the controller itself.

The controller bandwidth defines the area, in which enough phase margin (>= 60°) is available.

The following closed loop speed controller frequency responses shows four resonance frequencies, where - at first sight - current setpoint filters might be required.

Figure 7-19 simulated speed control loop



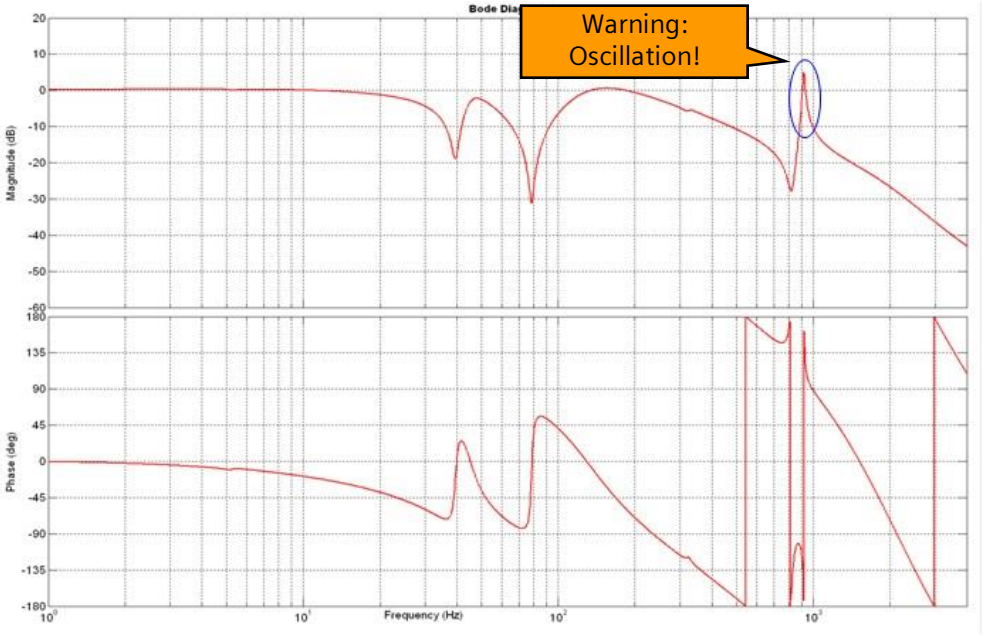
First three resonance frequencies are located in the area of the controller bandwidth (noticeable at the phase margin).

At the fourth resonance frequency the phase margin equals 0°. But the amplitude margin is still enough.

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After raising the proportional gain factor, only the fourth resonance spot gets over 0dB. In this area, there is no (not enough) phase margin. The other poles have approximatedto the 0dB line.

Figure 7-20 simulated speed control loop



The amplitude amplification above 0dB indicates an instable condition of the control loop. Here **one** current setpoint filter is recommended.

There is no amplitude amplification over 0dB at the rest of the resonance frequencies noticeable. Because of the phase margin these resonances are damped by the speed control loop itself. **No current setpoint filters necessary for these resonances.**

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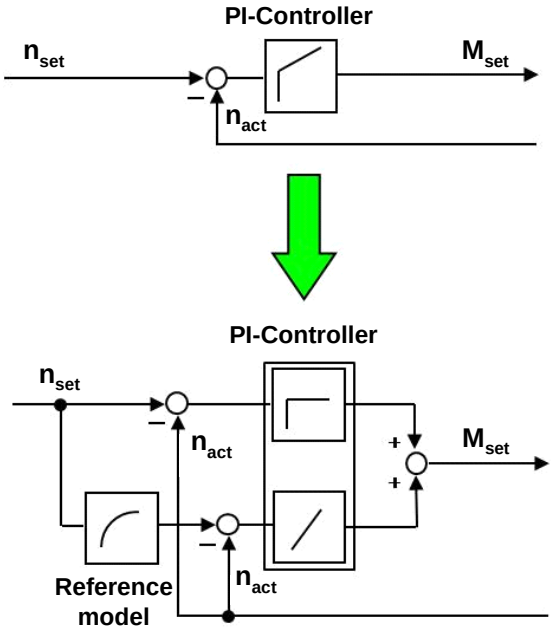
7.6 Reference model

Note Optional improvement for applications with dynamic setpoint changes.

The reference model is located between the speed command value and the speed actual value of the speed controller's integral component (see block diagram).

In this way, a separation of setpoint value controlling and disturbance value controlling is reached. The reference model delays the command actual value deviation for the speed controller's integral component. In this way, only the P-Component is relevant for command value controlling. The integral component of the speed controller will be blinded for setpoint changes.

Figure 7-21 block diagram: reference model



The typical goal of the reference model is to reduce the amplitude amplification (caused of a short integral time) in the lower frequency domain of the closed speed control loop. (The previously adjusted short integral time Tn ensures a good disturbance control.)

In time domain, the reference model effects a reduction of the actual value overshoot but retains the integral component.

Using the reference model, a higher position controller gain can be reached.

NOTE The reference model only has an advantage, if speed pre-control (DSC) is used!

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To activate the reference model, set the select menu „Reference model“ in the speed controller menu to ON. By clicking on the now appeared button „Reference model“, the following parameter can be adjusted:

Figure 7-16 switch on reference model

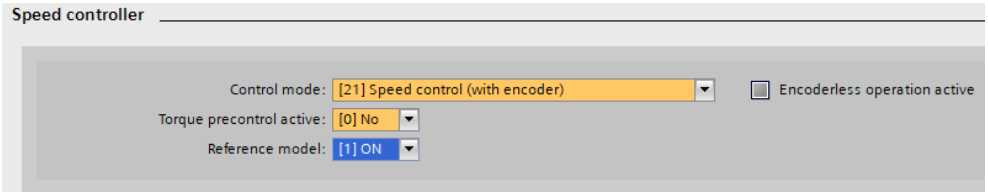
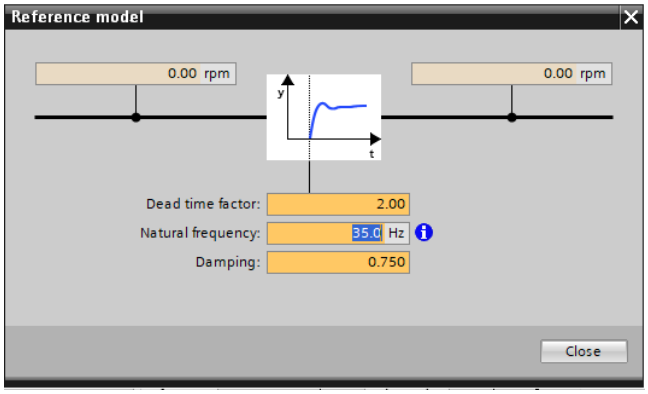


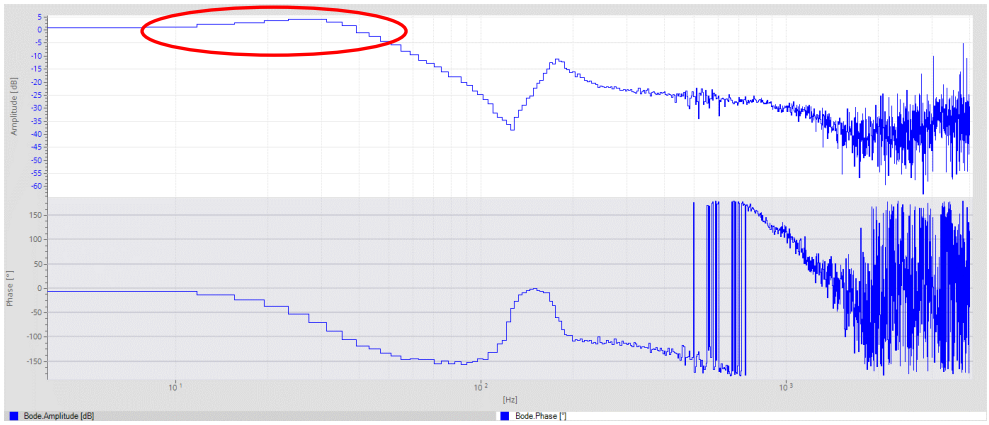
Figure 7-17 configuration of the reference model



Natural frequency [p1433]:	Start value: frequency at which the phase of the closed speed control loop reaches -90° for the first time. Hint: Set start value slightly smaller. Afterwards, shift the amplitude reduction (effected by the reference model) below the amplitude raise by increasing the natural frequency p1433
Damping [p1434]:	default-value; adjust if necessary
Dead time factor [91435]:	default-value; adjust if necessary

To optimize the reference model, you can use the measuring function “speed controller setpoint frequency response (after speed setpoint filter)”.

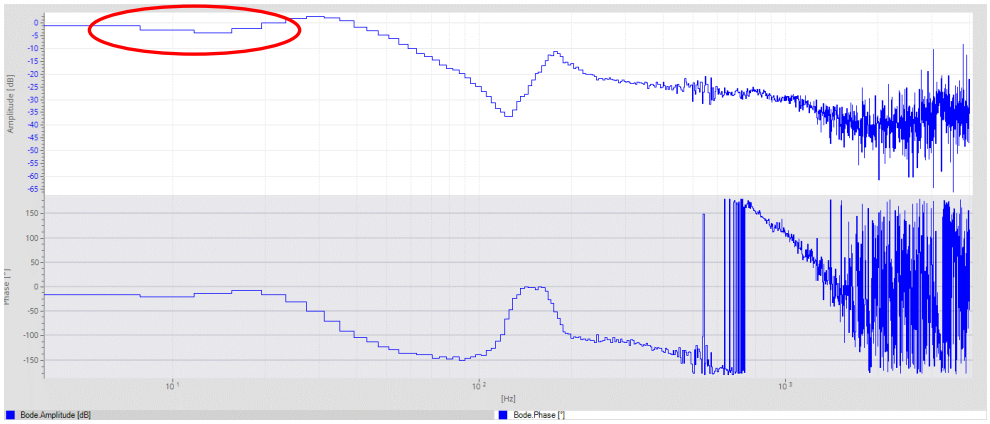
Figure 7-22 Reference model OFF



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Amplification because of „low“ integral time recognizable

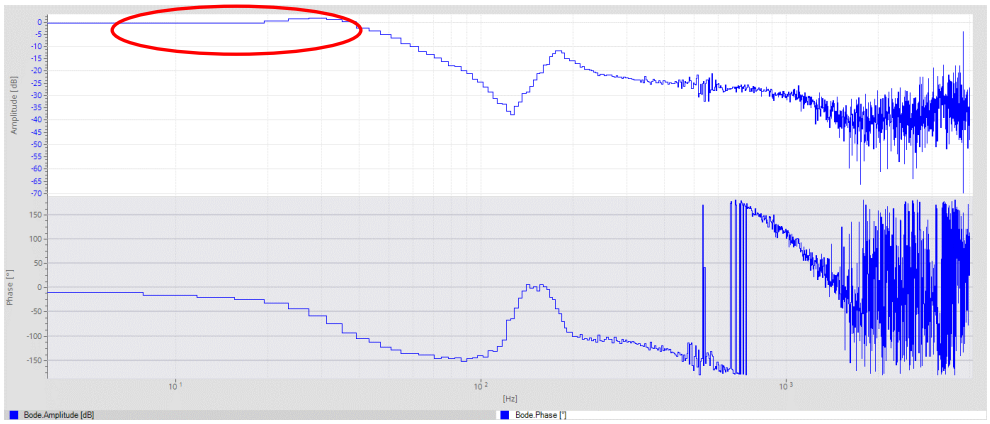
Figure 7-23 Reference model ON



Natural frequency too low: Reduction of the amplitude recognizable

With increasing the natural frequency, the reference model time constant decreases. The command value reaches the integrator earlier.

Figure 7-24 Reference model ON



Better configuration: only low amplitude ovvershoot

7.7 Actual speed filter

In the case of a bad encoder signal (noisy actual speed value) the value can be smoothed by a PT1 filter. The drive parameter p1441 is available for this purpose.

A common smoothing time is about 2-3ms. This must be adapted to the respective circumstances.

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8 Position controller optimization

Premise: Optimized current controller and speed controller

Compared to the current- and speed controller (PI controller,) the position controller is realized as a P-controller.

For servo drives, a position controller with speed pre-control is recommended.

The most important position controller parameters:

- Kv position controller proportional gain factor
- Kpc speed pre-control weighting factor
- vTC balancing time (velocity Time Constant)

and:

- DSC Dynamic Servo Control (active per default)

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8.1 DSC (Dynamic Servo Control)

The function "Dynamic Servo Control" (DSC) is a controller structure calculated in the speed controller sample time. With the DSC, the dynamically active component of the position controller is calculated in the drive (usually in 125us cycle).

Advantages of DSC:

- Higher Kv (position controller gain) possible
- Larger bandwidth -> higher dynamic response
- Shorter response times for disturbance characteristic

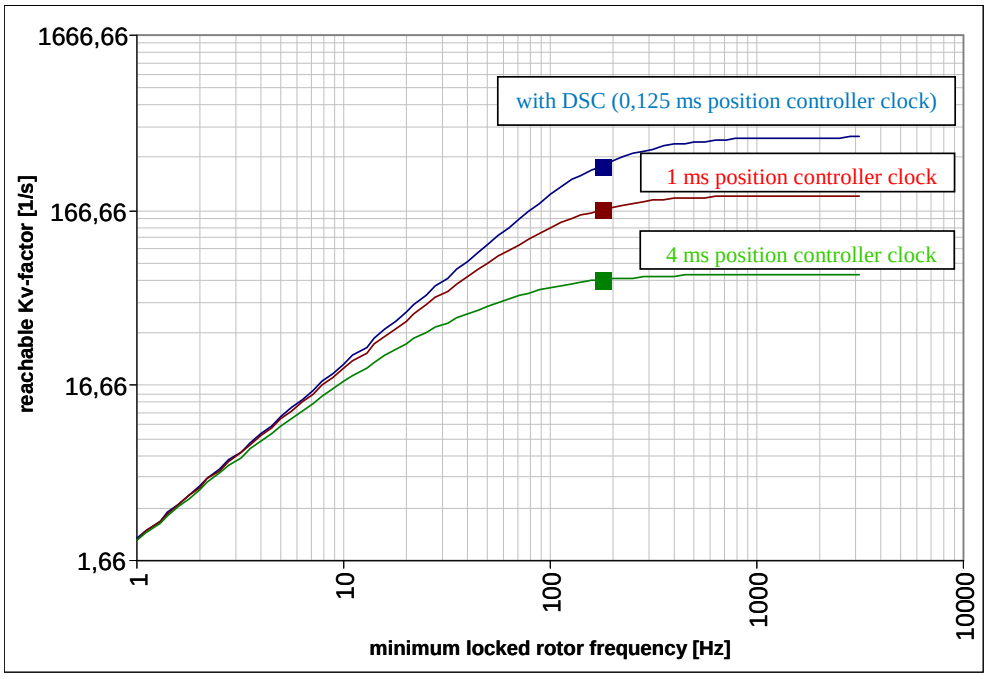
Use DSC especially for dynamic applications!

For a position axis with position control and an assigned SINAMICS drive, the system sets DCS by default. Deactivation only in offline mode.

Note To use the DSC function, the position controller must be set as P controller.

You can see in the chart below, that the benefit of DSC (higher reachable Kv factor) is even bigger, the higher the minimum locked rotor frequency of the systems is.

Figure 8-1 Kv-factor relating to the locked rotor frequency



Attention **In practice, only approx. 2/3 of the Kv factor shown in the chart can be reached!**

This is because of the damping, which isn't considered in this chart.

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8.2 Unit of the position controller gain factor (Kv)

Attention **There is a difference between the servo gain factor unit of the SIMOTION/SIMATIC position controller and the E-Pos (basic positioner) in SINAMICS!**

This unit differs also in the machine tool control system SINUMERIK.

Basically, the servo gain factor Kv is defined by the formula:

$$Kv = \frac{linear\ speed}{following\ error}$$

The Kv factor unit depends on different units of the parameter mentioned above:

SIMATIC/SIMOTION: $\left[Kv_{(MC)}\right] = \frac{1}{s}$

E-Pos / SINUMERIK / SINAMICS: $\left[Kv_{(EPos/MT)}\right] = \frac{1000}{\min}$

The result is a conversion factor of 16.6:

$$Kv_{(MC)} = 16{,}6 \cdot Kv_{(EPos/MT)}$$

There is a relation between the reachable servo gain factor and the least locked rotor frequency of the mechanical system.

$$Kv_{(MC)} = \frac{f_{T\min}}{10} \cdot 16.6 \left[\frac{1}{\mathrm{s}}\right]$$

$$Kv_{(EPos/MT)} = \frac{f_{T\min}}{10} \left[\frac{1000}{\min}\right]$$

(see also: chart, chapter 8.1)

NOTE This is important when the value which was determined by OBT shall be used.

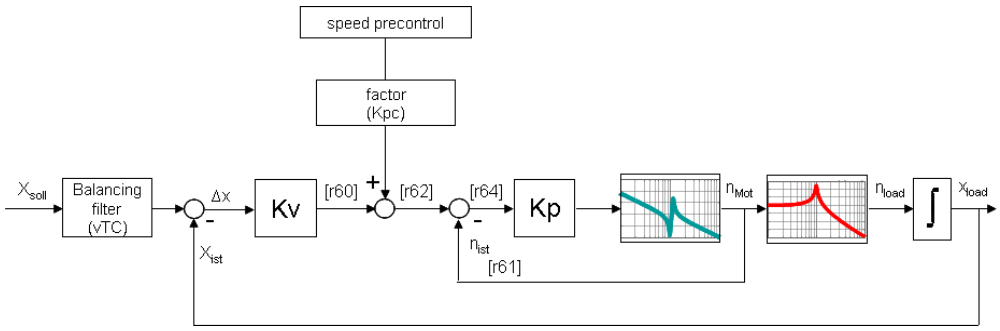
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8.3 Speed pre-control and balancing filter

The speed pre-control is used to reduce the following error during a positioning process. In this way, the position controller gets more dynamic.

The speed command value is added directly to the position controller output. The speed controller input is available faster, because the known speed setpoint can by-pass the position controller.

Figure 8-2 Figure 8-2 block diagram - speed pre-control



The additional command value is scaled by thy speed pre-control weighting factor Kpc.

Note

Except for special exceptions, the factor Kpc should be kept 100%!

The remaining function of the position controller using speed pre-control is the disturbance rejection.

There are two time constants available:

- tTC Current control loop equivalent time
  (not used)
- **vTC Speed control loop equivalent time**
  (for balancing filter)

The vTC-time constant is used. Thus, the position setpoint is delayed by the balancing filter time constant. This prevents overdriving of the speed-setpoint by the position controller in the acceleration and braking processes. This time constant will be discussed in more detail in the next chapter.

vTC too short: Position command value delay not sufficient. The position controller compensates the following error in addition to the speed pre-control. The result is an overshoot of the speed command value during acceleration and deceleration (Figure 8-9 Measurement 1: vTC clearly too small).

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vTC too long: Delay to strong. System deviation between command value and actual value negative (position exceeded). The position controller reacts against the speed pre-control In the trace, a creeping in into the final position is noticeable (Figure 8-10 Measurement 2: vTC too large).

vTC ideal: The system deviation equals 0. Consequently, the controller output without pre-control [r60] equals 0 as well (Figure 8-11 Measurement 3 vTC optimal (vTC from One-Button-Tuning)).

Attention **If speed pre-control is deactivated, (Kpc = 0%) set vTC = 0ms!**

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8.4 Position controller parameter

NOTE In this chapter, the position controller optimization is described for TIA/Startdrive.

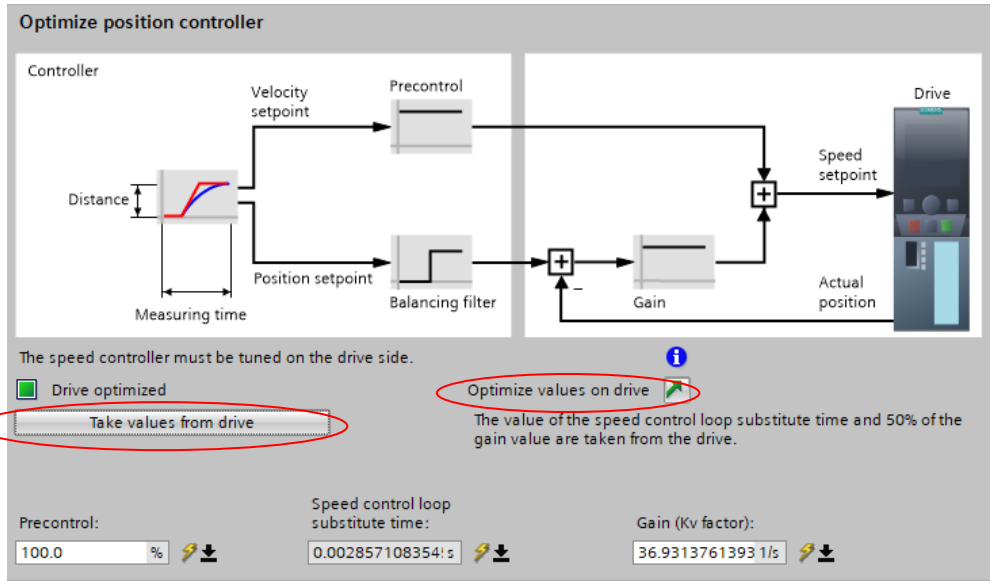
8.4.1 Optimization of Kv and vTC with One-Button-Tuning

You can't trace frequency responses of the Position Controller in TIA/Startdrive. Measurement functions for determining the balancing filter time constant vTC are also not available.

But you can use the One-Button-Tuning here. It determines the Kv-factor and the vTC-time-constant in the drive, which can then be transferred to the axis. But before you do this you should note the manually determined speed controller parameters, because these are also overwritten by the OBT.

To do this, the corresponding axis must be selected in the technology objects of the plc. Then go to Commissioning and chose Tuning.

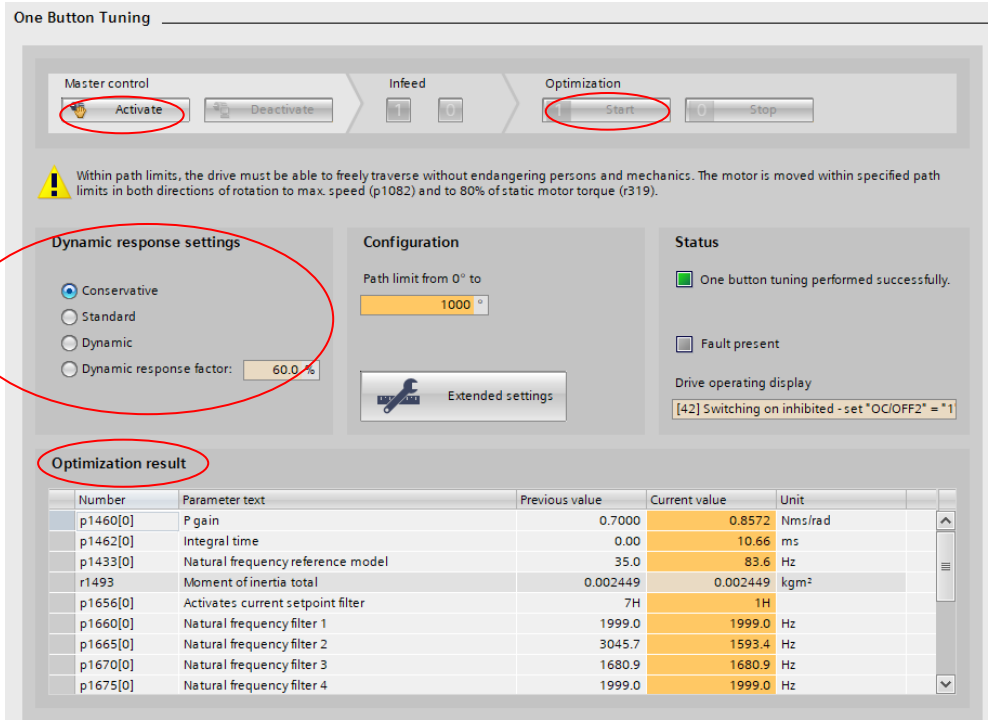
Figure 8-3 Figure 8-3 Mask optimize position controller



Clicking on the arrow next to "Optimize values drive" takes you to the one-button tuning in the drive. After that has been carried out, the determined controller parameters can be transferred to the axis with "Take values from drive".
The Kv factor is automatically converted into the correct unit.

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Figure 8-4 Mask One Button Tuning



After activating the master control, the desired dynamic setting must be selected. Then the optimization can be started.

NOTE

Only parameters of the speed controller are displayed under Optimization result. However, the estimated position control parameters can be viewed in the expert list of the drive under r5276 and r5277.

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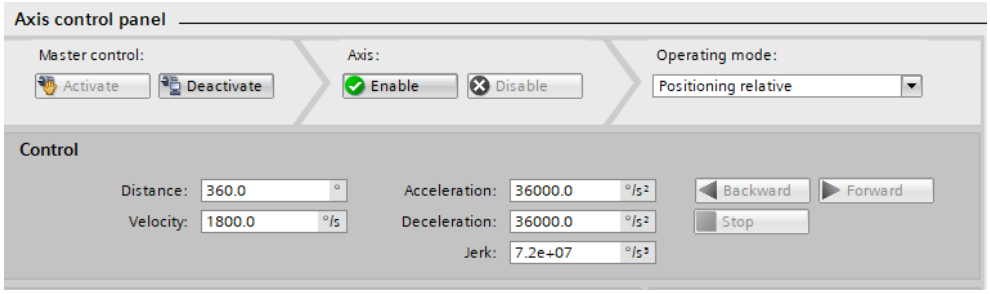
8.4.2 Verification of the vTC time constant

The vTC time constant determined in the OBT can now be checked for plausibility. For this purpose, the following values must be be selected at the beginning of the verification:

- precontrol Kpc = 100%
- balancing filter time constant = 0ms
- Gain Kv = “optimized value”

A very dynamic speed profile must be run for the check. Since there is no function generator available in TIA/Startdrive, this profile must be specified via the axis control panel with high acceleration, deceleration and high jerk:

Figure 8-5 Axis control panel for trapezoidal profile



NOTE

The jerk is the time derivative of the acceleration and thus defines the change in acceleration. As the jerk decreases, the "corners" become more rounded when the acceleration changes.

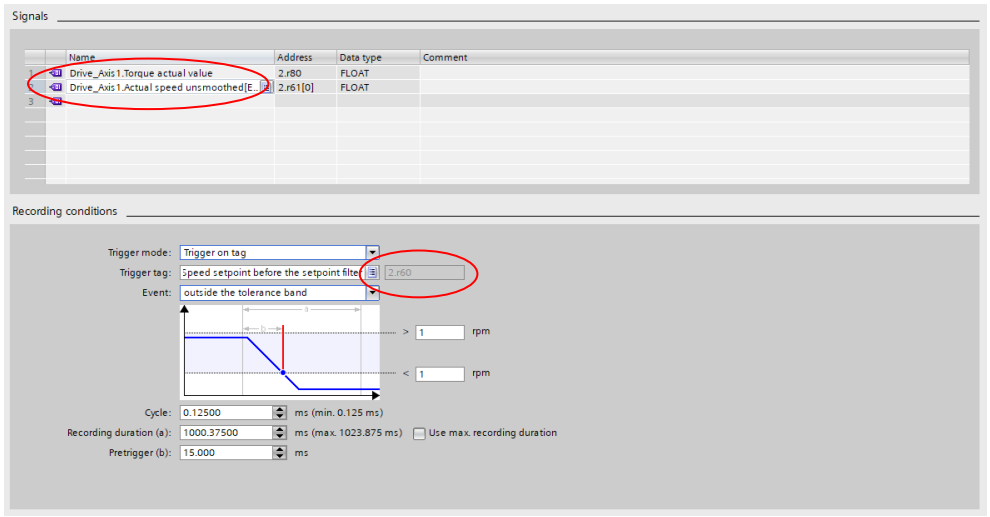
NOTICE

When performing the following measurements, it must be ensured that the torque limit (negative/positive) is not exceeded due to excessive acceleration or excessive jerk at a defined speed.

The current torque limit can be found in the drive under “Parameterization → Open/closed-loop control → Speed controller → Torque limiting”.

At first, a trace with the actual torque value [r80] and the actual speed value [r61] must be recorded in the drive.

Figure 8-6 Figure 8-6 Trace for permissible maximum torque



Note: Recording started by trigger

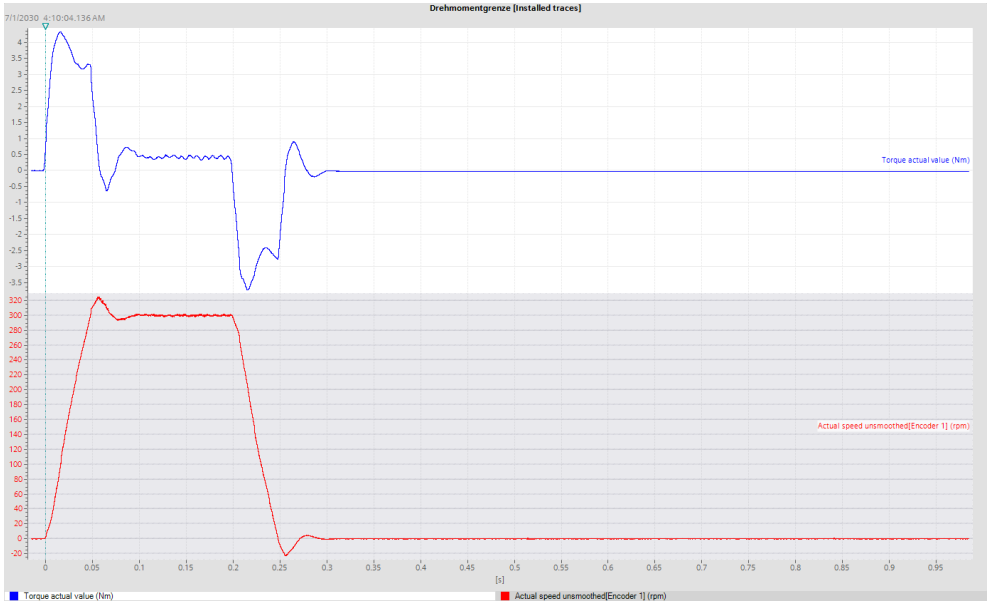
Trace is started with the "Activate recording" button. The axis must then be enabled and turned with the trapezoidal via the axis control panel. The torque limit can be approached by adjusting the parameters velocity, acceleration and jerk.

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NOTE

It is recommended to maintain a reserve of at least. 10% of the torque limit value!

Figure 8-7 actual Torque (blue) and actual speed (red)



In this case the torque limit is 5 Nm. Therefore, a maximum value of 4.5Nm would be possible. A maximum torque of 4Nm is achieved here.

Once the velocity profile has been defined, the measurement to determine the balancing filter time constant vTC can be carried out.

These are the relevant parameters:

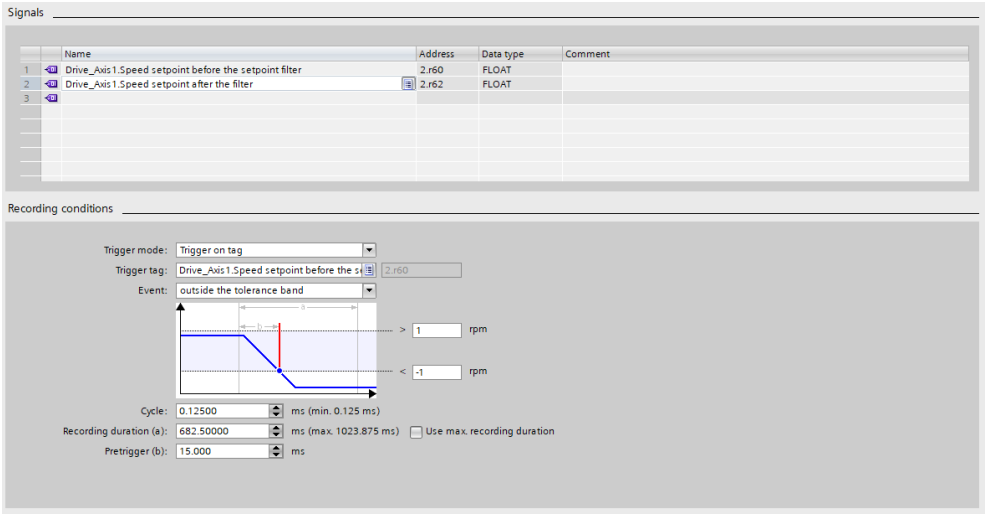
- [r60] Speed setpoint before the setpoint filter [rpm]
- [r62] Speed setpoint after the filter [rpm]

Based on these parameters, the optimization can be carried out using two criteria:

- The speed setpoint [r62] is reached quickly without overshooting
- Speed setpoint without pre-control value [r60] as close as possible to 0rpm

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Figure 8-8 Trace speed setpoints



The blue curve in Figure 8-9 shows the position controller output with pre-control value (signal [r62]).

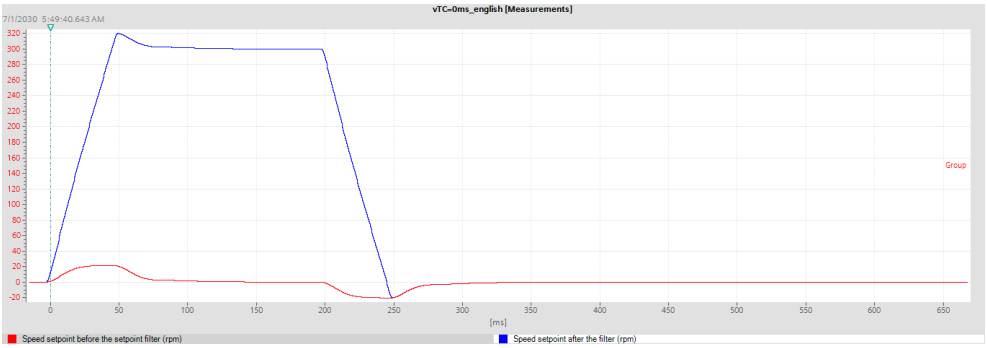
The measurement shows a clear overshoot of the speed setpoint.

The red curve represents the output of the position controller before summation with the pre-control (signal [r60]).

With deactivated pre-control (Kpc = 0%), the signals [r60] and [r62] are congruent.

With active pre-control (Kpc = 100%), the value of [r60] should ideally approach 0.

Figure 8-9 Measurement 1: vTC clearly too small (0 ms)

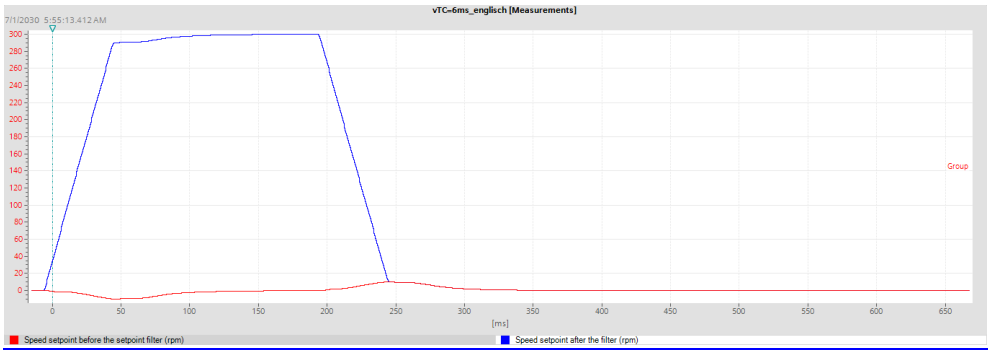


If the balancing filter time constant is not well selected, the position controller "helps" at the beginning of the acceleration and deceleration phases (in addition to the pre-control). Therefore, there is a deviation of the red curve from the value 0 during acceleration and braking.

The overshooting of r62 and the deviation of 0 from r60 indicate that the balancing filter time constant is too short.

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Figure 8-10 Measurement 2: vTC too large

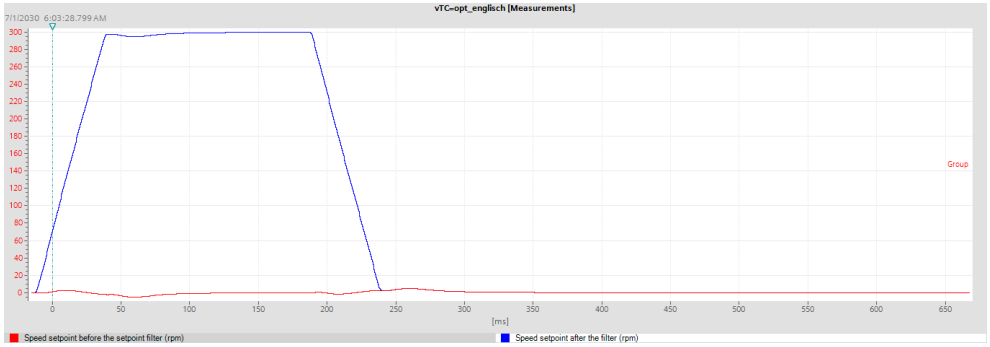


If the vTC selected is too long, the speed setpoint after filter sneaks into the setpoint.

At the speed setpoint before the setpoint filter, there is a counteracting due to a negative control difference.

Measurement 3 shows that the position controller output [r60] is almost equal to 0. With an optimally selected vTC, the speed setpoint after filter [r62] reaches its end value quickly and without overshooting.

Figure 8-11 Measurement 3 vTC optimal (vTC from One-Button-Tuning)



The validation using the parameter [r62] (speed setpoint after filter) is sometimes difficult, since the boundary between sneaking in the end value and reaching it quickly is difficult to identify.

Therefore, the parameter [r60] (position controller output without pre-control value) is better suited for fine adjustment of the balancing time.

In this way, the optimum balancing filter time constant can be approached, if the One-Button-Tuning didn’t find a good vTC-time-constant.

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9 Controller and filter adaption

The controller adaption adapts the controller parameter continuously dependent of an adaption signal. Therefore, the controller dynamic remains the same, even the controller loop changes.

NOTICE	**The controller adaption should be used to linearize the control loop!** **Otherwise, every change of the control loop would influence the superimposed control loop.**

9.1 Current controller adaption

The inductance of the motor depends on the motor current.

Due to the fact, that the current controller gain is proportional to the time constant of the motor winding, the gain must be reduced with high motor current. Thus, the controller performance can be kept constant and instability can be avoided.

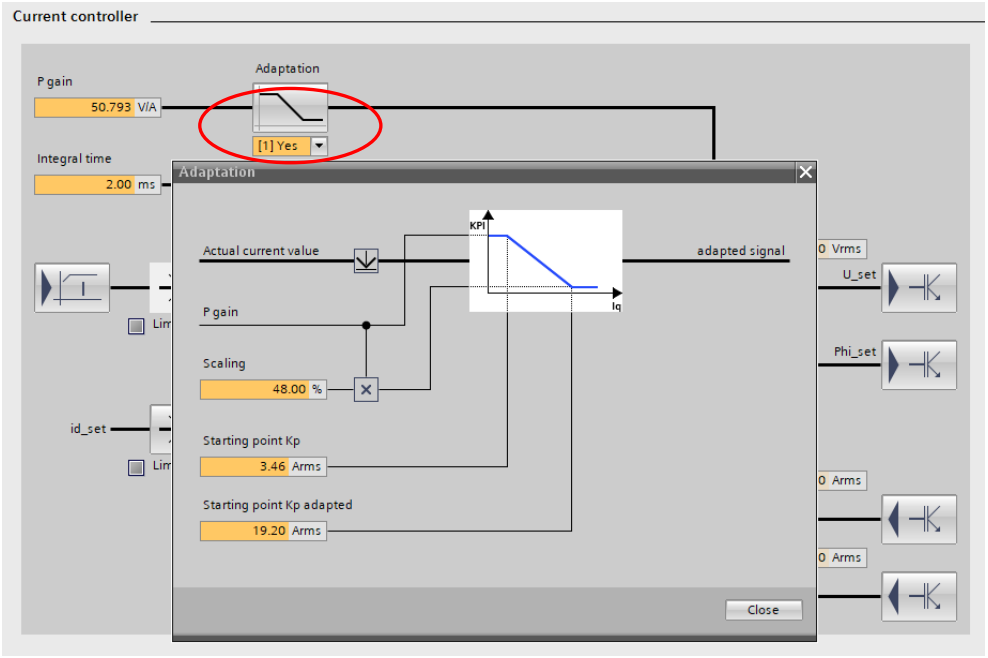
This is especially important for servo motors which are operated with a current higher than the rated current.

The current controller adaption can be found in the current controller settings in the drive in "open-loop/closed-loop control" (see **Fehler! Verweisquelle konnte nicht gefunden werden.**).

NOTE	Siemens motors: The current controller adaption is active per default. The DriveCliQ data sheet provides the correct settings. Third-party motors: Check "SINAMICS S120/S150: Requirements placed on third-party motors" https://support.industry.siemens.com/cs/ww/en/view/79690594 As of SINAMICS FW > V5.1, the current controller Kp adaptation is set by the rotating measurement. The measurement must be executed without ramp-function generator!

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Figure 9-1 Mask – current controller adaption



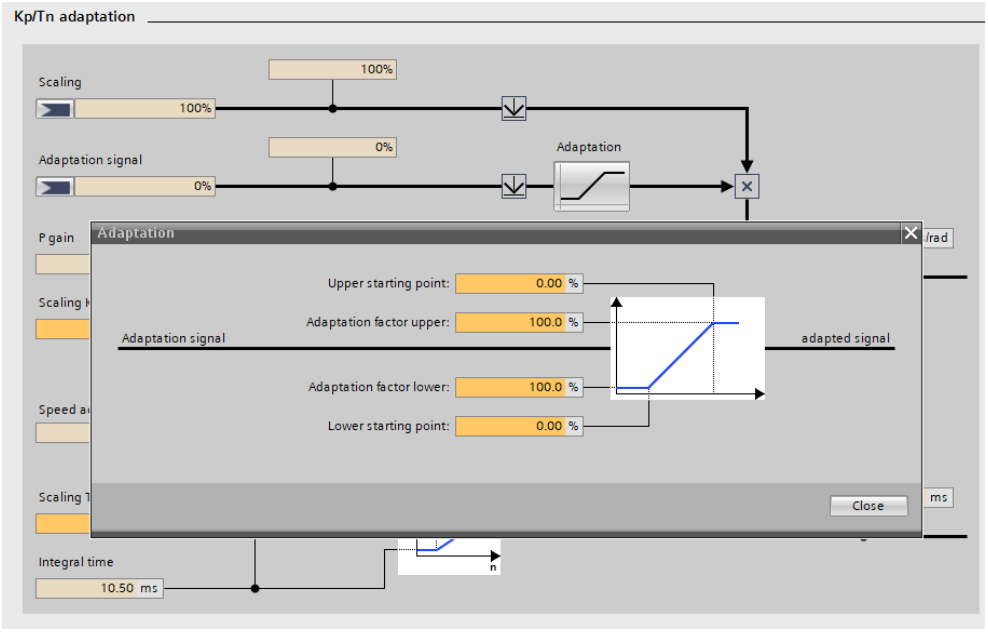
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9.2 Speed controller adaption

As a result of changing load inertia, it might be necessary to adapt the speed controller parameter Kp and Tn.

One use case is the changing inertia of a winder during the winding process. With increasing diameter, the speed controller gain must be increased due to an increasing inertia of the load. With decreasing diameter, the Kp must be reduced.

Figure 9-2 mask – speed controller adaption



By clicking on "Adaption", the Kp-adaption can be configured. The x-axis describes the adaption signal (e.g. diameter), the y-axis the adaption factor. The values need to be determined during controller optimization for minimum and maximum adaption signal.

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9.3 Current Setpoint Filter adaption

In special use cases the current setpoint filter described in chapter Speed controller optimization must be adapted as a result of a changing mechanical resonance frequency.

Two use cases can be distinguished:

- Adaption during machine runtime
- Adaption during machine standstill

In both cases, the goal is to adapt the filter without the use of an engineering system.

NOTE Only one of 4 current setpoint filter can be adapted!

Adaption during machine runtime

The SINAMICS S120 provides a function module for this (inertia estimator).

Simplified functional principle:

If a resonance frequency has been excited enough that the internal activation threshold is exceeded, the adaptation moves the bandstop filter to this resonance frequency. If the resonance frequency has not been excited enough or there is no interfering resonance frequency, the bandstop filter stops and the current blocking frequency does not change.

NOTE For detailed information and boundary conditions see

SINAMICS S120 Function Manual Drive Functions

https://support.industry.siemens.com/cs/ww/en/view/109754299

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10 Feed-Forward (Pre-Control) & Compensation

Pre-Control means to by-pass a set point around the superimposed control loop. This reduces the workload of the controller for setpoint controlling and improves dynamic behavior of the controller.

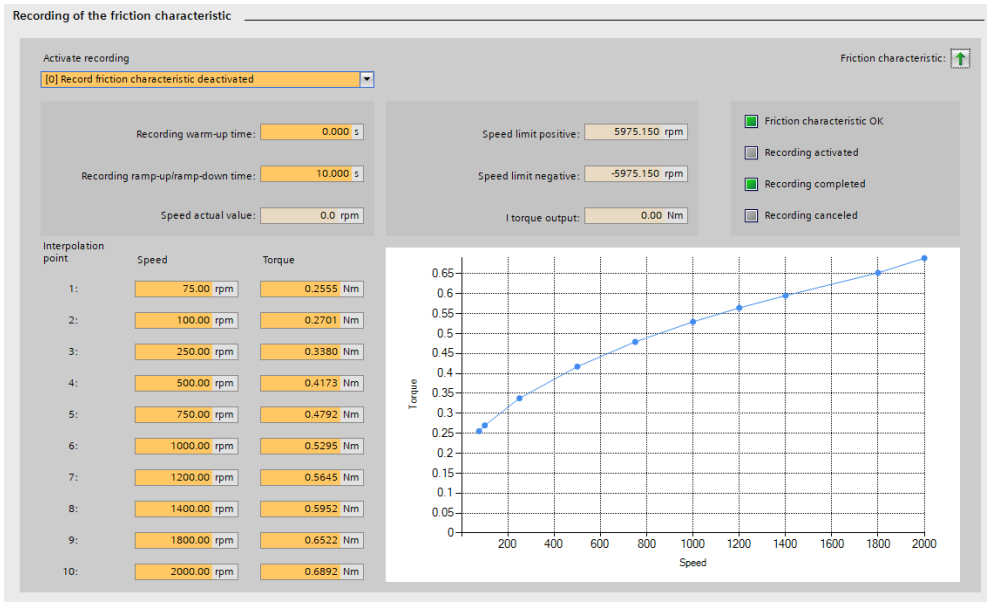
The speed controller gets a speed via the pre-control path, without the position controller has to create it. The current controller gets a torque via the pre-control path, without it needs to be created in the speed controller.

There are different types of pre-control possible which are either calculated in the system or by application.

10.1 Friction torque

A common type of pre-control is the friction torque pre-control. The friction characteristic curve is used to compensate the friction torque for the motor and the driven machine. The friction characteristic enables the speed controller to be pre-controlled and improves the response.

Figure 10-1 Recording friction characteristic



After the recording of the friction characteristic is getting selected, it will be executed with the next enable command of the drive.

The drive accelerates to the parameterized speed levels and measures the actual torque (which is the friction torque in this situation) after a short settling time.

The result is a curve like shown in the screenshot above.

The friction characteristic should be recorded without (heavy) load. However, this can vary dependent on the mechanical situation.

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NOTE The acceleration between the speed levels could be relatively high! Sensitive mechanic should be disconnected before the measurement.

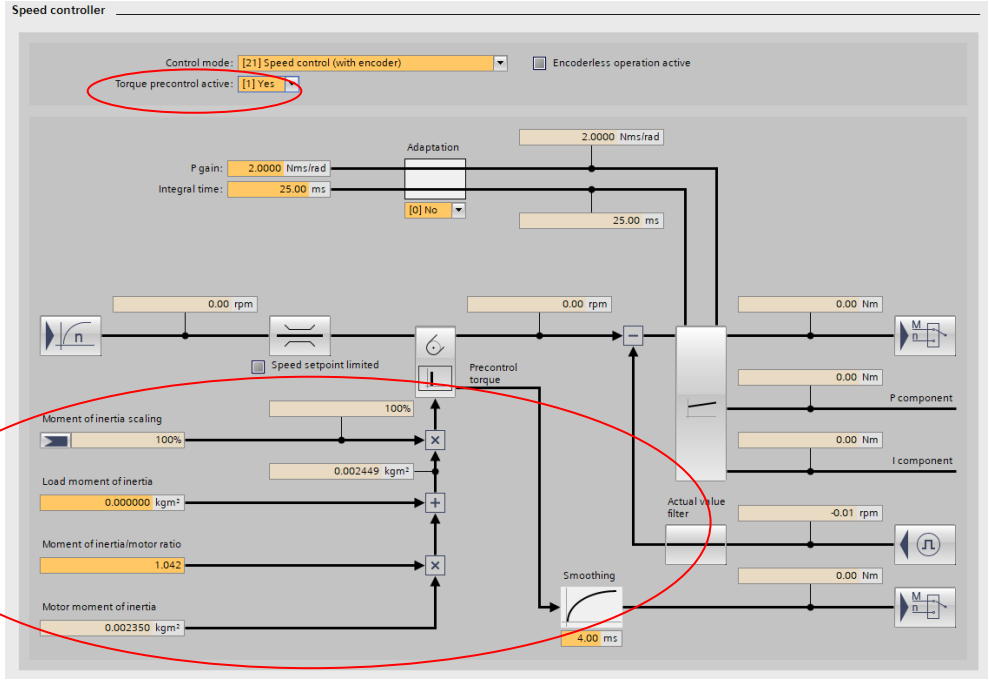
NOTICE **During the measurement the axis moves by several rotations in positive or negative direction.**

The user has to make sure the axis can be rotated freely, and no hardware limitations are violated.

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10.2 Acceleration torque

Figure 10-2 Torque precontrol active



Since the dynamic response in operation without an encoder is lower than in operation with an encoder, acceleration torque pre-control is implemented to improve the control dynamic performance. Considering the drive torque, the existing torque and current limits as well as the load moment of inertia (motor moment of inertia: p0341 · p0342 + load torque: p1498), the required torque for a demanded speed dynamic is pre-controlled.

The torque pre-control can also be activated if a motor encoder is used.

NOTE

If SIMOTION is used for position control of the respective axis, it is recommended to use DSC Spline for torque pre-control.

This torque pre-control function in the drive includes the position controller output in the torque feedforward calculation. Usually this is not intended.

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10.3 DSC Spline

An advanced form of torque pre-control using **SIMOTION** is DSC with Spline. **This function is only available in Scout/Starter.**

With the Dynamic Servo Control (DSC) function, the position controller in the drive is executed in the cycle clock of the speed control loop. In the drive, intermediate setpoints are generated in the speed controller cycle clock from the position setpoints transferred in the position controller/communication cycle clock via linear fine interpolation.

With the DSC with spline function, the position controller is executed in the drive in the cycle clock of the speed control loop. The intermediate values in the drive are generated via polynomial functions. Intermediate setpoints are also generated for speed and torque, in addition to position. Using the intermediate setpoints, highly dynamic motions down to the current controller cycle clock are simulated exactly and pre-control is possible right down to the torque.

The setpoints are fine-interpolated in the following way:

- Position setpoint - cubic fine interpolation
- Speed setpoint - quadratic fine interpolation
- Acceleration setpoint/torque setpoint - linear fine interpolation

DSC with spline provides the following advantages and functionality:

- Extended support for highly dynamic motions
- Process response is determined by the lower current controller equivalent time

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The following requirements must be satisfied for the use of DSC with spline:

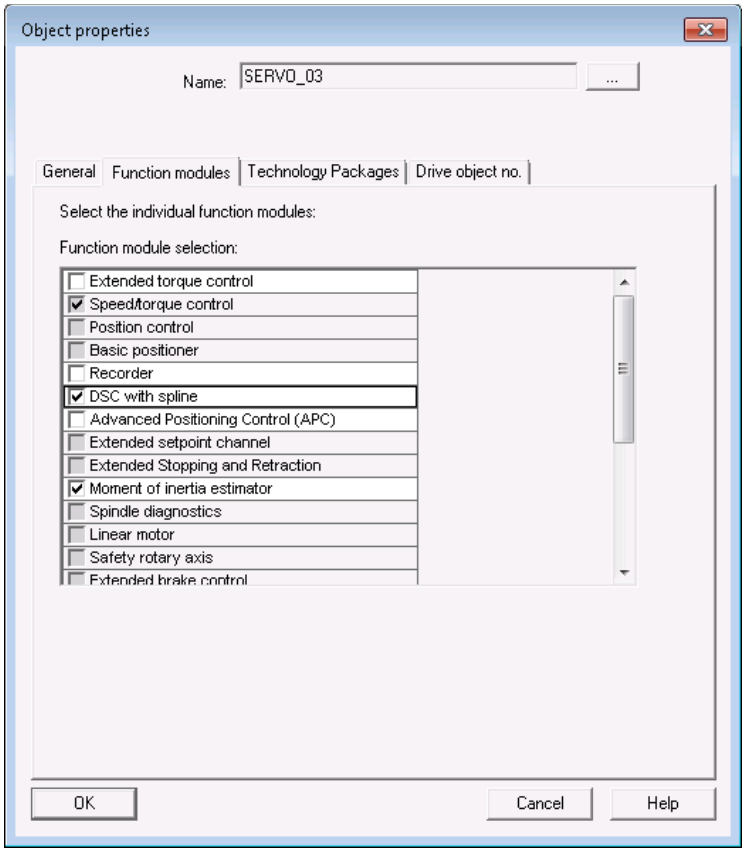
- Telegrams 125 and 126 must be supported by the drive
- Consistent setpoints

  Position and velocity setpoints must be consistent with each other, i.e. the setpoint pair must originate from the same cycle clock time of the motion control. In the setpoint calculation of the technology object, the position setpoints and the velocity are consistent with each other and are limited to the maximum values. If the setpoints are modified using compensation values or limits after the setpoint calculation, the consistency of position and velocity must be ensured by the user. If the setpoints are defined by the user, the user must ensure consistency. System variable with DSC spline status display: servoData.dscSpline
- High-resolution measuring system

  DSC with spline requires a high setpoint resolution. The setpoint resolution in the system is based on the actual value resolution. If the actual value only has a low resolution, you can increase the setpoint resolution internally. (Set p0418, e.g. to 18-bit)

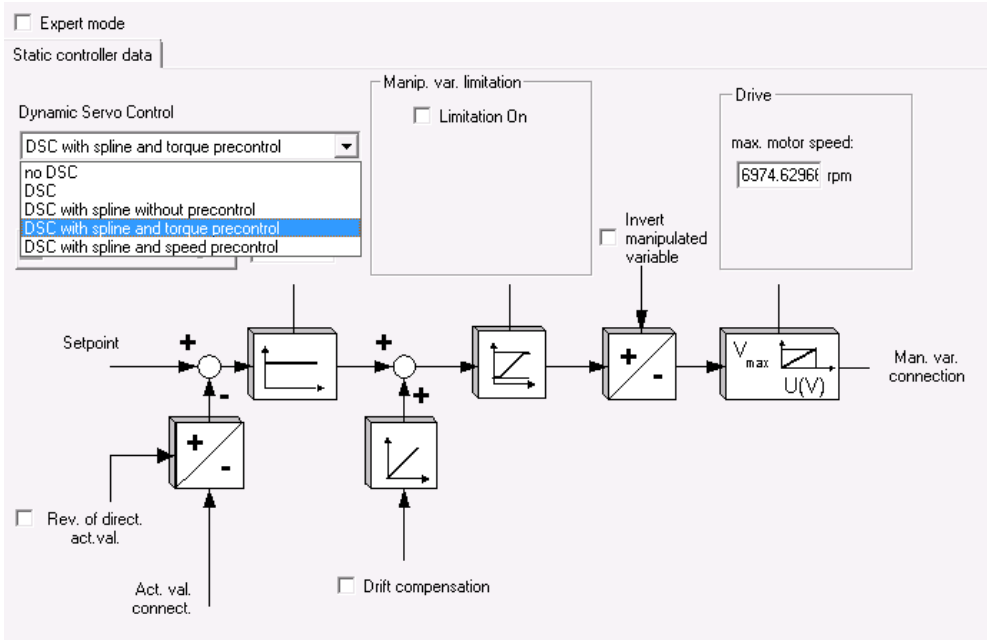
To use DSC Spline, the function module "DSC with Spline" must be activate in the drive.

Figure 10-3 Activation of the Spline function module in the drive



Now the Spline pre-control can be activated in the axis position control menu:

Figure 10-4 Activation Spline pre-control in the axis



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Beside the standard DSC, the following pre-control types are possible:

- DSC with spline and torque pre-control
    - The torque is pre-controlled.
    - Speed and position are controlled taking into account the equivalent time of the current controller in the balancing filter in the drive.
    - The torque is calculated in the drive from the acceleration and the total moment of inertia.
    - Balancing of the position setpoint and of the speed setpoint using the current controller equivalent time (ttc).

- DSC with spline and speed pre-control
    - The speed is pre-controlled.
    - The position is controlled taking into account the equivalent time of the speed controller (VTC) in the balancing filter in the drive.
    - The speed controller equivalent time is taken into account in the balancing filter.

- DSC with spline without pre-control
    - Speed and torque are not pre-controlled.
    - The position is controlled in the drive.

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Additional required settings:

- The TO resolution should be set to the maximum value (1.000.000/unit). This setting can be done in the axis configuration "unit" tab.
- Set the fine resolution of the encoder to the maximum value. Expert list parameter p418 (fine resolution Gx_XIST1) → 18
- The motor and especially load moment of inertia must be configured as precisely as possible (p0341, p0342, p1498 and p1497)

To optimize and fine tune the torque pre-control, the speed controller output can be monitored. During acceleration / deceleration the value should be close to 0. Adjustments can be done by adapting the load inertia setting in small steps.

10.4 APC (Advanced Position Control)

The "Advanced Position Control" (APC) function module provides closed-loop control-related functions to actively dampen mechanical oscillations. The function actively responds to measured oscillations using an appropriate manipulated signal. The motor executes a superimposed movement to compensate the oscillation. If the oscillation frequency changes, e.g. because of the axis loading or mechanical changes, APC is also effective for the changed frequency.

Regardless of the method used, the mechanical vibration must be measurable with a measuring system assigned to the axis. The following methods are available for this purpose when using APC.

1. APC is using motor variables (motor encoder, current).
2. APC is used together with a direct measuring system.
3. APC is used with an external acceleration sensor installed in the system.

NOTE For detailed information and boundary conditions see SINAMICS S120 Function Manual Drive Functions

https://support.industry.siemens.com/cs/ww/en/view/109754299

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10.5 VIBX (VIBration eXtinction)

The Technology Package VIBration eXtinction (VibX) is an option package for SIMOTION SCOUT. It is used to change the setpoint of an axis so that there is as little vibration as possible caused by the natural frequency of the moving mechanical components.

This is achieved by a setpoint filter which, for instance, adapts the acceleration or jerk value in a way, so that an excitation of the dominant natural vibration of the mechanics is avoided and thus achieves a vibration-free positioning and at the same time the mechanics is spared.

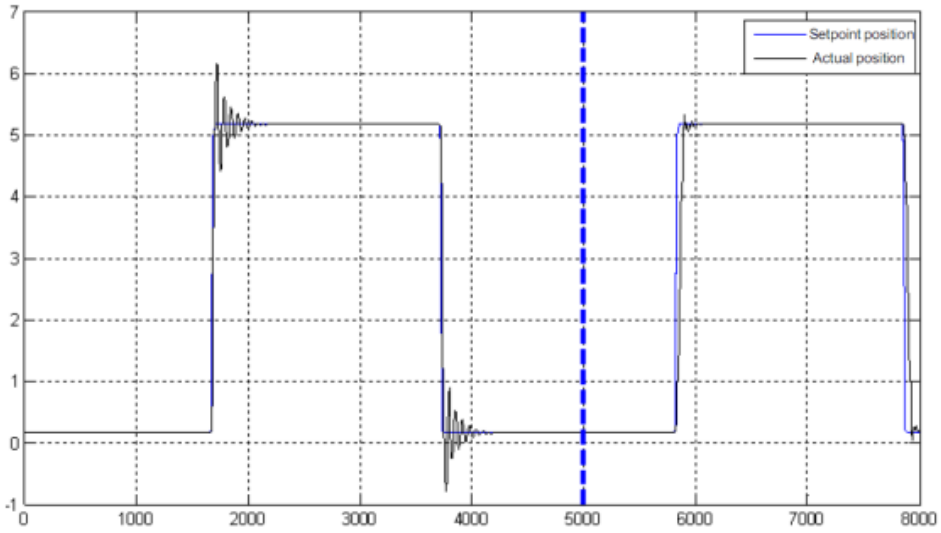
This leads to a vibration-less positioning, less stress on the material, noticeable improvement in smoothness and finally to trouble-free operation and higher machine cycle rates.

Structural changes or additional sensors or actuators are not required. VIBX can easily be retrofitted to existing applications.

The value of the frequency of the dominant natural frequency can be simply determined with trace- and measuring functions of the engineering system.

NOTE VIBX is available for SIMOTION and SINAMICS!

Figure 10-5 Traversing motion without (left side) and with (right side) activation of VIBX



10.6 Cogging torque compensation

For synchronous motors, the cogging torque can be compensated to improve radial eccentricity as there is a fixed connection between the absolute location and cogging force in these motors.

The entire cogging torque compensation is executed via a compensation table which, depending on the position of the motor measuring system, is read out and pre-controlled.

SINAMICS S120 provides a function module for this.

Restrictions:

- This function module is only available for the SERVO drive object
- Induction motors are not suitable for cogging torque compensation
- A motor encoder is always required for the cogging torque compensation
- Transistor-transistor logic or HTL encoders are not suitable for cogging torque compensation
- The encoder must have absolute information. Thus, it must be an absolute value encoder or have a clear zero mark or be distance-coded.
- Due to the premature validity message of absolute information, DQI encoders are only suitable with a bypass (Encoder Data Set switchover after start-up)
- The compensation is then applied to the torque-generating current setpoint. It is only effective if neither current nor voltage limiting intervenes and the frequency is not higher than the current controller bandwidth

NOTE For detailed information and boundary conditions see SINAMICS S120 Function Manual Drive Functions

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10.7 Further pre-control types

Dependent on the use case, some additional pre-control types can be useful:

- Tension torque pre-control

  Pre-control of the required torque (mostly constant) to maintain a specified web tension (paper, foil, cable, etc.)

- Cutting torque pre-control

  Pre-control of the required torque to cut/deform a material (e.g. cross cutter, servo press, etc.)

- Torque which is required for a defined movement of a kinematic

  The handling toolbox provides a library which calculates the required torque for different kind of kinematics for the involved motors.

  There are the following advantages of pre-control:

  - The accuracy of the path movement gets improved
  - The mechanics are protected due to smoother controller settings
  - The peak motor torque is getting reduced

  For additional information see:

  https://support.industry.siemens.com/cs/ww/en/view/109747826

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11 Mechanically coupled axes

This must be distinguished into two cases:

- Axes/motors which are connected through a product (e.g. paper web)
- Axes/motors which are connected to the same mechanics through a fix coupling

Axes coupled through a product

In this first case, the axes are more or less independent from each other and thus shall be optimized separately from each other.

However, for special use cases (high dynamic interaction between axes in the system) a so-called **dynamic compensation or dynamic response adaption** can be done after the single optimization of the axes.

A use-case is a material web which is getting accelerated by several axes. If those axes have a different dynamic response, the web tension between the segments would not be constant.

Background:

Different axes in the machine often have different mechanics. Therefore, the speed controller and position controller optimization of these axes can be quite different.

The result of this: one axis is more dynamic as another one.

To activate the dynamic compensation, use the expert list of a specific axis (Configuration data: “DynamicComp”) or set the checkbox **“Dynamic response filter”** in the closed-loop control menu.

More dynamic axes can be delayed to less dynamic axes through a PT2 filter.

Axes coupled through fix mechanic

Motors which are driving one mechanic together (e.g. gantry,…) should be optimized together – if possible. This avoids other motors from creating an additional load.

In general, with the onboard measuring functions, only one motor can be excited by the measuring function at the same time.

However, the so-called "free measuring function" described in 15.3 Measuring functions during program runtime provides remedy. The axes can be moved together via the user program, while the measuring signal (noise signal) is superimposed on one of the axes via the free measuring function.

NOTE The offset speed in the measuring function must be set to 0.0!

Alternatively, to the free measuring function:

Many kinematic systems have one master motor, which has a position-controlled axis TO in SIMOTION and several slave motors which get the speed setpoint (r62) provided from the master on SINAMICS side.

That means, if the master motor gets excited by the measuring function, the same noise signal is also forwarded to the slave motors. For this, the user has to ensure that the slave motors are getting enabled together with the master motor (e.g. connecting the control bits in the expert list).

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NOTE This procedure is only possible, if all the involved motors are located on the same CU. Otherwise the motors have to be optimized independently of each other. In this case the inactive motors act as an additional load for the motor being optimized.

Usually, the controller settings can be copied from one motor to the others, since the mechanical system is the same (motor, coupling and mechanics).

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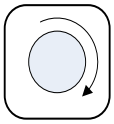
12 Torque motors

Basically, the optimization of torque motors follows the same principles described above in this document. However, dependent on the type and mounting of the motor, additional steps should be checked/performed in advance.

Torque motors often are so-called component motors, which means the three parts stator, rotor and encoder are assembled on site. Therefore, a special attention must be paid to the motor encoder.

Checking the rotation direction

It is recommended, to check the rotational directions of motor and encoder before starting. By default, the direction of the motor is clockwise. This means, if you look on the face side of the motor output shaft, a clockwise rotation corresponds to positive speed.



Prepare a trace with r63 (= actual speed smoothed) of the drive, which direction you want to check. Rotate the motor output shaft (if possible just mechanically) clockwise. r63 should return positive values. In case you receive positive values, the rotational directions match and you can continue with the encoder adjustment. If you receive negative values, the encoder actual value must be inverted. You can do this by changing p410.

NOTE Always invert (or do not invert) p410.0 and p410.1 together. Both parameters should have the same value!

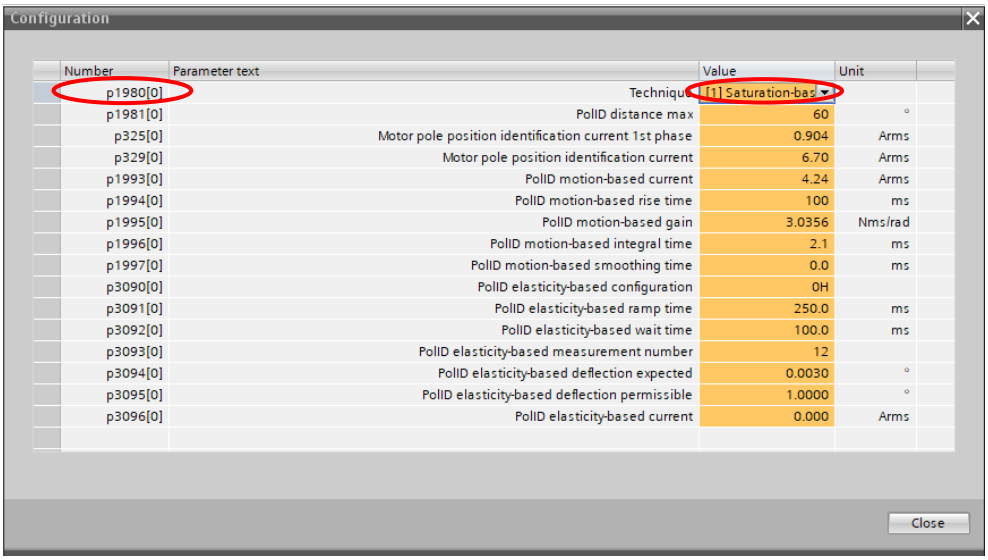
Encoder adjustment

The function determines the angular commutation offset and writes it in p0431 (angular commutation offset: angular difference between electrical position of encoder and flux position).

To execute the encoder adjustment, navigate in the project tree to the desired drive to "Rotate & optimize" > "stationary/rotating measurement". Choose "encoder adjustment" as measuring type:

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Figure 12-1 Configuration of encoder adjustment



For p1980[0] PolID technique choose [1] Saturation-based 1st harmonics.

Activate the measurement with the button and enable the drive (e.g. via control panel). The angular commutation offset will be determined.

NOTE If the measurement fails, the phases of the motor might be connected wrong. Therefore, check if the phases of the motor are connected properly (U-V-W to U-V-W).

NOTE Refer also to chapter 5 Mot-ID (Motor-Identification) especially when using third-party motors.

Controller optimization

In the next step, current, speed and position controller can be optimized like described in the chapters above.

NOTE For third party motors the current controller adaption should be activated.

Refer to chapter 9.1 Current controller adaption

For SIEMENS motors it is already active.

Position controller setpoint frequency response (Starter/Scout)

Due to the high stiffness and small damping, it can be necessary to reduce the measuring amplitude. This is especially necessary, if the gain factor is very high due to high load inertia.

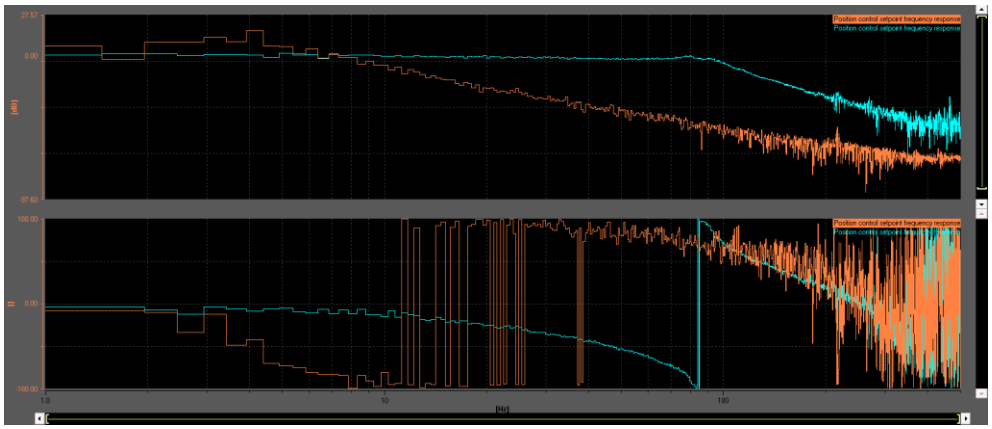
It might be necessary to decrease the measuring amplitude stepwise with increasing gain factor. The need can be recognized on a noisy signal or no reaction to parameter changes of the gain factor.

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The following example shows the position controller frequency response recorded with different measuring amplitudes, 0,1 (orange) and 0,001 (cyan). Both measurements were recorded with the same position controller gain.

In this example there is a risk, the gain is set too high, because the frequency response (orange) does not show the desired behavior (cyan).

Figure 12-2 Position controller setpoint frequency response with different amplitudes



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Encoder actual value smoothing

Dependent on the type of motor encoder, it might be necessary to smooth the actual value with a PT1 filter. For this, expert list parameter p1441 can be used. A suitable filter time could be 2-3ms. This value must be adapted to the respective circumstances

13 One Button Tuning

The speed controller and position controller of a drive can be automatically tuned with the "One button tuning" function. With OBT, the mechanical drive train is measured using short test signals. In this way, the controller parameters can be adapted optimally to the existing mechanical system.

OBT can be selected with the parameter p5300 and will be executed with the next enable of the drive. The axis should be enabled in speed controlled mode.

NOTE The SINAMICS function module “Moment of inertia estimator” must be activated in order to use the OBT functions.

OBT configuration:

With the parameter p5301 and p5271 single functions of the OBT can be selected or deselected:

- Determination of Kp and Tn of the speed controller
- Setting the current setpoint filters
- Setting of the speed controller reference model
- Determination Kv of the position controller (displayed in expert list r5276)
- Determination of the load inertia and thus activation of the torque pre-control (at the position controller or at the speed controller, depending on the control mode of the axis)
- Activating the speed pre-control at the position controller
- Determination of position controller pre-control symmetrization time constant (displayed in expert list r5277)
- Determination of zero and pole frequencies (displayed in expert list r5294, r5295)

NOTICE **Dependent on the setting in p5301, the axis accelerates with high dynamics. Be careful with mechanics connected to the motor!**

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Traversing distance:

The traversing distance for the measurement must be defined in the parameter p5308. With this the maximum traversing distance can be limited as well. This specification is on the motorside, possible spindles or gear ratios must be taken into account.

Dynamic factor:

With the dynamic factor in p5292 the calculated P gain can be influenced.

Notice: If the value is too big, the control loop might be instable!

Position control gain:

If position control is implemented using a higher-level control system, the values can be taken over from r5276 and r5277.

NOTE

The value displayed in r5276 corresponds to the theoretically maximum possible position controller gain.

The value can be directly used for the E-Pos.

For SIMATIC and SIMOTION, the value must be multiplied by the factor 16.66 (see chapter 8.2).

Also keep in mind, that r5277 (vTc) is displayed in [ms], but SIMATIC and SIMOTION require the value in [s]!

Boundary conditions:

OBT is basically designed for feed drives / positioning axes. OBT is less suitable for mechanics with extremely high load inertia conditions.

NOTE

For detailed information see SINAMICS S120 Function Manual Drive Functions

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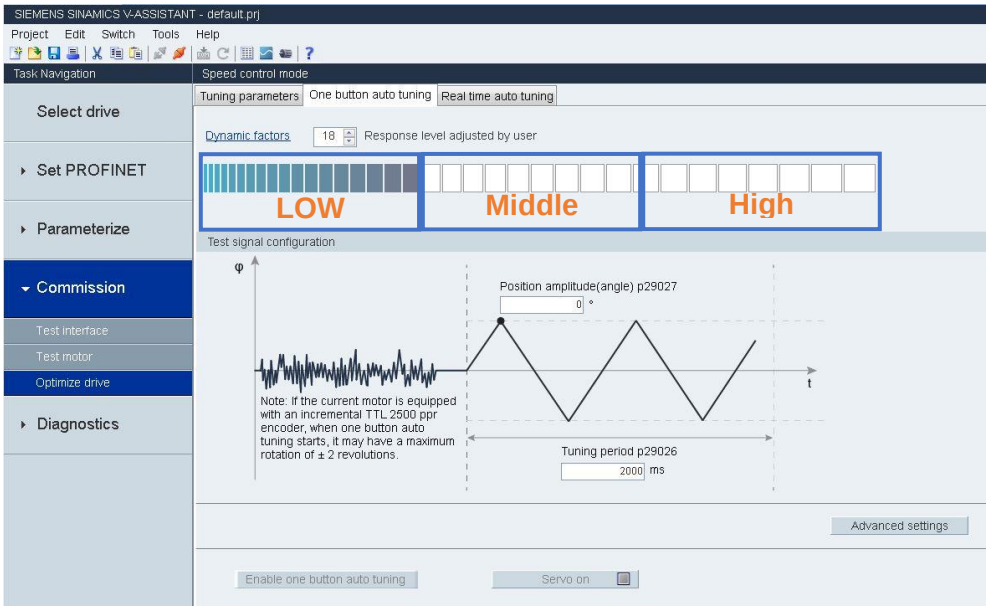
14 Optimization of other drives

14.1 V90

V90 drives are being configured and optimized using V-Assistant. Therefore, two modes are available:

- One-Button-Tuning
- Real-time auto tuning

Figure 14-1 V-Assistant tuning menu



With One-Button-Tuning, the drive will be optimized during an exclusively triggered measurement/traversing.

In contrary, the real-time auto tuning optimizes the drive during a movement triggered by a higher-level controller (e.g. PLC). The function remains active the whole time and adapts the controller parameter continuously, if necessary.

The user can influence the tuning result with a dynamic factor dependent on the mechanical situation (e.g. stiffness). Higher dynamic factor means higher tracking ability and shorter settling time but also higher possibility of resonance.

NOTE In the "Diagnostics" menu, the user can analyze the control loop using frequency responses like known from STARTER/SCOUT. A manual tuning is possible.

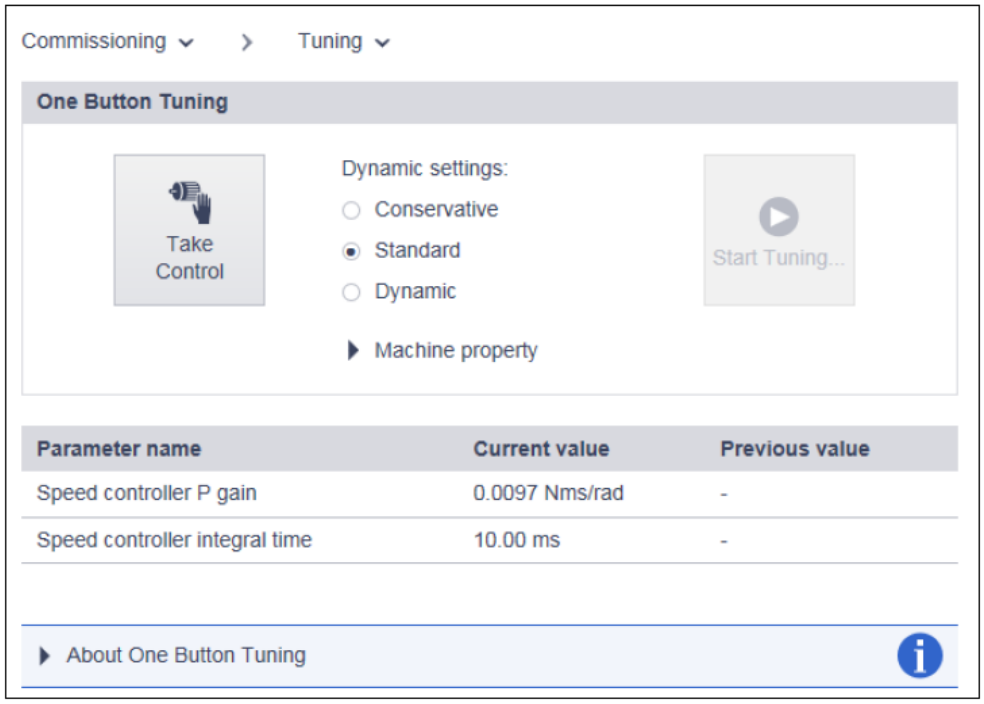
NOTE For detailed information see SINAMICS V90 PROFINET, SIMOTICS S-1FL6 Operating Instructions
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14.2 S210

S210 drives are being configured and optimized using the integrated web server or TIA-Portal/Startdrive.

Figure 14-2 Web server OBT menu



One Button Tuning optimizes the drive based on the selected dynamic response setting:

- "Conservative":
  60 % speed control dynamic performance without pre-control
- "Standard":
  80 % speed control dynamic performance with torque pre-control
- "Dynamic":
  100 % speed control dynamic performance with fast torque pre-control

NOTE If the machine vibrates or creates humming noise at certain speeds after One-Button-Tuning, then the dynamic response setting is too high. In this case, select a lower dynamic response and repeat the One-Button-Tuning.

NOTE For detailed information see SINAMICS S210/SIMOTICS S-1FK2

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15 Further Optimization Methods

15.1 Current controller setpoint jump

Alternative to the Current controller setpoint frequency response, the current controller can be inspected/optimized by a setpoint jump (time domain).

The optimization with a setpoint jump is applied because in a setpoint jump many frequency components are included. To "get to know" the system which should be controlled, as many frequencies as possible must be stimulated to see the dynamic of the current controller.

Figure 15-1 Measuring function settings

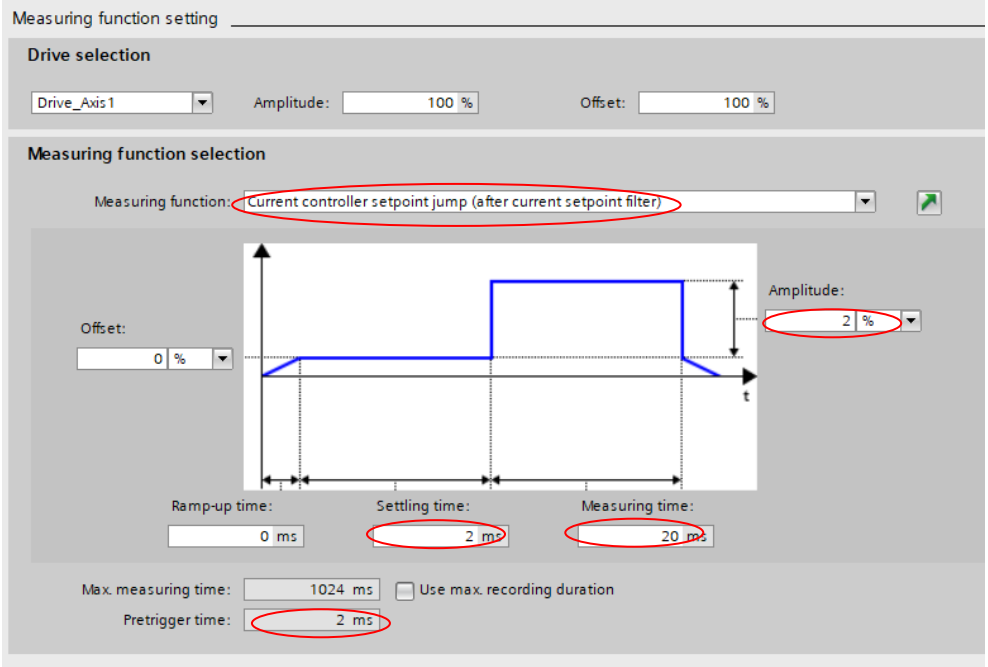
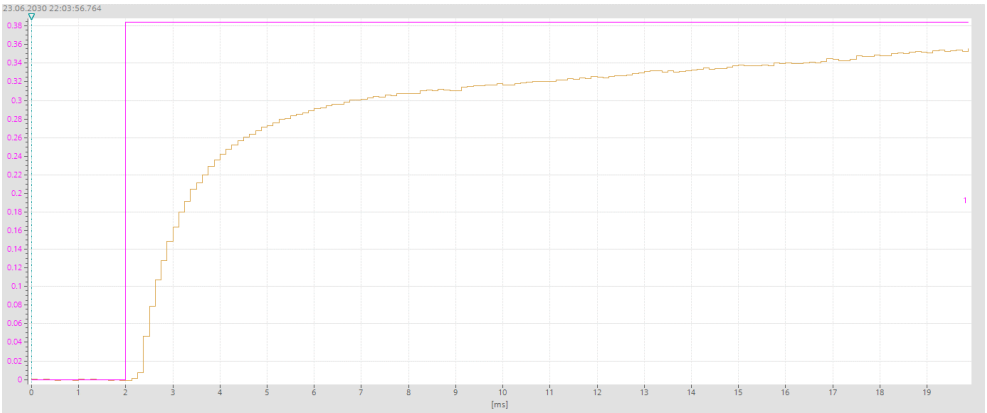


Figure 15-2 currrent controller setpoint jump – Kp too low



As you can see in the figure, there is a very high rise time.

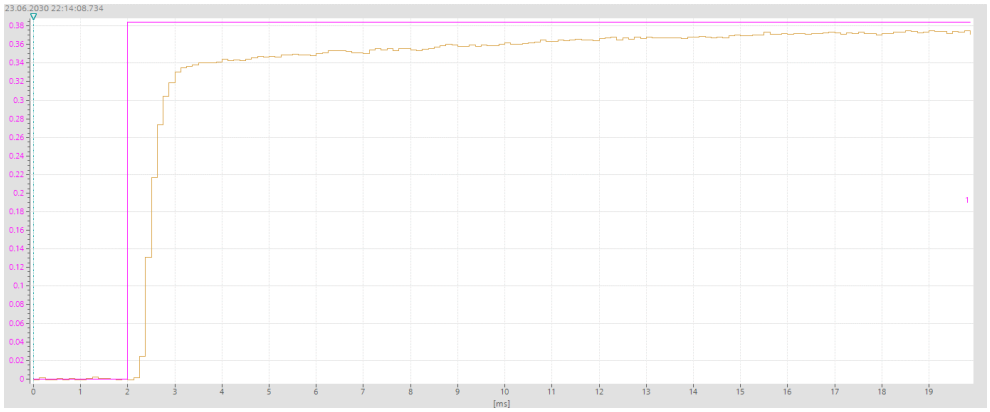
Furthermore, the system deviation is too high.

→ raise proportional gain factor Kp

Attention	**Pay attention to the same scaling of the curves!**

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Figure 15-3 current controller setpoint jump – higher Kp

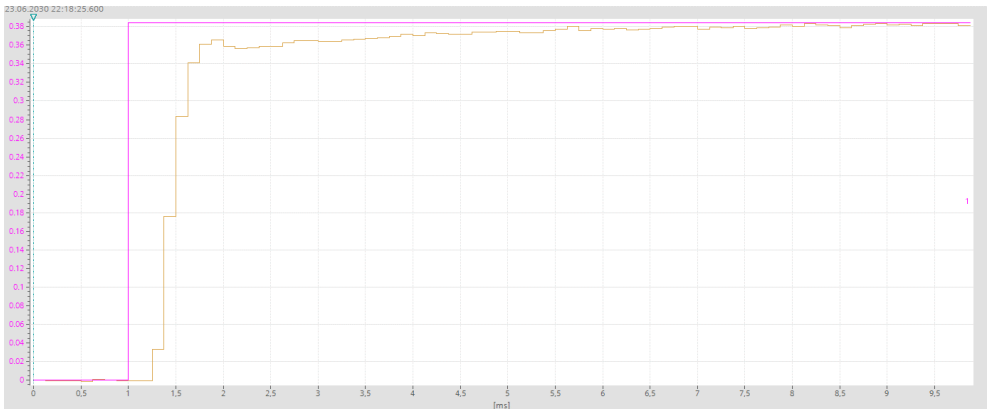


The result of raising Kp is a smaller system deviation and a quicker rise time.

For elimination of the persistent system deviation, the integral component of the control loop has to be activated.

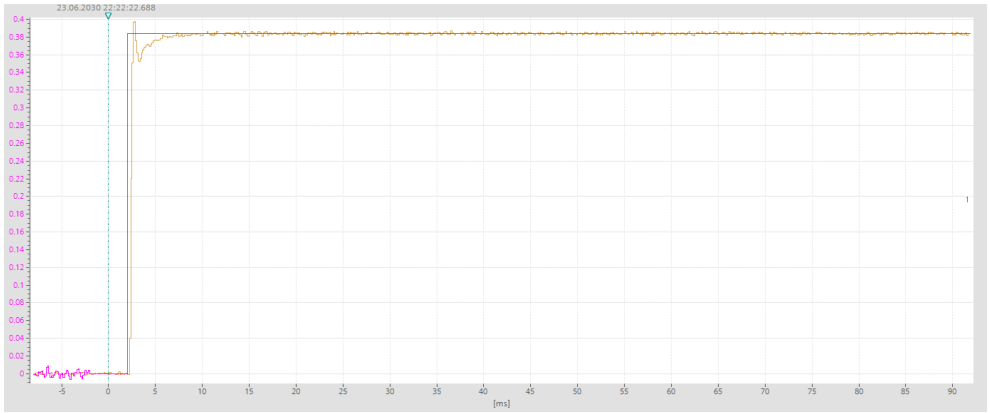
→ reduce integral time

Figure 15-4 current controller setpoint jump – Tn activated



No more persistent system deviation.

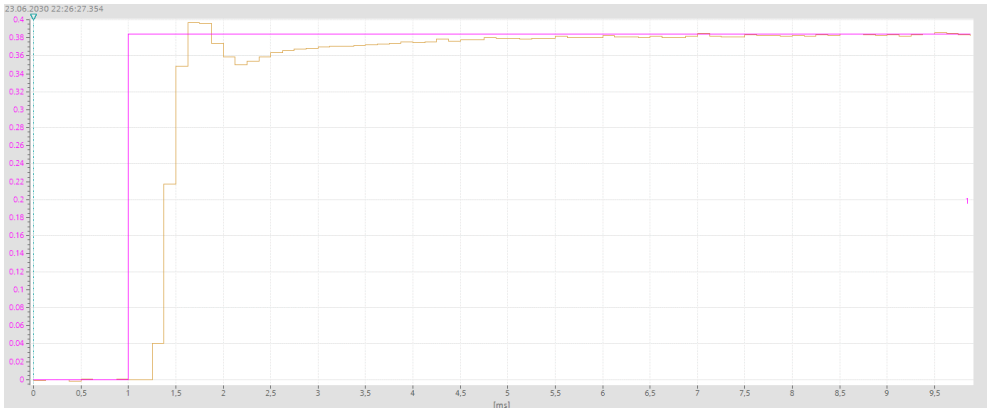
Figure 15-5 current controller setpoint jump – measurement duration 100ms



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If you continue raising the proportional gain factor, the current controller reacts faster. At the same time the overshoot increases.

Figure 15-6 current controller setpoint jump – measurement duration 10ms



Attention **Overshoot not bigger than 4%!**

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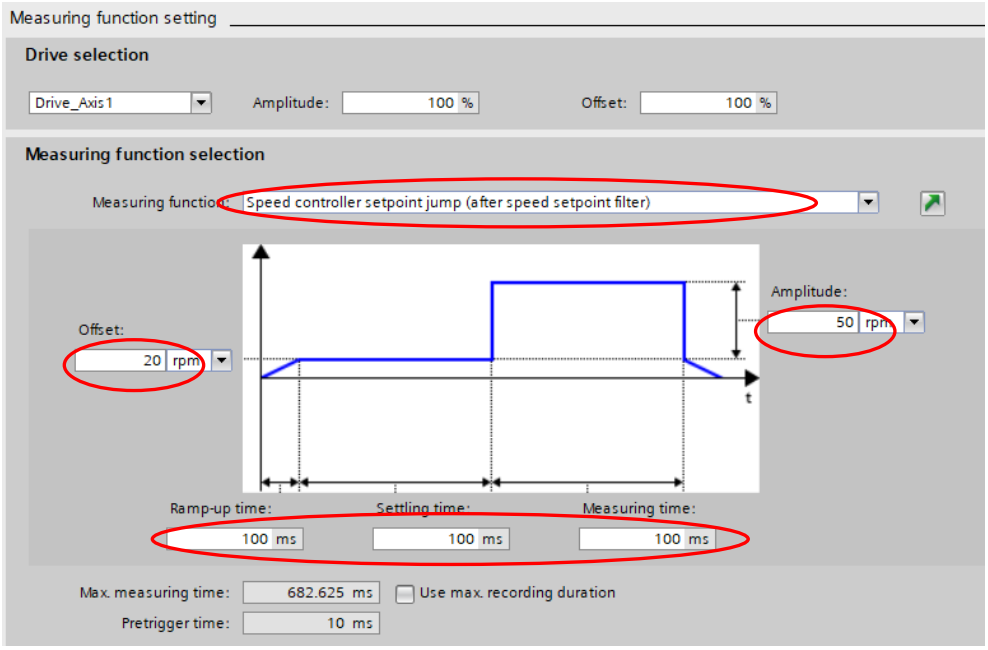
15.2 Speed controller setpoint jump

Alternatively to the speed controller frequency response, the speed controller can be optimized with a setpoint jump (time domain).

The optimization with a setpoint jump is applied because in a setpoint jump many frequency components are included. To "get to know" the system which should be controlled, as many frequencies as possible must be stimulated to see the dynamic of the speed-controller

The goal is to achieve a short rise time with no or small overshooting.

Figure 15-7 Measuring function speed controller setpoint jump

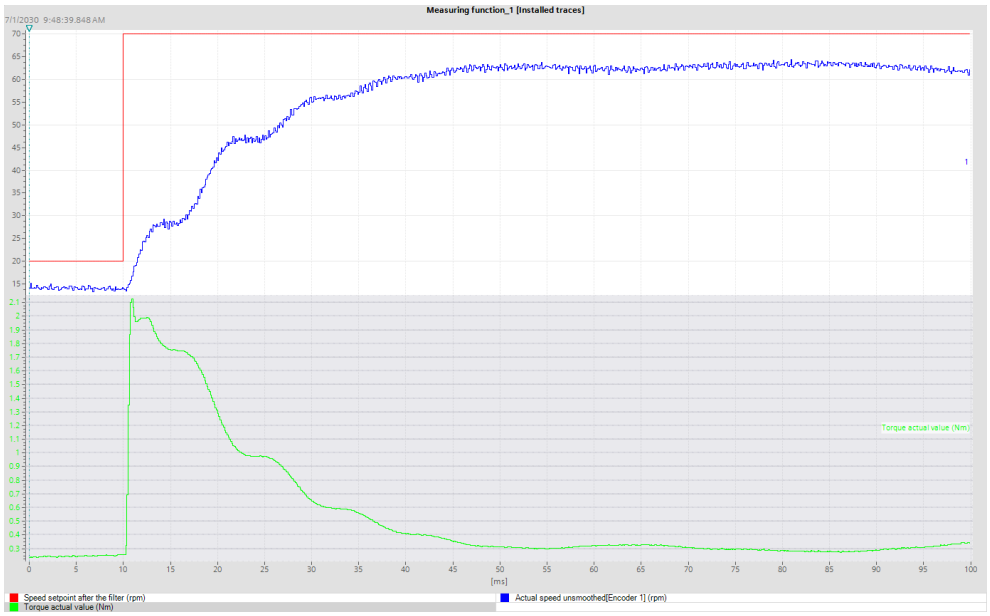


Measuring function:	Speed controller setpoint jump (after speed setpoint filter)
Settling time:	to reduce oscillations caused by ramp-up
Amplitude:	defines the height of the jump
Offset:	basic-speed (otherwise jump from standstill)
Ramp-up time:	ramp-up time to the adjusted offset

The following trace shows the result of an undersized proportional gain factor:

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Figure 15-8 speed controller setpoint jump – Kp too low



The rise time and the system deviation are too high.

The red curve shows the speed setpoint [r62], the blue curve the actual speed [r61]. The green curve represents the torque actual value [r80].

Attention **Pay attention to the same scaling of the curves!**

Tracing the torque actual value is not required mandatorily, however it should be noticed.

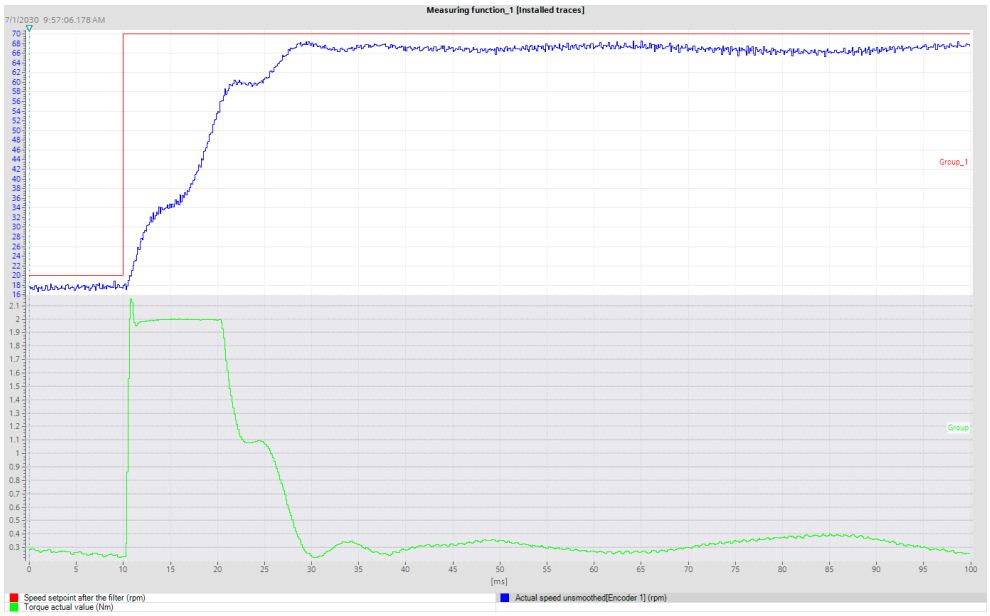
The parameters r1538 and r1539 in the expert list show the positive and negative torque limit. Do not exceed these values at any time.

Note Keep a reserve of ca. 10% to the torque limit values to consider machine run in in the course of time.

→ raise proportional gain factor Kp

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Figure 15-9 speed controller setpoint jump – higher Kp

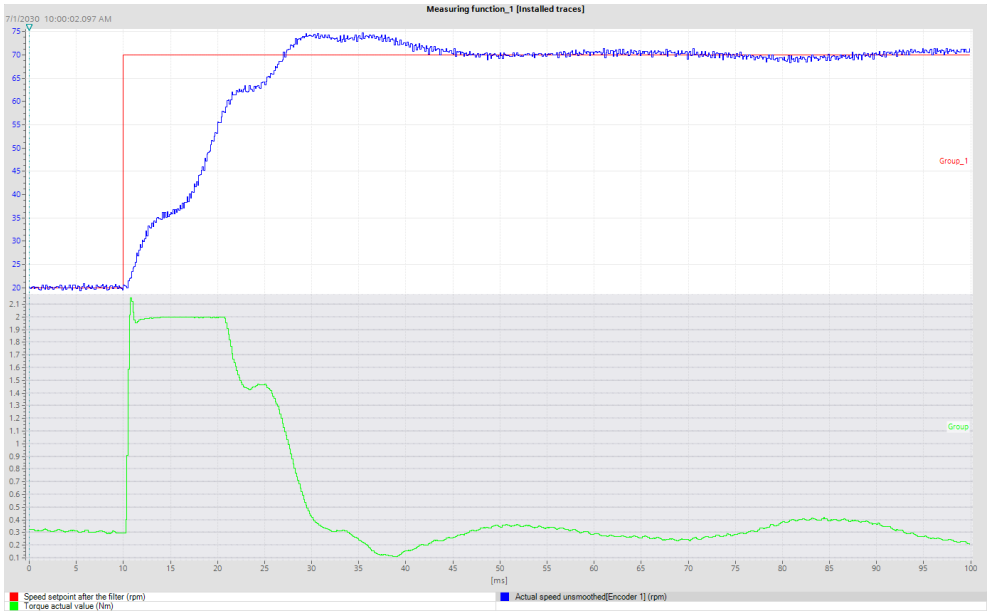


The result of raising Kp is a smaller system deviation and a quicker rise time.

For elimination of the persistent system deviation, the integral component of the control loop has to be activated.

→ reduce integral time

Figure 15-10 speed controller setpoint jump – shorter Tn



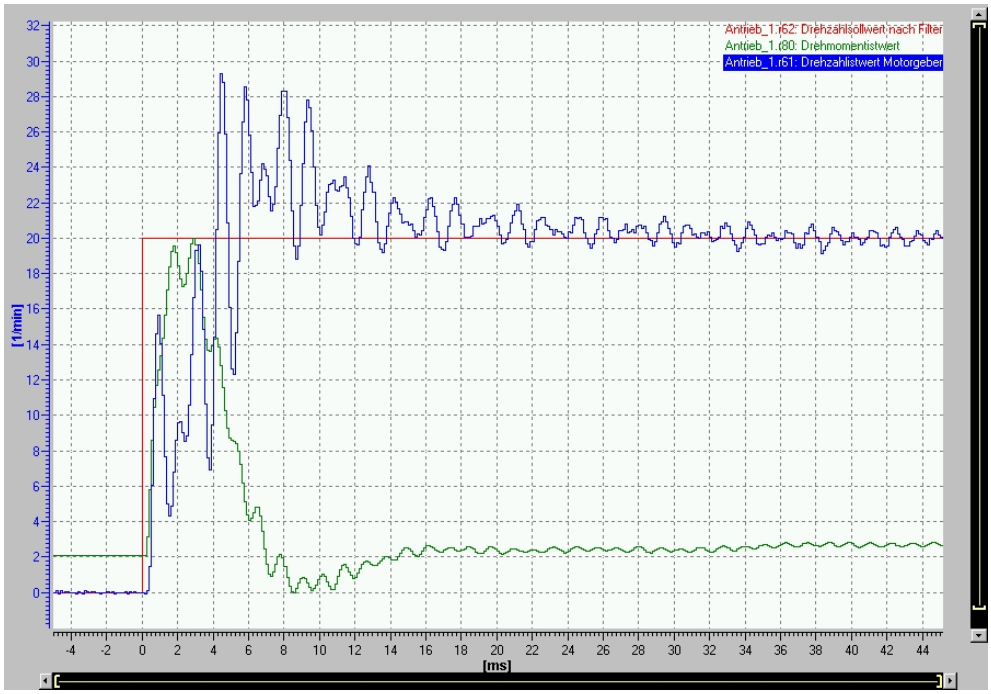
Symmetric optimum: One-time overshoot up to 43%

Attention	**Not in all applications an overshoot of the actual speed is acceptable!**

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In the following trace the speed controller proportional gain factor is too high:

Figure 15-11 Kp too high – oscillating actual value



The oscillating actual speed is an indication of a too high proportional gain factor. The control loop is unstable.

→ reduce Kp!

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15.3 Measuring functions during program runtime

This function is only available in Starter.

The previously introduced optimization methods are based on measurements which have been recorded during "dry run". That means, the axis was free in movement, without any contact to material or product or any other part of the mechanics.

For most cases this is sufficient. However, in some cases it might be useful or even mandatory to perform measurements for drive optimization during machine runtime, while the machine is producing.

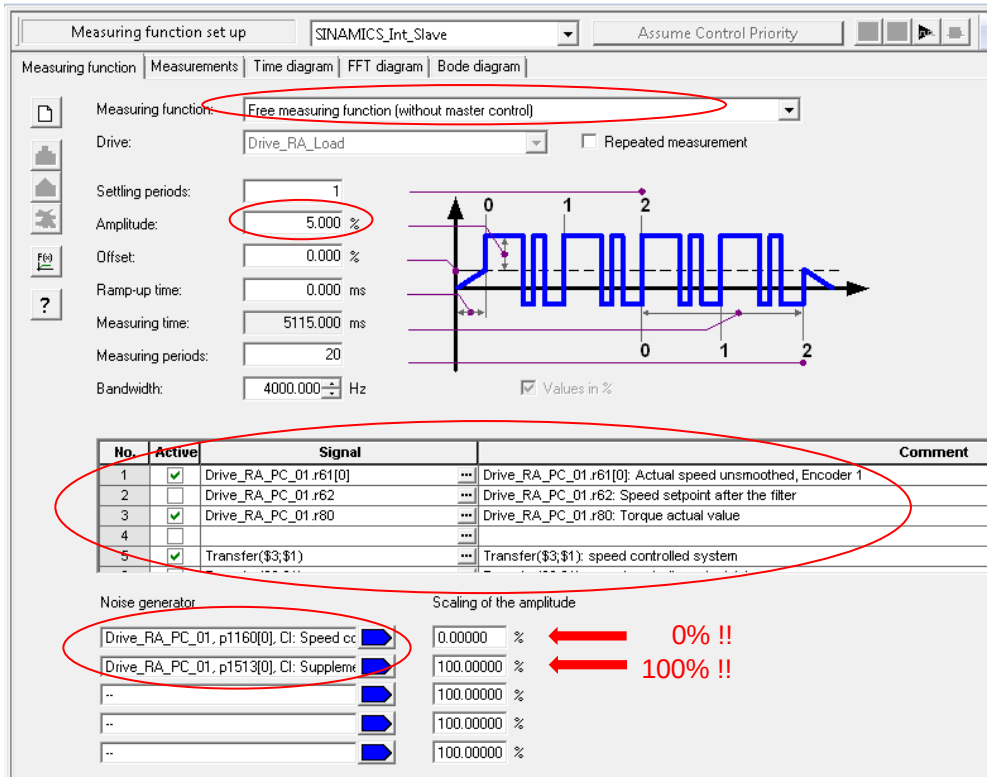
For example, another passive axis is in contact with the driven axis (e.g. printing cylinder and passive impression cylinder).

The following described measuring functions add a noise signal to the basic motion of a higher prior controller. **However, this function is only available in Scout/Starter.**

15.3.1 Speed Controlled System

The following settings must be made:

Figure 15-12 Settings for measurement of the speed controlled system



Device selection: Select the device on which the drive you want to measure is located (e.g. SINAMICS_Integrated).

Measuring function: “Free measuring function"

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Signals:	- r61 Actual speed
	- r80 Actual torque
	- Transfer function (r80;r61)
Amplitude:	ca. 3% - 5% of reference torque (Default-settings)
	→ Too big amplitude may affect the measuring result negatively! (Limitations can be reached)
	→ Check sound during measurement: audible but not abnormal
Offset:	not necessary, since basic motion already active!
Measuring periods:	ca. 20
	→ More measuring periods increases the accuracy (averaging)
	→ Affects the measuring time (shorten dependent on bandwidth)
Bandwidth:	4000Hz
	→ Distribution of the measuring points about the frequency range

The location where the noise signal is added has to be selected below "noise generator".

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NOTE It is essential to ensure that the noise signal is applied to the additional torque input p1513.

Parameter p1160 (speed setpoint 2) must be scaled with 0%!

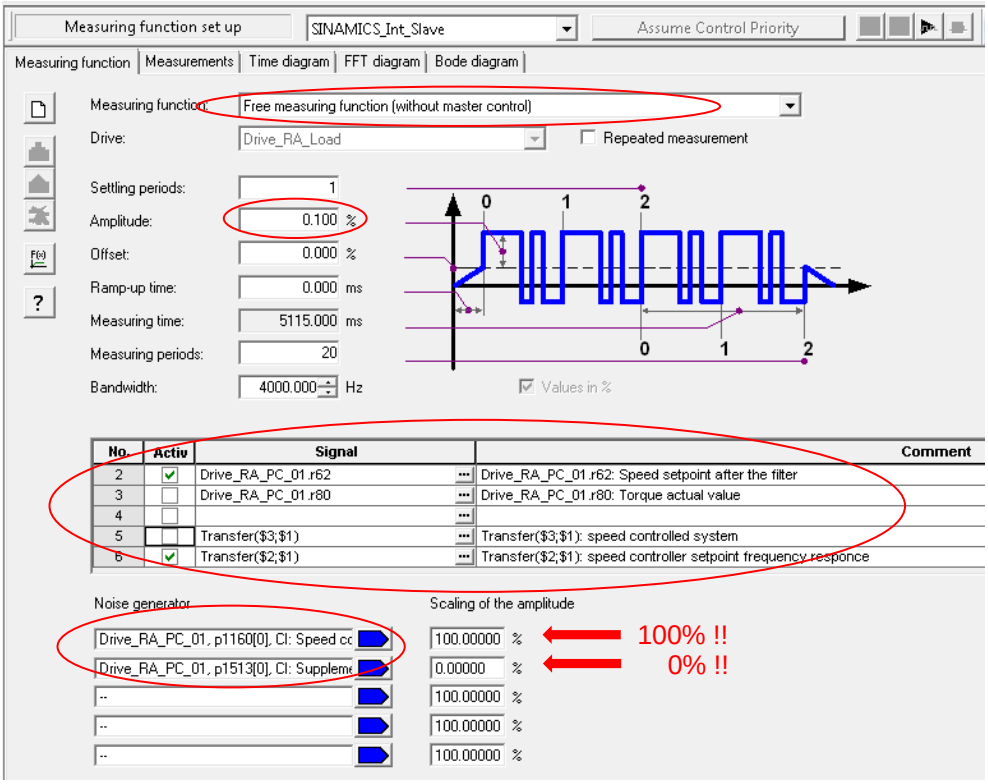
NOTE It is important to adjust the amplitude level to the frequency response to be measured. In particular, when the speed controller setpoint frequency response is recorded after the sped controlled system.

The amplitude represents in one case a torque, in the other case a speed!

15.3.2 Speed Controller Setpoint Frequency Response

The following settings must be made:

Figure 15-13 Settings for measurement of the speed controller setpoint frequency response



Device selection:	Select the device on which the drive you want to measure is located (e.g. SINAMICS_Integrated).
Measuring function:	“Free measuring function"
Signals:	- r61 Actual speed - r62 Speed setpoint - Transfer function (r62;r61)
Amplitude:	approx. 0.1% (the unit can be changed to 1/min with the checkbox "values in %" → Too big amplitude may affect the measuring result negatively! (Limitations can be reached) → Check sound during measurement: audible but not abnormal
Offset:	not necessary, since basic motion already active!
Measuring periods:	ca. 20 → More measuring periods increases the accuracy (averaging) → Affects the measuring time (shorten dependent on bandwidth)

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Bandwidth: 4000Hz

→ Distribution of the measuring points about the frequency range

The location where the noise signal is added has to be selected below "noise generator".

NOTE It is essential to ensure that the noise signal is applied to the speed setpoint 2 input p1160.

Parameter p1513 (additional torque) must be scaled with 0%!

NOTE It is important to adjust the amplitude level to the frequency response to be measured. In particular, when the speed controller setpoint frequency response is recorded after the sped controlled system.

The amplitude represents in one case a torque, in the other case a speed!

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15.4 Inverse filtering of locked rotor frequency

Attention **The following described methods should only be applied by experienced users! If the filters are set incorrectly, instability could appear.**

Setting a filter on the locked rotor frequency, which causes an amplitude- and phase amplification, can improve the characteristic angular frequency and therefore the dynamic of the control loop.

To parameterize such a filter, **choose filter type “band-stop” first**.

The notch frequency is the value of the locked rotor frequency. Set bandwidth and notch depth corresponding to characteristics of locked rotor frequency.

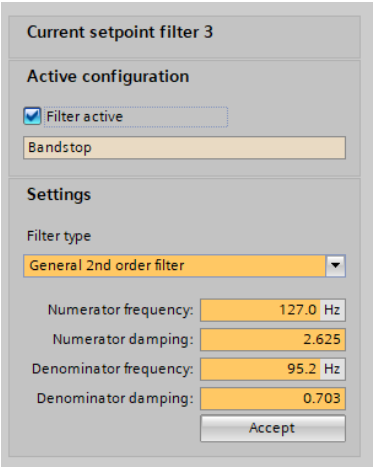
After setting these values, change the filter type to „General filter 2nd order“.

The new filter parameters are taken automatically.

To complete the parameterization, raise the numerator damping till vertical exaggeration of magnitude and phase is noticeable.

If required, numerator frequency, denominator frequency and denominator can also be adapted.

Figure 15-14 filter configuration



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The following traces show the speed controller open (top) and closed control loop (bottom) with and without filter.

Proportional gain factor Kp = 2.0 for both measurements.

Figure 15-15 open control loop with inverse filter (blue) and without filter (green)

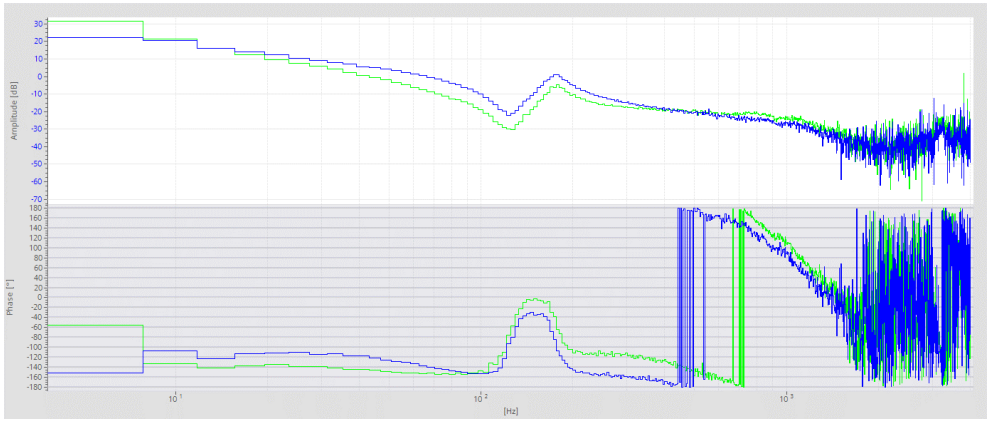
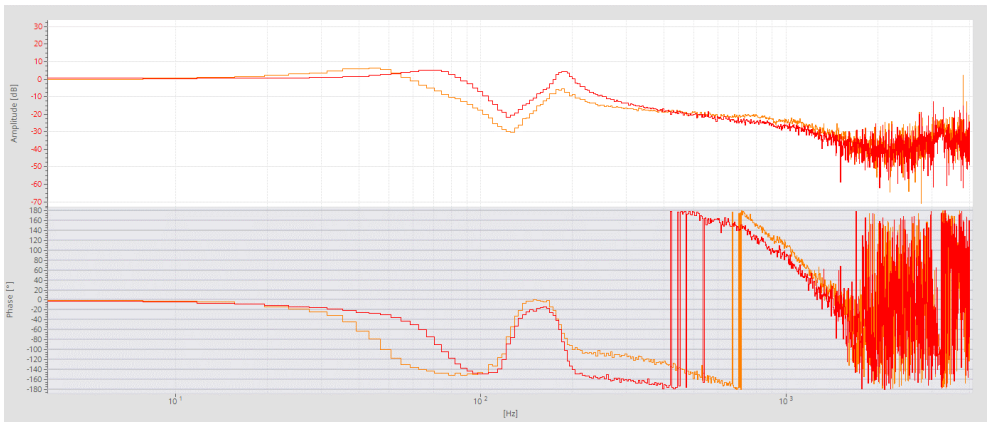


Figure 15-16 closed control loop with inverse filter (red) and without filter (orange)



In both traces, the active filter is identified by a better damping of the locked rotor frequency.

Furthermore, the controller bandwidth could be increased (from ca. 40 Hz to 65 Hz).

→ The control loop is more dynamic.

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15.5 Phase shift filter

While band-stop filters are usually set directly on a resonance frequency in order to dampen the amplitude (generate amplitude reserve), one can use a band-stop filter as a so-called "phase shift filter" as well.

In this case, the filter frequency is set slightly in front of the resonance frequency. The band-stop filter raises the phase behind the filter frequency. The goal is to "push" phase underneath the resonance frequency, because there is too less phase given by the control system. The resonant frequency is thus not actively damped, but the control system gets more phase provided so that it can dampen the resonance by itself.

This type of filter can be used if the "normal" band-stop filter, which is intended to dampen a strong resonance peak in amplitude, would have to have a very large notch depth in order to fully dampen the resonance, and thus cost a lot of phase. At this point, the phase shift filter with a smaller notch depth can provide phase to the controlled system.

Same as a "normal" band-stop, the phase shift filter costs phase in front of the filter frequency as well. However, since this type of filter can be parameterized with less notch depth, the phase loss is lower compared to the standard band-stop filter.

Without a filter, the open-loop speed control circuit (Figure 15-17) shows the semi-stable amplitude curve (no amplitude margin, where the phase already reaches -180 °). The phase tilts at 400Hz. The control loop would be not stable enough without band-stop.

With the phase shift filter, the bandwidth could be increased by about 100Hz. It leads to stability and good closed loop damping.

In this case it would even be possible to increase the gain by about 50%.

The phase shift filter used in this case has a filter frequency of 260 Hz, a bandwidth of 700 Hz and a notch depth of -10 dB.

NOTE Despite the advantages shown, the filter should be used with care. In case the resonant frequency would move unfavorably - due to mechanical changes (e.g., wear, shrinkage of bearings, etc.), this can lead to instability in the worst case.

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Figure 15-17 Open speed control loop

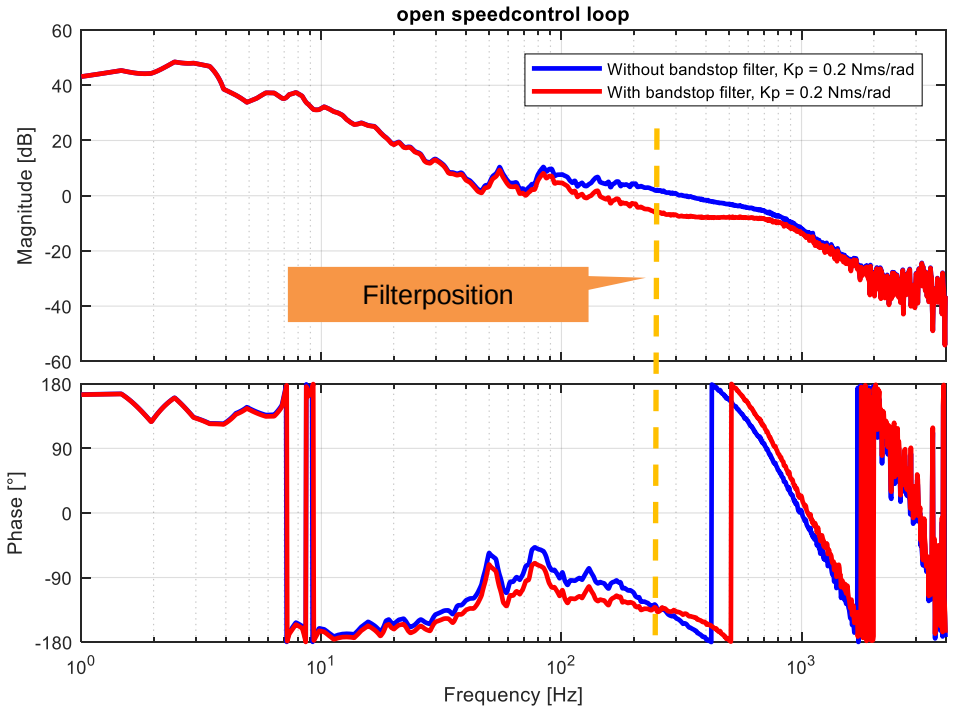
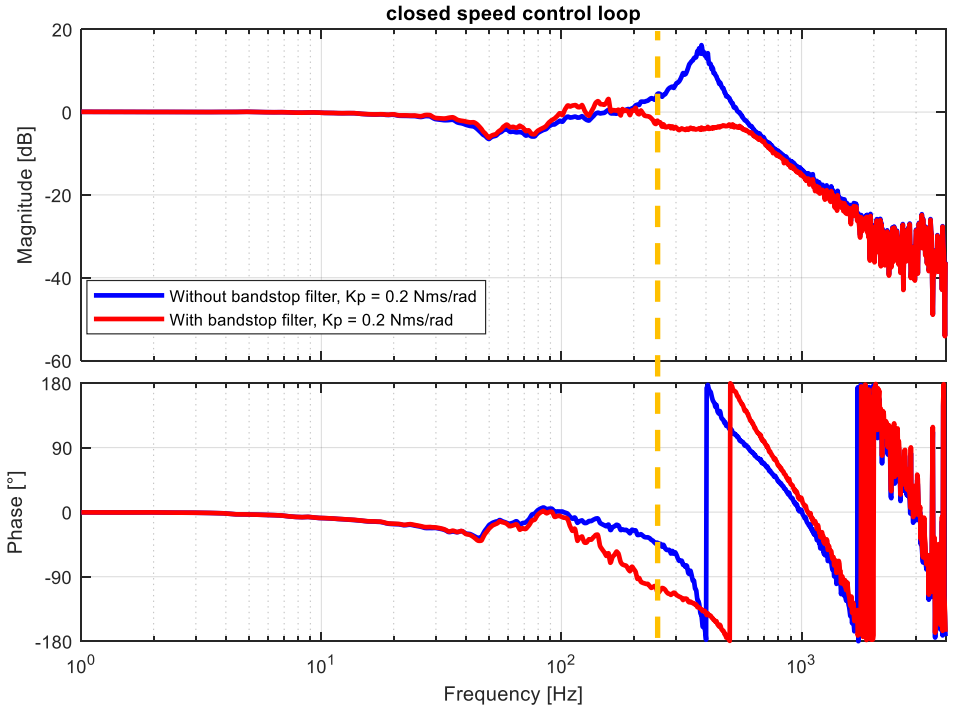


Figure 15-18 Closed speed control loop



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16 Appendix

16.1 Service and support

Industry Online Support

Do you have any questions or need assistance?

Siemens Industry Online Support offers round the clock access to our entire service and support know-how and portfolio.

The Industry Online Support is the central address for information about our products, solutions and services.

Product information, manuals, downloads, FAQs, application examples and videos – all information is accessible with just a few mouse clicks:
https://support.industry.siemens.com/

Technical Support

The Technical Support of Siemens Industry provides you fast and competent support regarding all technical queries with numerous tailor-made offers – ranging from basic support to individual support contracts. You send queries to Technical Support via Web form:
www.siemens.com/industry/supportrequest

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- Plant data services
- Spare parts services
- Repair services
- On-site and maintenance services
- Retrofitting and modernization services
- Service programs and contracts

You can find detailed information on our range of services in the service catalog:
https://support.industry.siemens.com/cs/sc

Industry Online Support app

You will receive optimum support wherever you are with the "Siemens Industry Online Support" app. The app is available for Apple iOS, Android and Windows Phone:
https://support.industry.siemens.com/cs/ww/en/sc/2067

16.2 Application Support

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Digital Factory Division
Factory Automation
Production Machines
DF FA PMA APC
Frauenauracher Str. 80
91056 Erlangen, Germany

mailto: tech.team.motioncontrol@siemens.com

16.3 Links and literature

Table 16-1

	Topic
\1\	Siemens Industry Online Support https://support.industry.siemens.com
\2\	Download page of the article https://support.industry.siemens.com/cs/ww/en/view/60593549
\3\	SINAMICS S120 Function Manual Drive Functions https://support.industry.siemens.com/cs/ww/en/view/109754299
\4\	SINAMICS V90 PROFINET, SIMOTICS S-1FL6 Operating Instructions https://support.industry.siemens.com/cs/ww/en/view/109757719
\5\	SINAMICS S210/SIMOTICS S-1FK2 https://support.industry.siemens.com/cs/ww/en/view/109760645
\6\	SINAMICS S120/S150: Requirements placed on third-party motors https://support.industry.siemens.com/cs/ww/en/view/79690594
\7\	Elektrische Vorschubantriebe in der Automatisierungs-technik Author: G. Wiegärtner, H. Groß, J. Hamann Publicis Corporate Publishing, 2006 ISBN: 978-3-89578-278-7
\8\	SIMATIC S7-1500(T): Basics of axis control with technology objects and approach to axis optimization https://support.industry.siemens.com/cs/ww/de/view/109779884/en

16.4 Change documentation

Table 16-2

Version	Date	Modifications
V1.0	06/2012	First Version
V1.1	11/2012	Minor updates
V2.0	03/2019	New and revised content
V2.1	05/2019	Error correction
V2.2	04/2012	Updates OBT Error correction leakage inductance
V3.0	08/2023	Update TIA-Portal/Startdrive

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