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Drive Optimization Guide

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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 in the comment column 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

Measurement scaling

Some measuring functions contain two bode plots in one measurement. The scaling of the curves does not necessarily match! Make sure to adapt the scaling to one of the curves before analyzing them.

This is even more important when two measurements are superimposed to evaluate parameter changes.

Manual optimization using frequency responses

Many of the measuring functions which are described in this document can only be used for SINAMICS S120 in STARTER/SCOUT.

For other drives or engineering systems like TIA Portal/Startdrive, other methods are available. For details, check the respective chapters in this manual.

Third-party motors

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

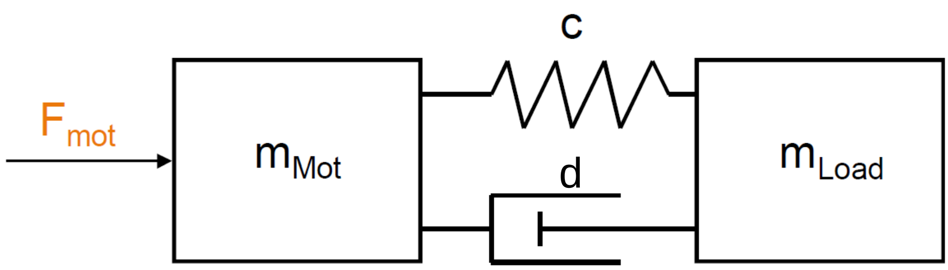
https://support.industry.siemens.com/cs/ww/en/view/79690594

2 Fundamentals & general information

2.1 Ideal two-mass-system

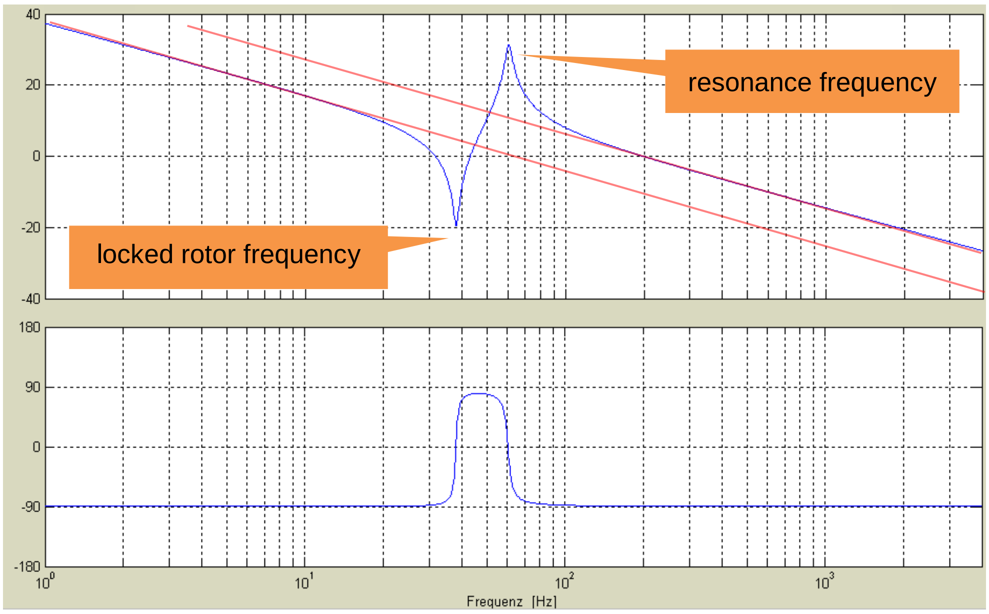
A mechanical system which is driven by a motor can be simplified by a so called two-mass-system.

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:

Figure 2-1 Simulated speed-controlled system frequency response



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:

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

With the frequency pair locked-rotor-frequency/resonance frequency the related 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. Right of the resonance frequency, the load inertia has decoupled - only the motor inertia is visible.

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

In contrary, the imaginary 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.

Stiffness and damping are reflected in the frequency response in the expression of the amplitude overshoot and how fast the phase tilts from 0 ° to -180 °. Large overshoot and fast turn off phase corresponds to a poorly damped system (see Figure 3-1 with Figure 3-2).

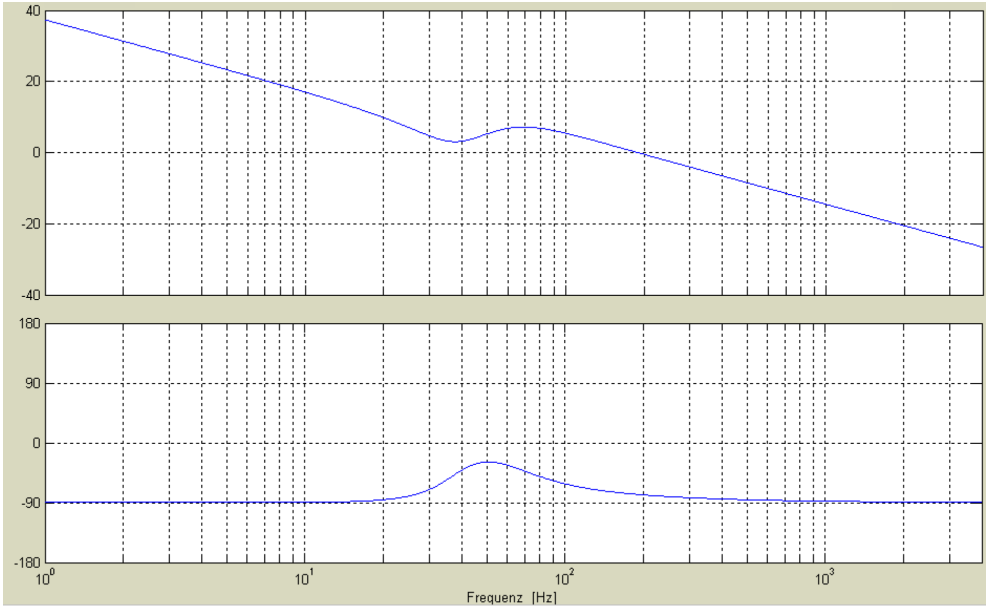
The frequency at -90 ° phase is also the peak of the amplitude overshoot. This is constant regardless of the attenuation.

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.

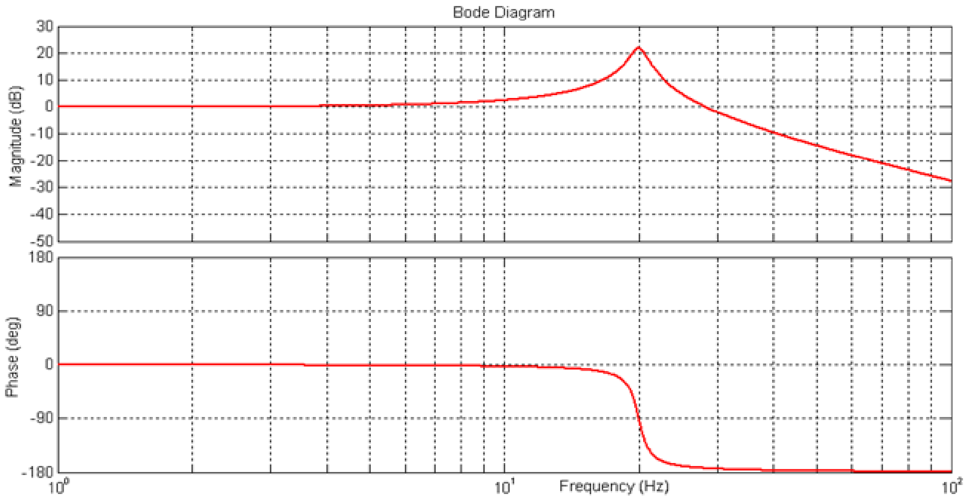
In the time domain, the damping affects only the amplitude of an oscillation, but not the frequency. (A certain mass with a specific stiff compound oscillates in air at the same frequency as in oil, but with a different amplitude.)

Figure 2-2 Speed-controlled system with higher damping



The following "mechanics frequency response" describes the decoupling of the load in a better way.

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.

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.

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 show the demands to the mechanical system in correlation with a motor with respect to a dynamic control loop with big 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.

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

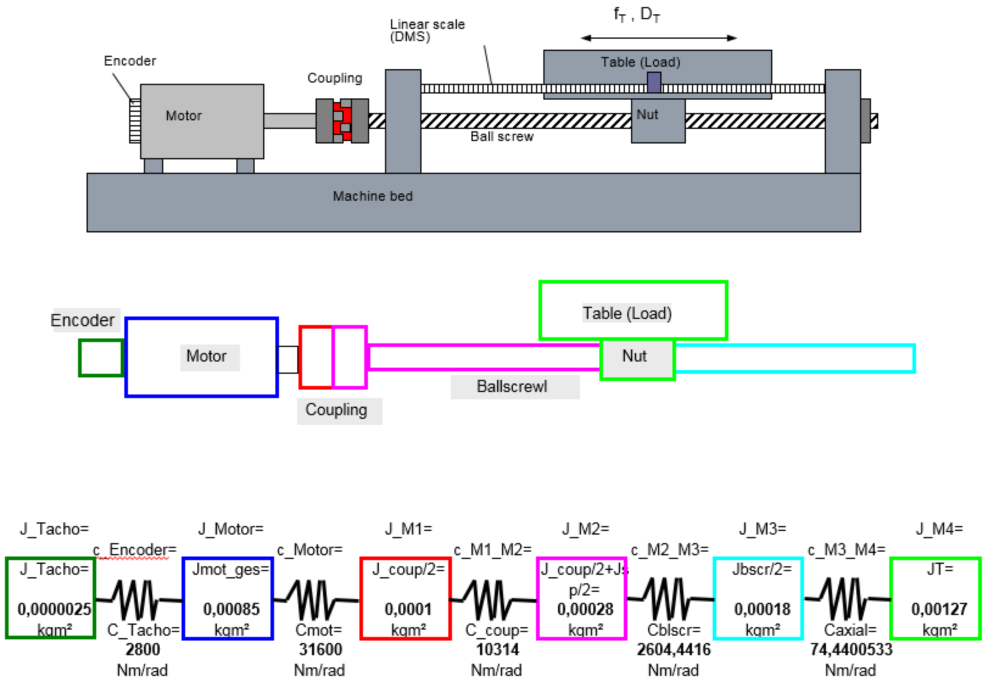
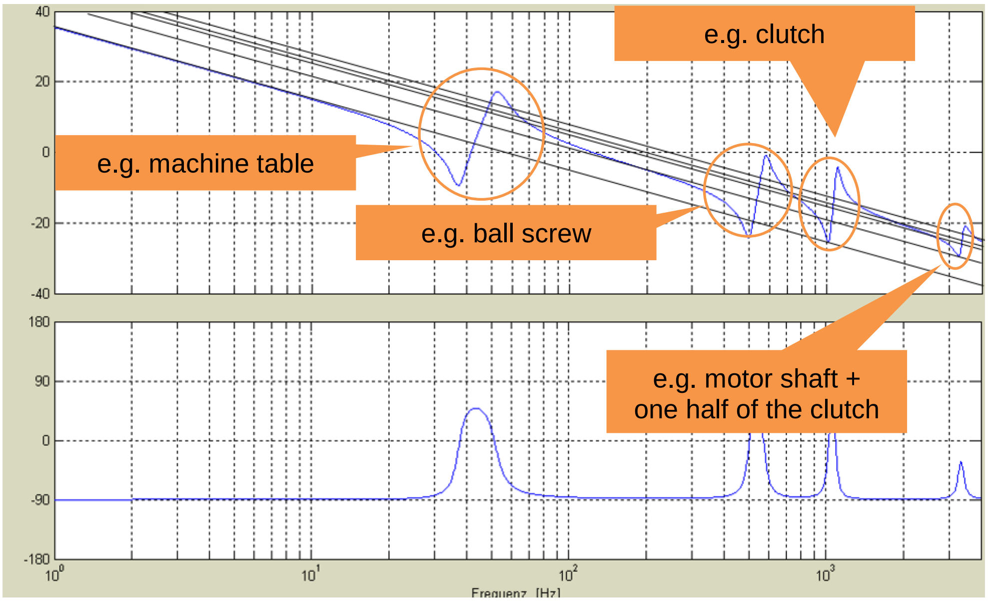


Figure 2-5 Speed-controlled system of a multi-mass-system



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.

There are two ways to assign a frequency to the mechanics:

- Calculate inertia from the frequency response before and after the locked rotor frequency. The difference is the inertia, which has decoupled. The inertia of the mechanical parts should be known from the CAD system.
- Use the function generator to generate a sine oscillation with the frequency of the locked rotor frequency which should be found. Now you should be able to hear / feel which part of the mechanics is vibrating.

CAUTION	**Touching moving parts can cause severe injury!**

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.

Advantage 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

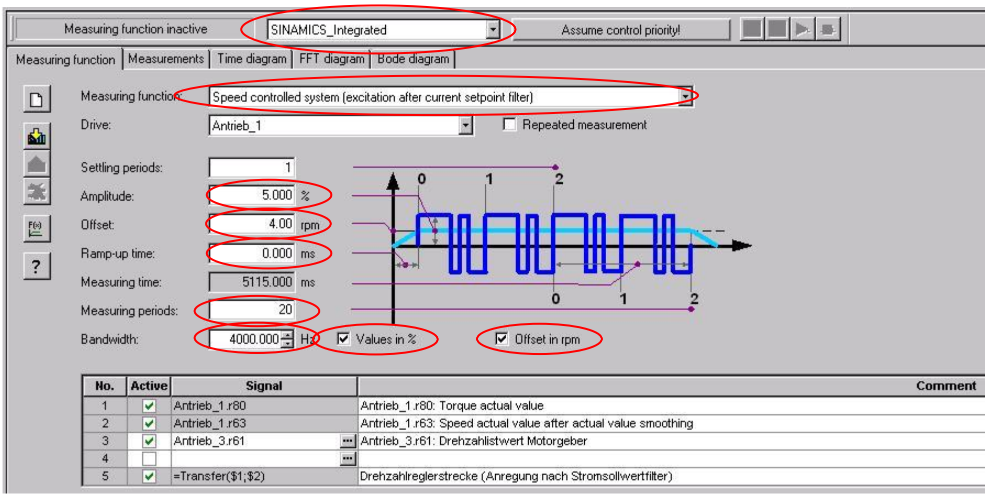
3.1 Speed-controlled system frequency response

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

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

Figure 3-1 toolbar in SIMOTION SCOUT

Figure 3-2 measuring function speed-controlled system frequency response



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

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.
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

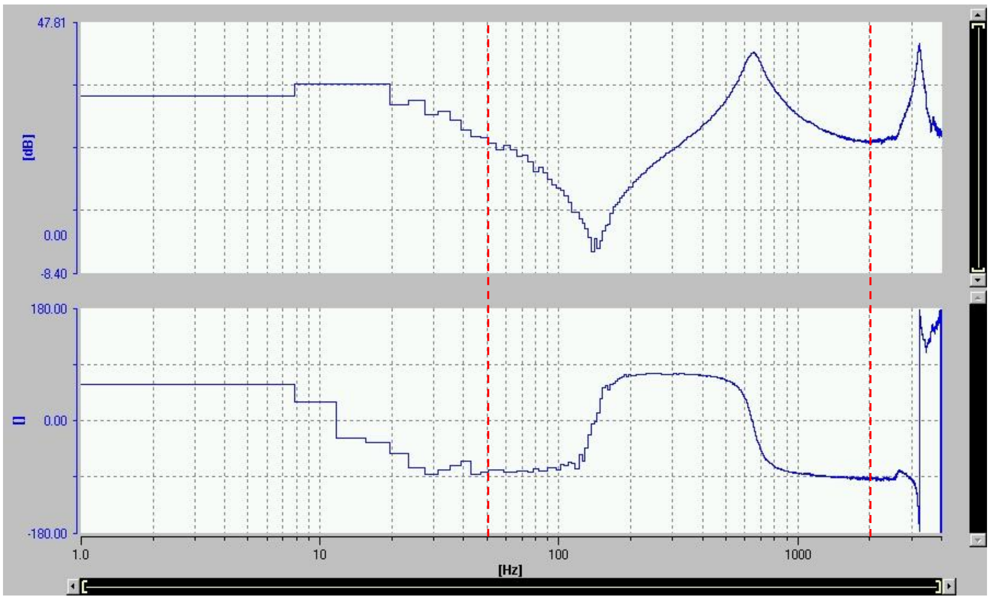
The speed controller must not be set too dynamically for the measurement since it will then "fight" against the noise signal (measurement signal). If it is too weak, the measurement will be negatively affected by the controller reaching to the offset speed level.

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 typical result of a speed-controlled system frequency response of a two-mass system. Locked-rotor frequency and resonance frequency are clearly visible.

The motor encoder can be seen by a pole frequency without a previous zero frequency. The phase tilts to -180°.

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 (approximate values).

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.

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).

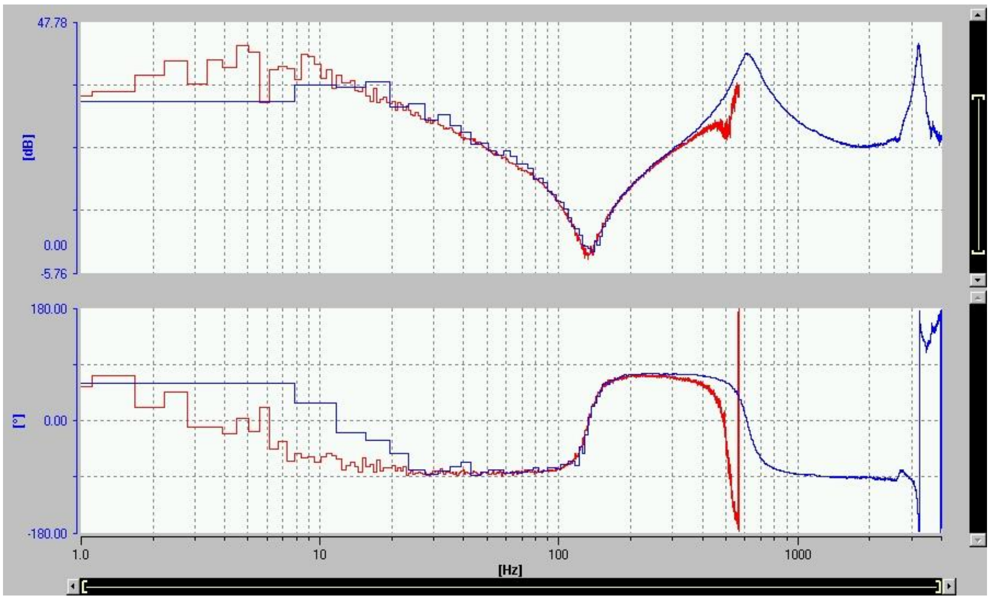
Both measurements can be displayed in a superimposed mode.

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)



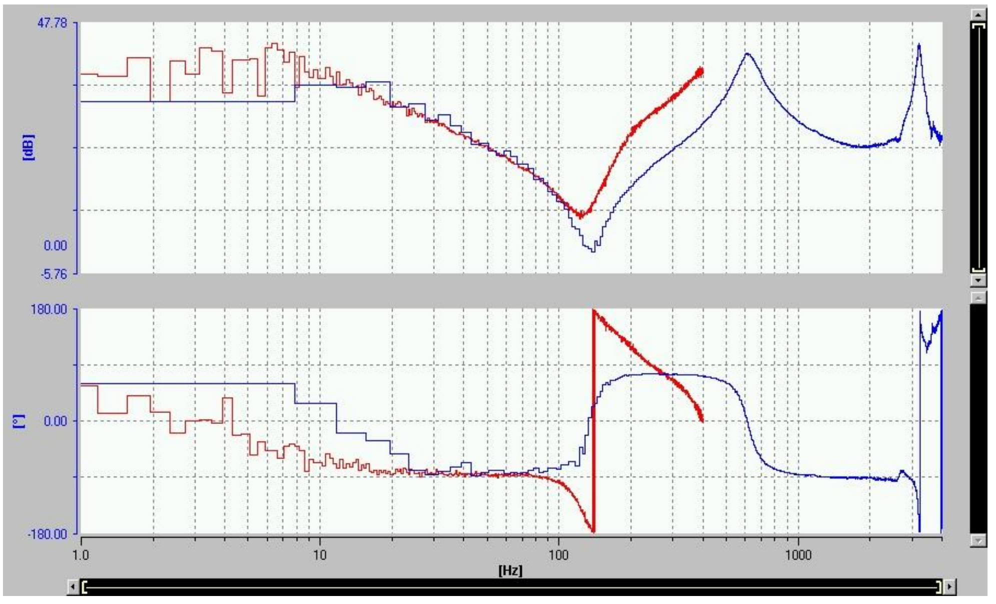
Attention **Same in this measurement, only the middle range is significant!**

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

In the low frequency range, the resolution has improved.

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)

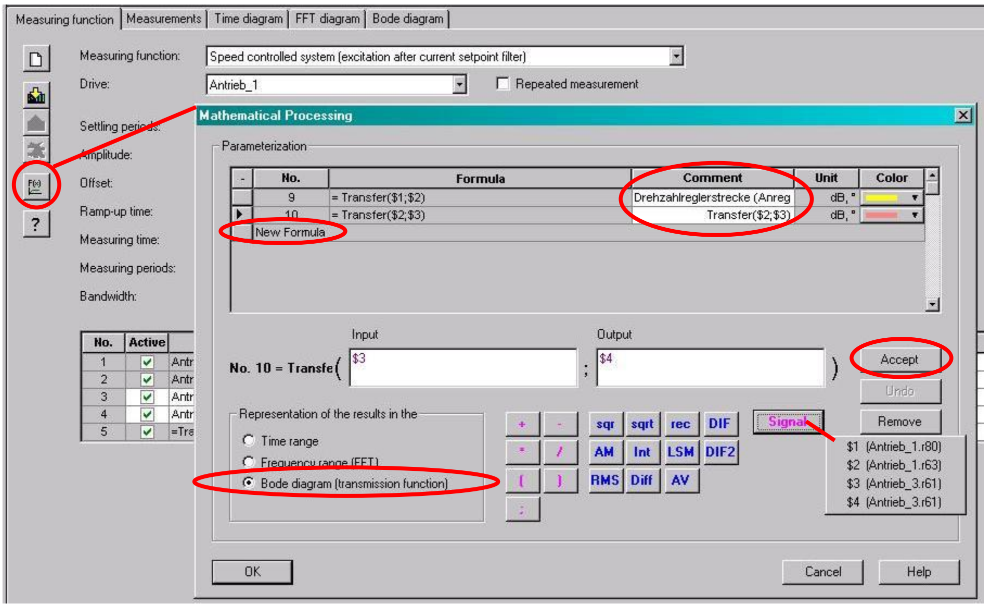
3.2 Mechanics frequency response

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 mathematics function



1) Open the Mathematics function
2) New Formula
3) Bode diagram (transmission function)
4) Choose Signals: „motor".r61, "load".r61
5) **Apply**

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

Note With Firmware V4.3 and higher encoders can be read in with the SINAMICS drive object "encoder". The evaluation occurs by SIMOTION with the TO "External Encoders".

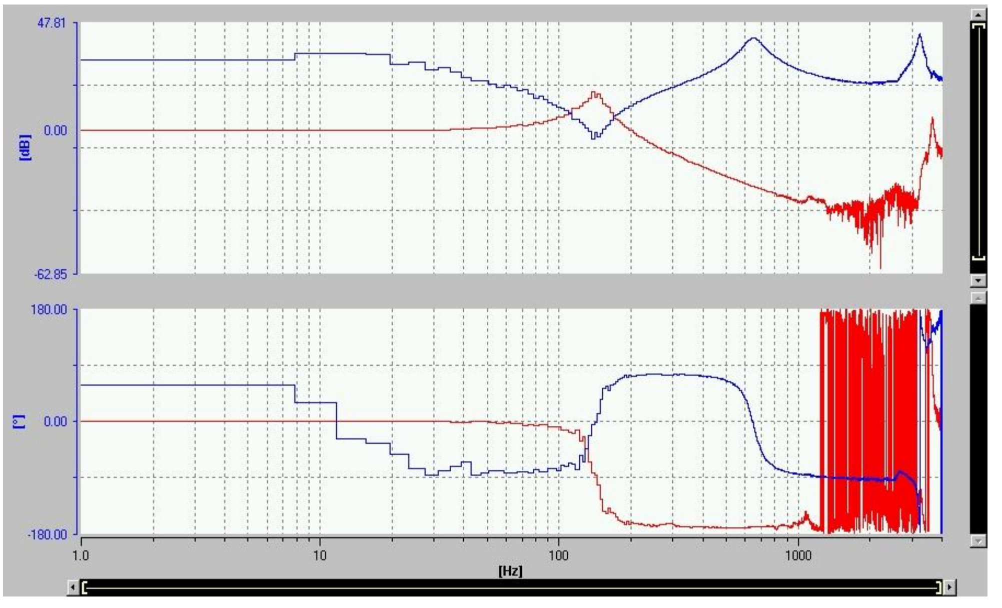
Note

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

Expert-List: p1821

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

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



Attention

Pay attention to the scaling!

Adapt the scaling of superimposed curves.

(right click on the trace window → Scaling: „As curve x.x“)

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.

If you scan a vibration of example 535Hz in 2ms clock, however, creates a mirror frequency at 35Hz.

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

NOTE

To ensure that a certain frequency actually exists mechanically, the measurement can be repeated with different rotation frequency (offset in the measurement parameters).

Make sure that the offset is not halved or doubled. For example, choose 70%, 90%, 110%, 130% instead.

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.

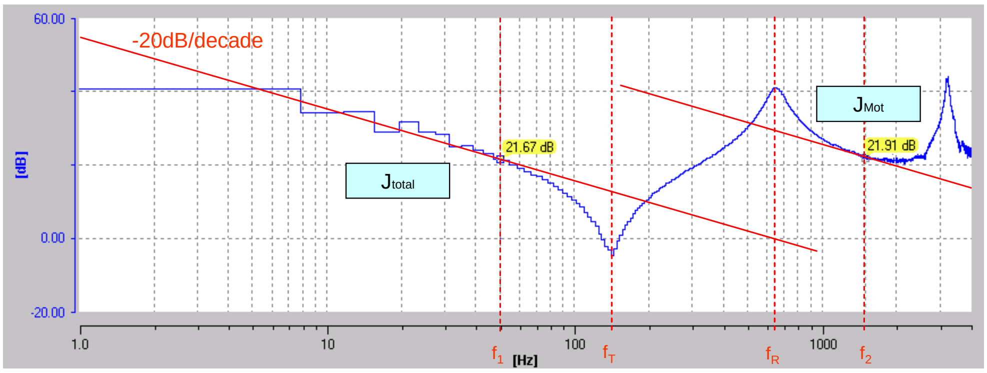
4.1 Frequency response

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 typical for 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 related 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 before the first locked-rotor-frequency.

After the first frequency-pair the first 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.

In the area in front of the first locked-rotor-frequency the total inertia can be determined. After the resonance frequency, only the motor inertia is left.

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 = 21.67dB and f_1 = 50Hz results in the total inertia of the system J_total = 0.002508kgm².

The pair of values y = 21.91dB and f_2 = 1500Hz results in the motor inertia

J_M = 0.000081kgm².

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.

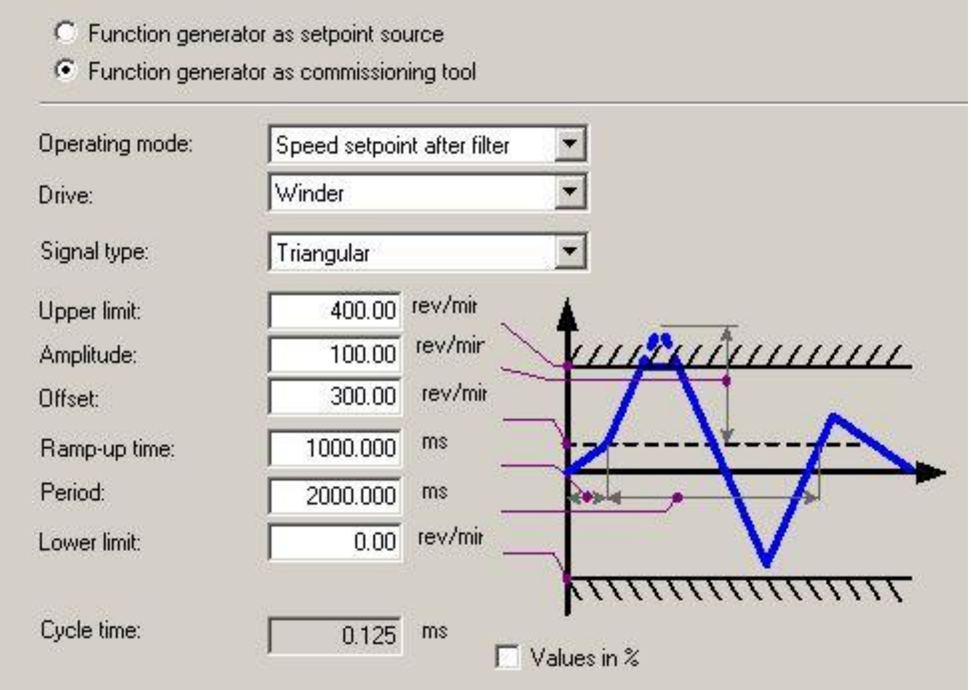
Depending on the known values you can use the following equations:

$$\boxed{c_T = 4 \cdot \pi^2 \cdot J_M \cdot (f_R{}^2 - f_T{}^2)} \qquad \boxed{c_T = \frac{(f_R \cdot 2\pi)^2}{\frac{1}{J_L} + \frac{1}{J_M}}} \qquad \boxed{c_T = (f_T \cdot 2\pi)^2 \cdot J_L}$$

4.2 Velocity profile using the ramp function generator

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:

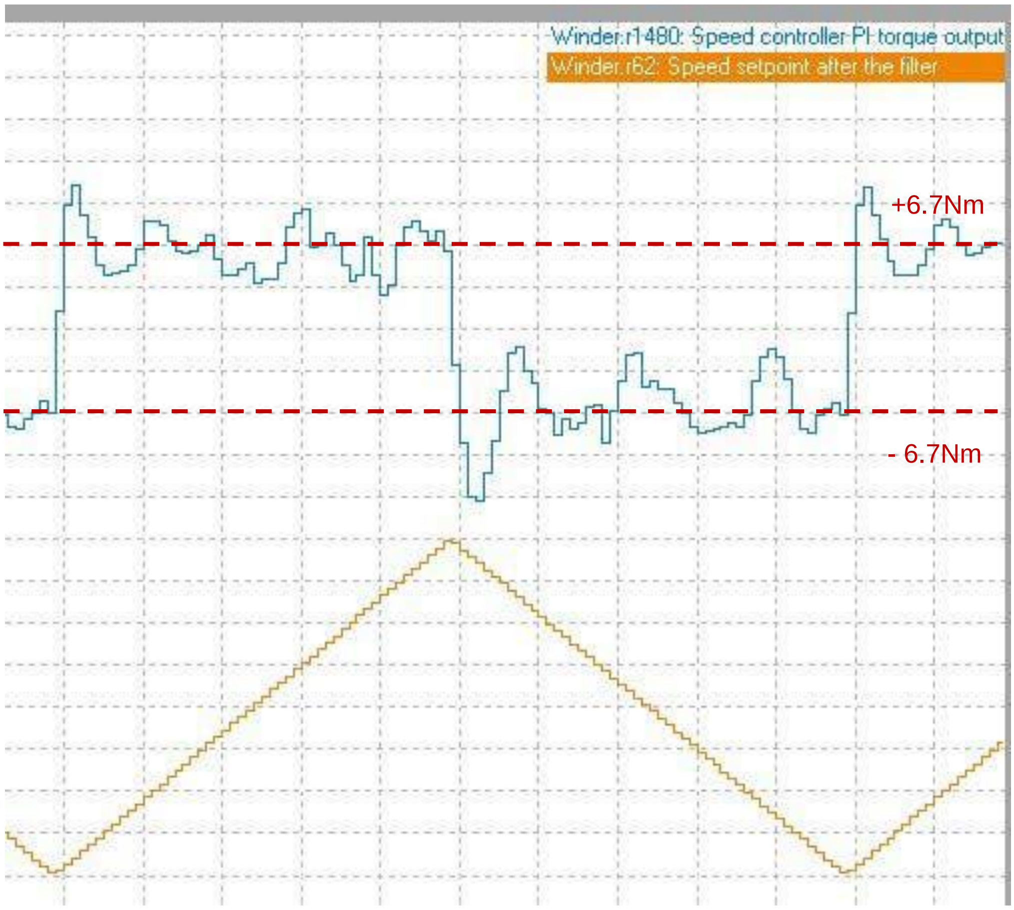
   The set acceleration (angular acceleration) is the result of the amplitude (rev/min) and the period time (ms):

   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.

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.

5 Mot-ID (Motor-Identification)

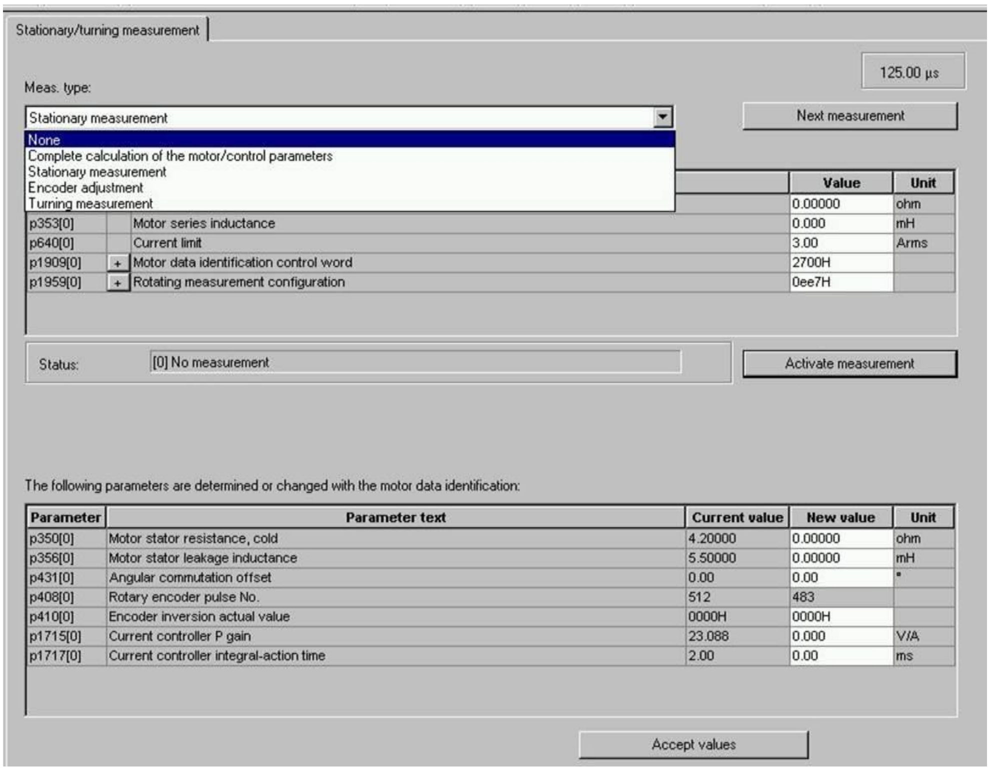
The Mot-ID can be used to adapt motor- and control parameters which are based on data sheet data to the real, motor specific data. The default values which are preset by inserting a drive can differ from the real motor values.

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 wizard to start the motor identification can be opened in the commissioning menu of the respective drive.

Figure 5-1 stationary/turning measurement



At first, choose the desired measurement with the drop-down-menu.

In the middle area parameter are listed which must be set **before** starting the 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".**

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 is drive enabled

Turning 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 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

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.

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 two 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, as the SINAMICS converters require the terminal-terminal inductance in parameter p356 and not the phase inductance as stated in many data sheets.

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

Offset: 0 1/min

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.

In the step response this conforms to an overshoot of maximum 4% of the stationary final value.

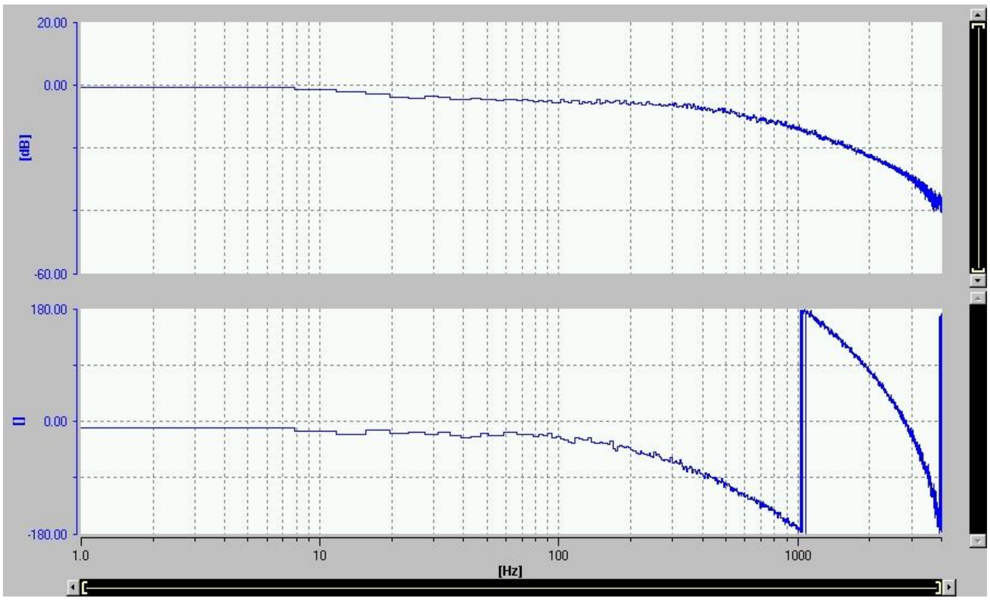
NOTE In the curve above, the slight reduction in the amplitude curve is not a too weak controller gain. The cause here is the locking time of the transistors in the frequency converters. The time is longer at low voltage modulation. If the measurement would be executed with higher measurement amplitude, 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.

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 15 Hz close to 0dB.

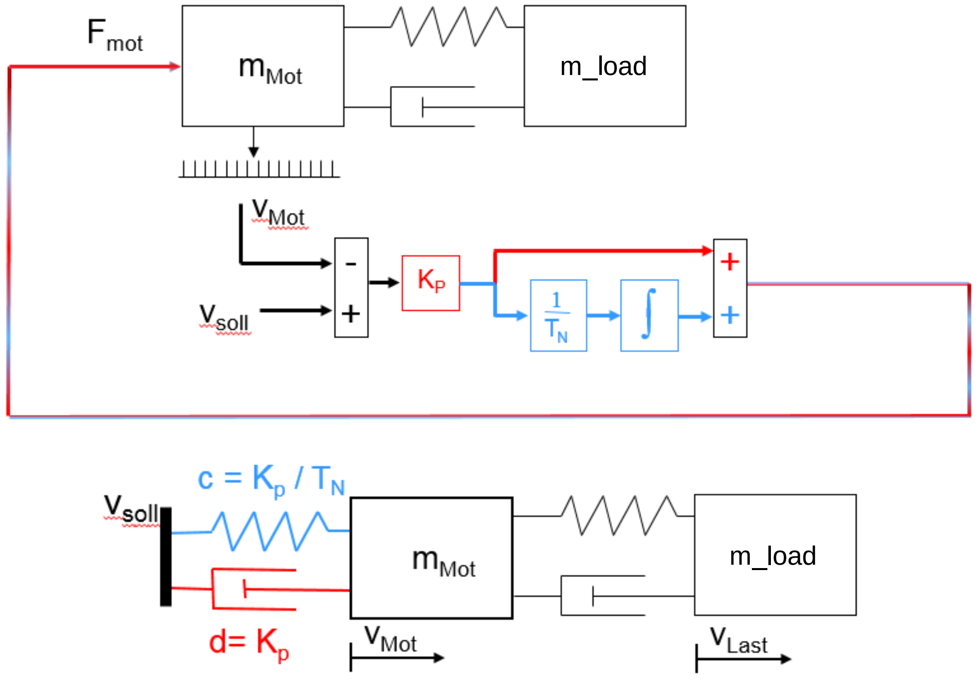
→ Increase Kp!

Note

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

7 Speed controller optimization

Figure 7-1 equivalent circuit of the speed control loop



The speed controller is a PI controller. The Kp corresponds to the damping of the motor in relation to the setpoint value, the integral time of the integrator acts like a spring.

NOTE

Thought experiment:

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, the sooner the weight will be stopped. If you remove the weight, the motor "springs back" to the initial position.

The speed controller can be optimized in two strategies:

- Interference optimum

  High controller gain. 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.

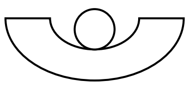
- Damping optimum

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

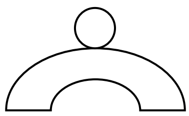
  However, disturbances on the motor side (e.g. gear or cogs) can have negative effects on the load side because the controller does not completely suppress them.

7.1 Stability criteria

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



Stable



unstable

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.

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.

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

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).

Note	Amplitude margin and phase margin must be evaluated in the open control loop response, the resonance magnification in the closed control loop response.

Figure 7-2 stability criteria

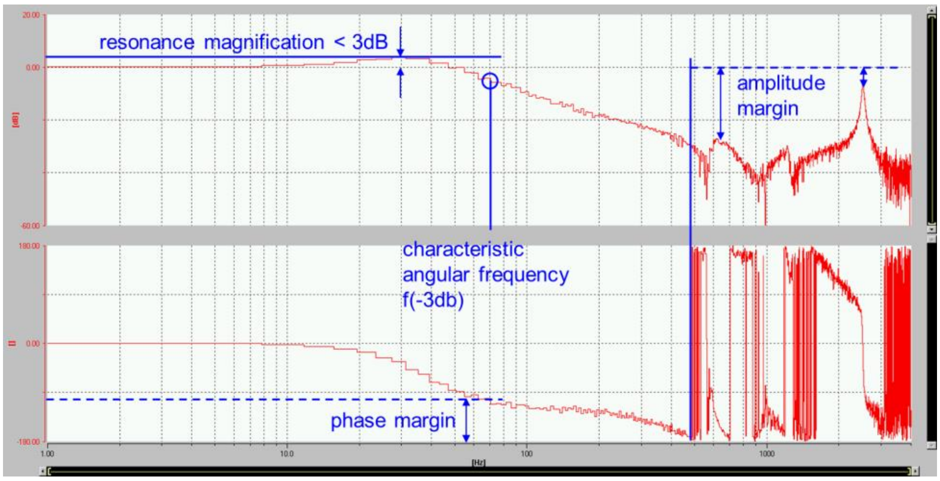


Table 7-1 – stability criteria

The following criteria should be observed:	
Resonance magnification:	Amplitude amplification in the lower frequency area. Amplitude amplification max 6dB tolerable. Corresponds to an overshoot of 43% (time domain). Related to a short integral time.
Characteristic angular frequency:	Frequency of -3dB in the amplitude response. The characteristic angular frequency should be as high as possible to reach a high dynamic and short rise time.
Amplitude margin:	Distance to 0dB in the amplitude response. Determines the damping behavior of the control loop (along with phase margin).
Phase margin:	Distance to -180° in the phase response. Determines the damping behavior of the control loop (along with amplitude margin).
Critical points:	If the phase reaches -180°, the amplitude margin should be at least 6dB. If the amplitude margin is smaller than 6dB -10dB, the phase margin should be approx. 40°.

NOTE	If these stability criteria will be complied, the control system is stable and damped sufficiently.

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.

In STARTER / SCOUT this is done by selecting Tn = 0 or by setting a very long reset time, e.g. 1000ms.

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.

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 smller than the motor inertia itself (see Chapter 2.1). The load "pushes" the motor at this point, wherby 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:

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

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:

$$\boxed{Kp \approx 1000 \cdot J_M}$$

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

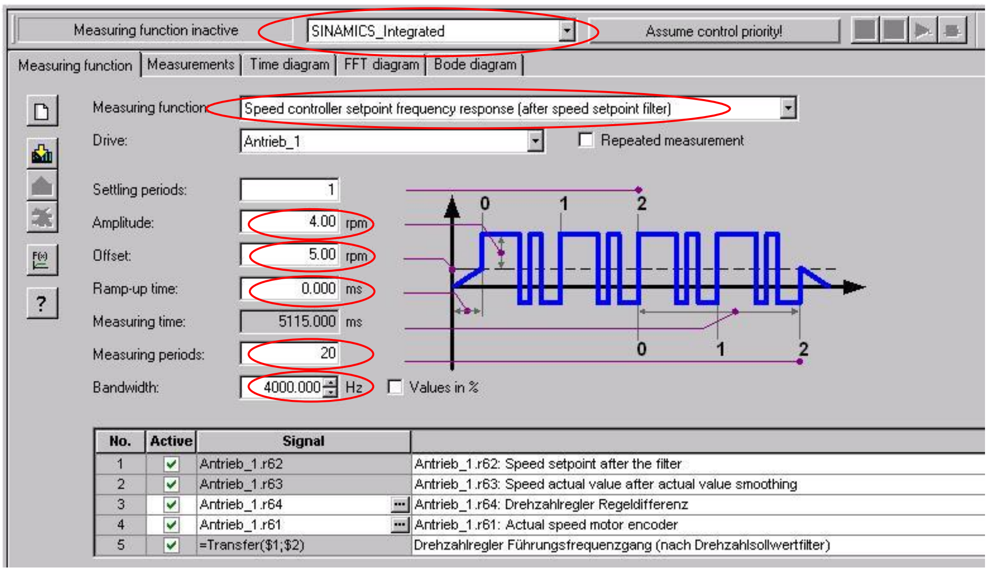
Depending on the load connection (characteristic of the locked-rotor frequency / resonance frequency), the amplitude and phase margin might be too small, which means the Kp would have to be reduced or current setpoint filters must be set.

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

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)

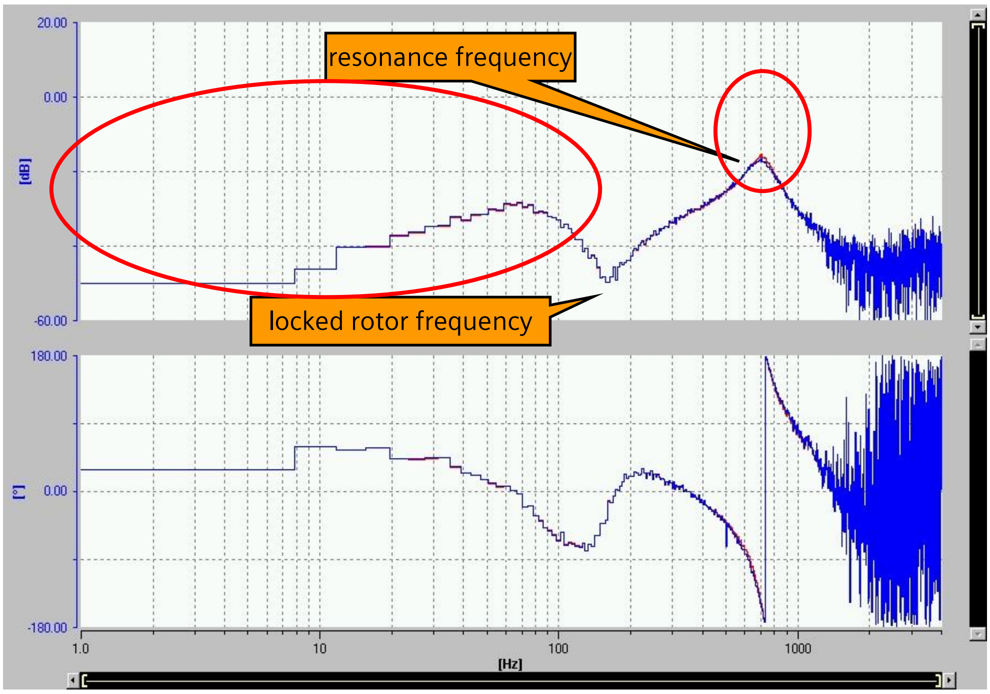
Figure 7-3 Measuring function “speed controller setpoint frequency response”



Device selection:	Select the device on which the drive you want to measure is located (e.g. SINAMICS_Integrated).
Measuring function:	"Speed controller setpoint frequency response (after speed setpoint filter)" → Additionally: **transfer function of open speed control loop** (see chapter 7.1)
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
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:	$K_p = 1000 \times J_M \times 1/3$ (default value)
Integral time:	Tn = 0 or 1000ms

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

Figure 7-4 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.

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 7-5 conversion logarithmic <-> linear

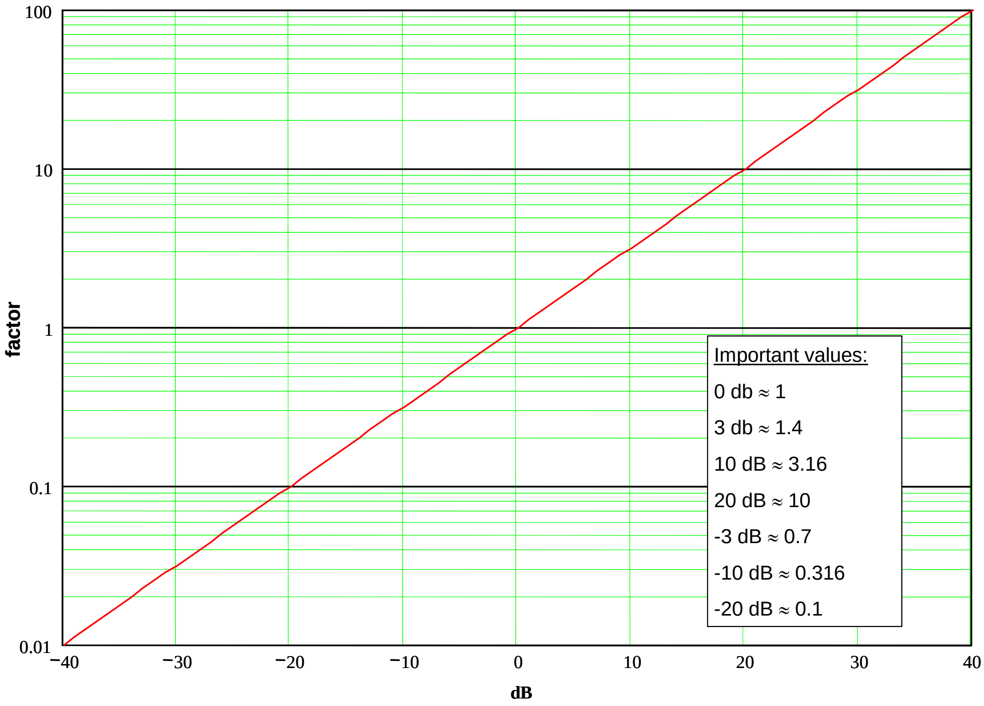


Figure 7-6 measurement 2: speed control loop

The open control loop magnitude (blue) reaches almost the 0dB line. At this point there is no phase margin left.

The speed controller can't compensate the resonance by itself.

In this case, the proportional gain factor must be reduced.

7.3 Current Setpoint Filter

Alternatively, the 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 patches.

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

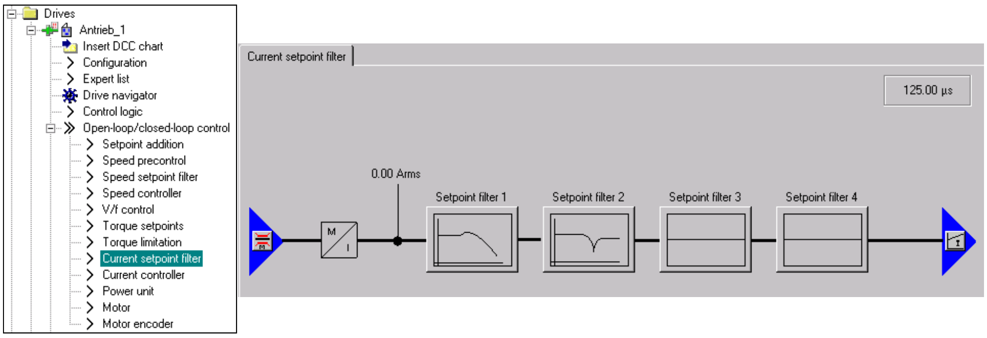
There are four current setpoint filters available to damp disturbing oscillations/resonances. One of these filters is active by default to mask out the encoder noise. It's configured as a low-pass filter with the characteristic frequency of 2000Hz and a damping of 0.7 (70%).

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.

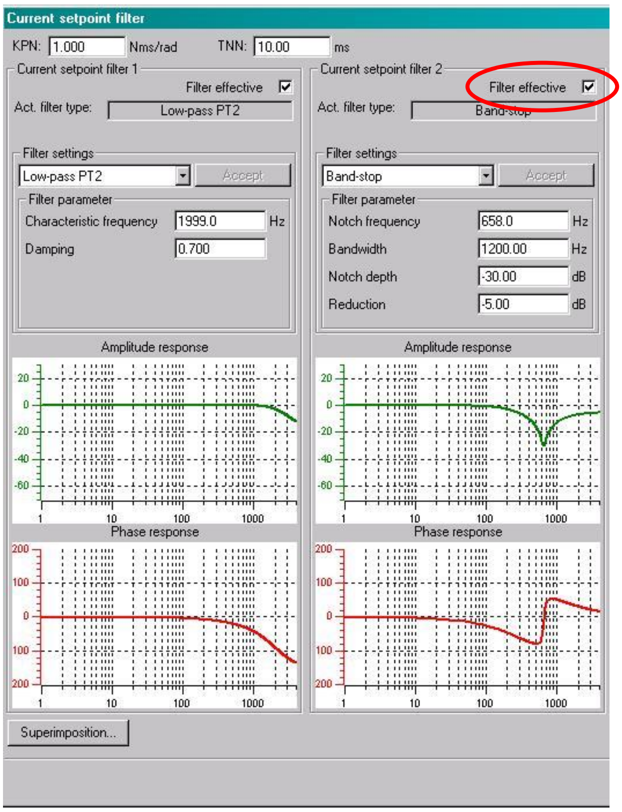
The extended current setpoint filters 5-10 can be activated via the parameter p5200[0] and configured with p5201-p5230.

Figure 7-7 current setpoint filters



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

Figure 7-8 settings of the current setpoint filter



To activate a filter check the checkbox „filter effective“

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

Note While low-pass filters have a better filter efficiency, band stop filters cause less phase tilt (see graphic above). This has advantages relating to 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: determined measuring cursor frequency (pole)

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!

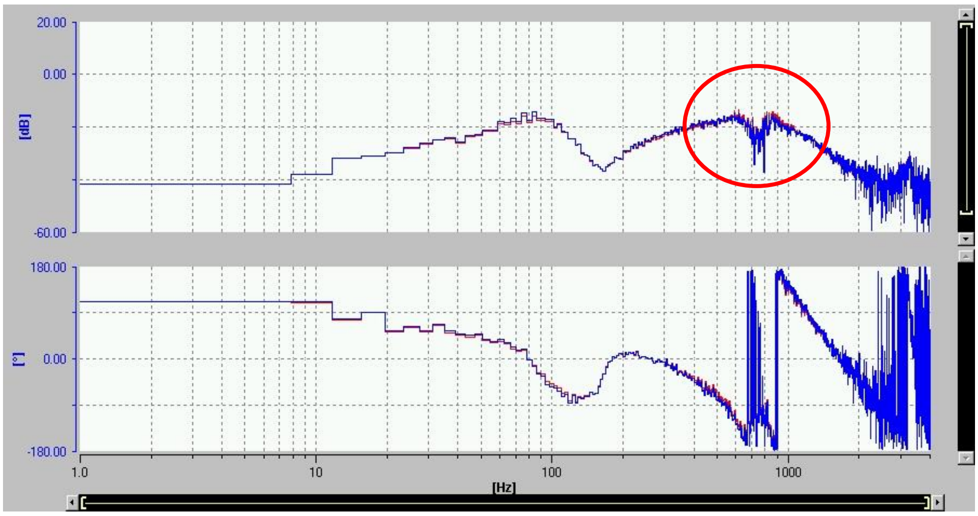
Reduction: Effects a permanent reduction of the magnitude after the notch.

Set only if required and as deep as necessary, as it causes phase tilt!

The characteristic of the parameterized filter is shown in the subjacent frequency response. With the button „Superimposition“, all activated filter will be summed up and displayed in one frequency response to have a look at the total filter characteristics.

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

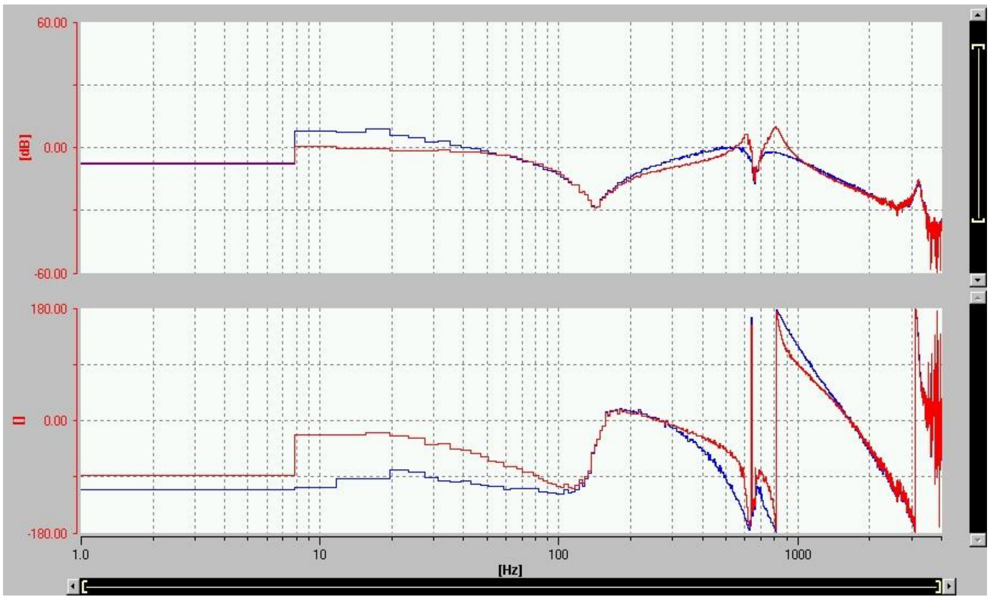
Figure 7-9 measurement 3: speed control loop (current setpoint filter active)



Because the filter the resonance frequency is damped, the trace shows an adequate amplitude margin.

Now the proportional gain factor Kp can be increased.

Figure 7-10 measurement 4: speed control loop



With this Kp factor, the control loop is close to a stability limit (amplitude margin too small).

The characteristic angular frequency f(-3db) = 50Hz.

In this case, the speed controller proportional gain must be reduced to guarantee an adequate amplitude margin (ca. 10dB).

Alternatively, it can be tried to achieve the amplitude margin by adjusting the current setpoint filter (e.g. raise the filter bandwidth and set a filter reduction).

Figure 7-11 measurement 5: speed control loop

Because of expanding the filter bandwidth, a Kp raise from 0.7 to 1.0 was possible. Furthermore, there is still enough amplitude margin.

The characteristic angular frequency amounts f(-3dB) 60Hz.

The amplitude amplification always amounts less than 6dB.

The resonance frequency is damped sufficiently, the amplitude margin is adequate.

➔ **The stability criteria are complied.**

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.

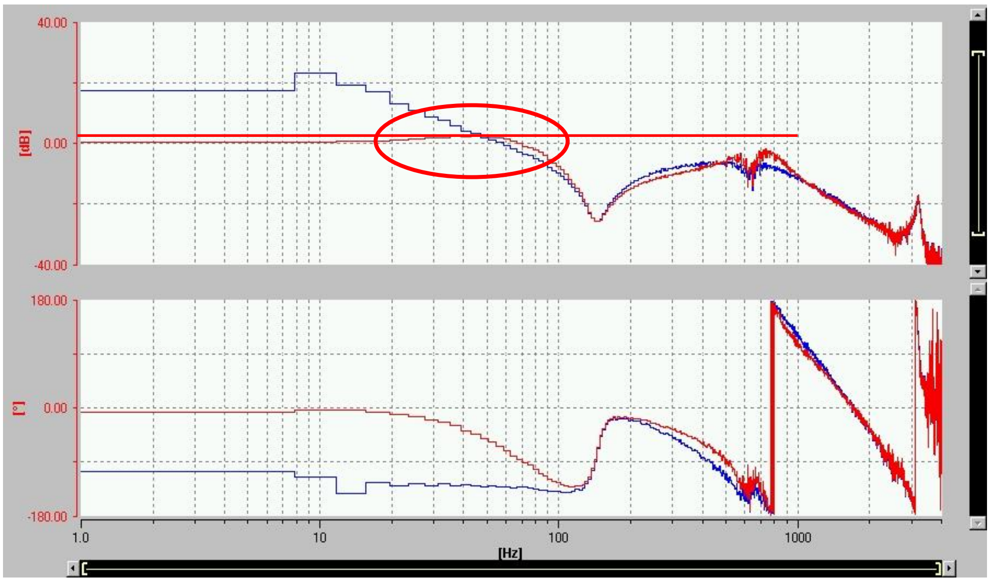
NOTE

Optimized for the symmetrical optimum, the resonance peak should not be higher than 6dB.

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.

If, for example, the Kp is reduced by a factor of 5, the startup time of the P-controlled system becomes longer by a factor of 5. Thus, the reset time must be increased by a factor of 5.

Figure 7-12 measurement 6: speed control loop



By reducing the integral time, the controller bandwidth got higher again (characteristic angular frequency f(-3dB) = 82Hz).

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

7.5 Current setpoint filters in multi-mass-systems

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

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

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

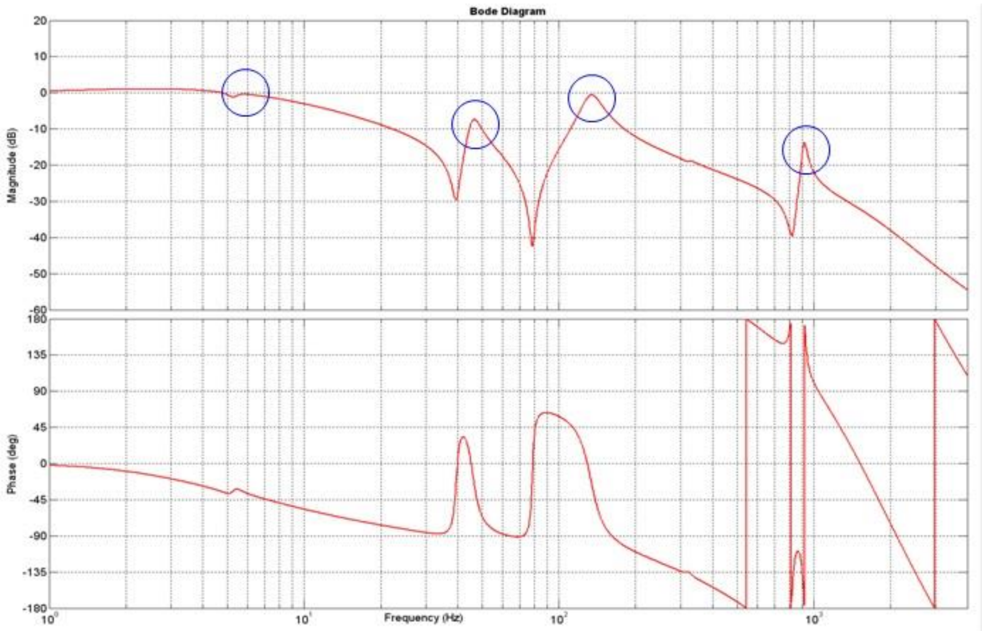
Not every resonance frequency has to be damped actively by a current setpoint filter.

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 7-13 simulated speed control loop

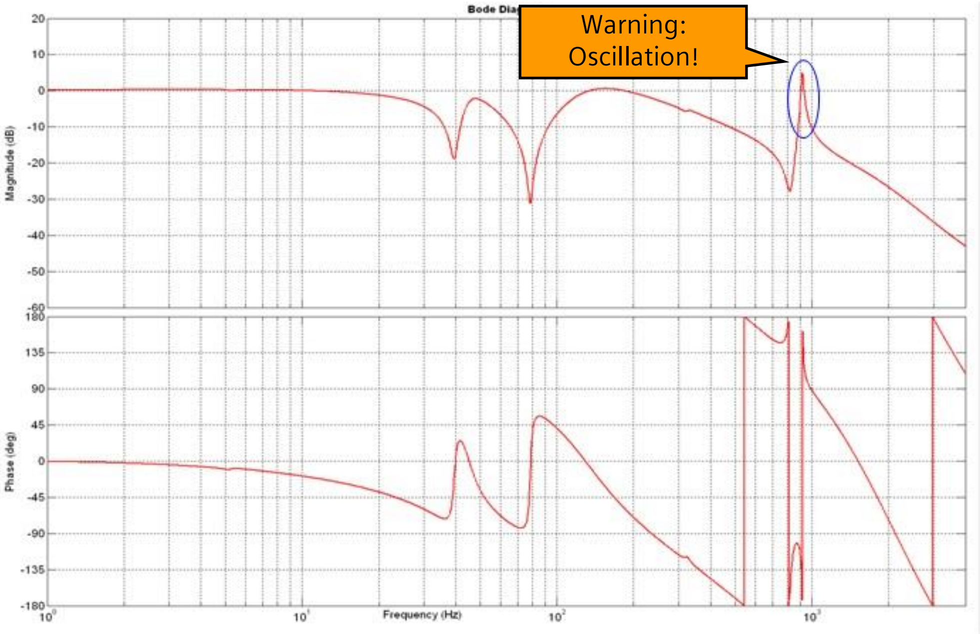


First three resonance frequencies are located in the space of the controller bandwidth (noticeable at the phase margin).

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

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 nestled to the 0dB line.

Figure 7-14 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.**

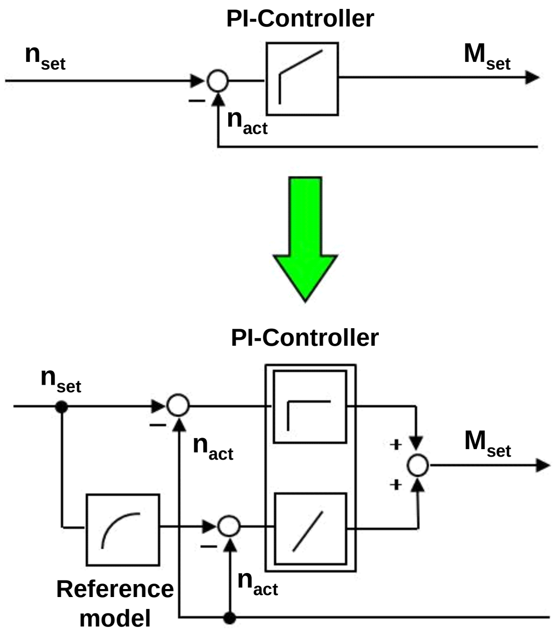
7.6 Reference model

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 7-15 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.

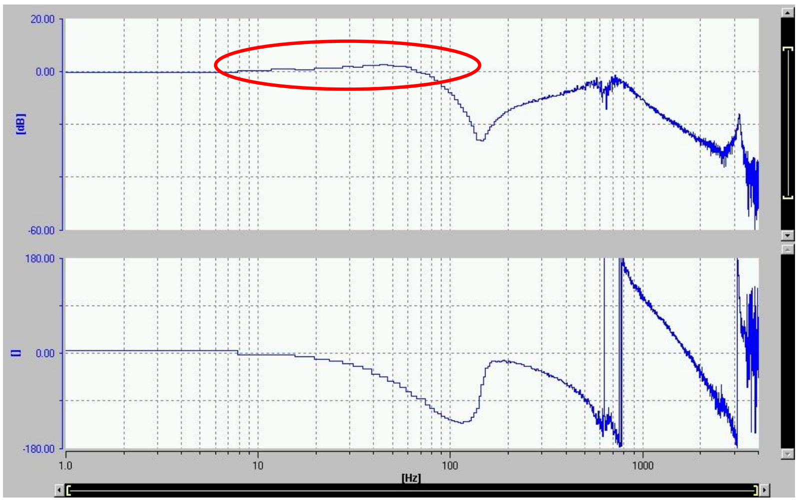
Using the reference model, higher values in the position controller gain can be reached.

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

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:

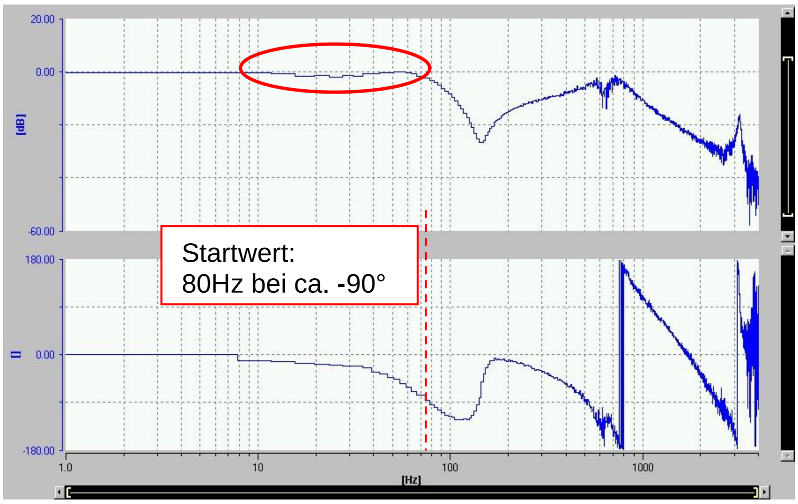
Natural frequency [p1433]:	Start value: frequency at which the phase reaches -90° for the first time. Hint: Set start value slightly smaller. Afterwards, shift the amplitude reduction (effected by the reference model) below the amplitude raise by increasing the natural frequency p1433
Damping [p1434]: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

Figure 7- reference model OFF



Amplification because of „low“ integral time recognizable

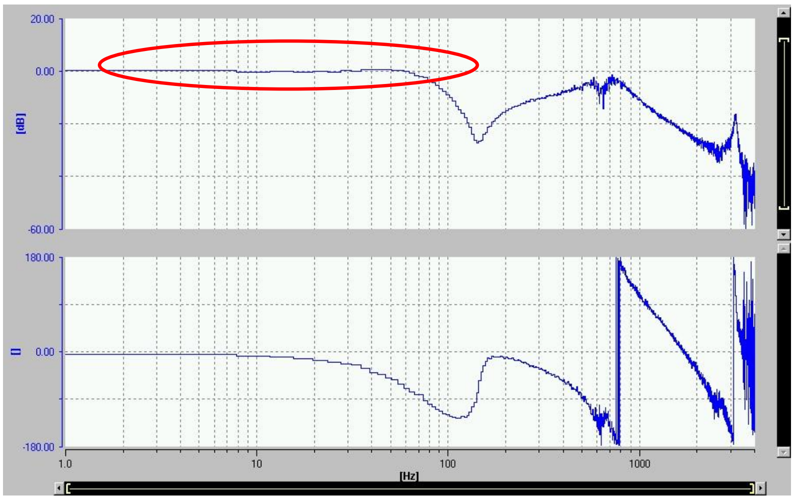
Figure 7-16 reference model ON



natural frequency too low: magnitude reduction recognizable

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

Figure 7-17 reference model ON



desired settings: magnitude consistently at 0 dB

7.7 Speed setpoint 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.

8 Position controller optimization (SIMOTION)

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.

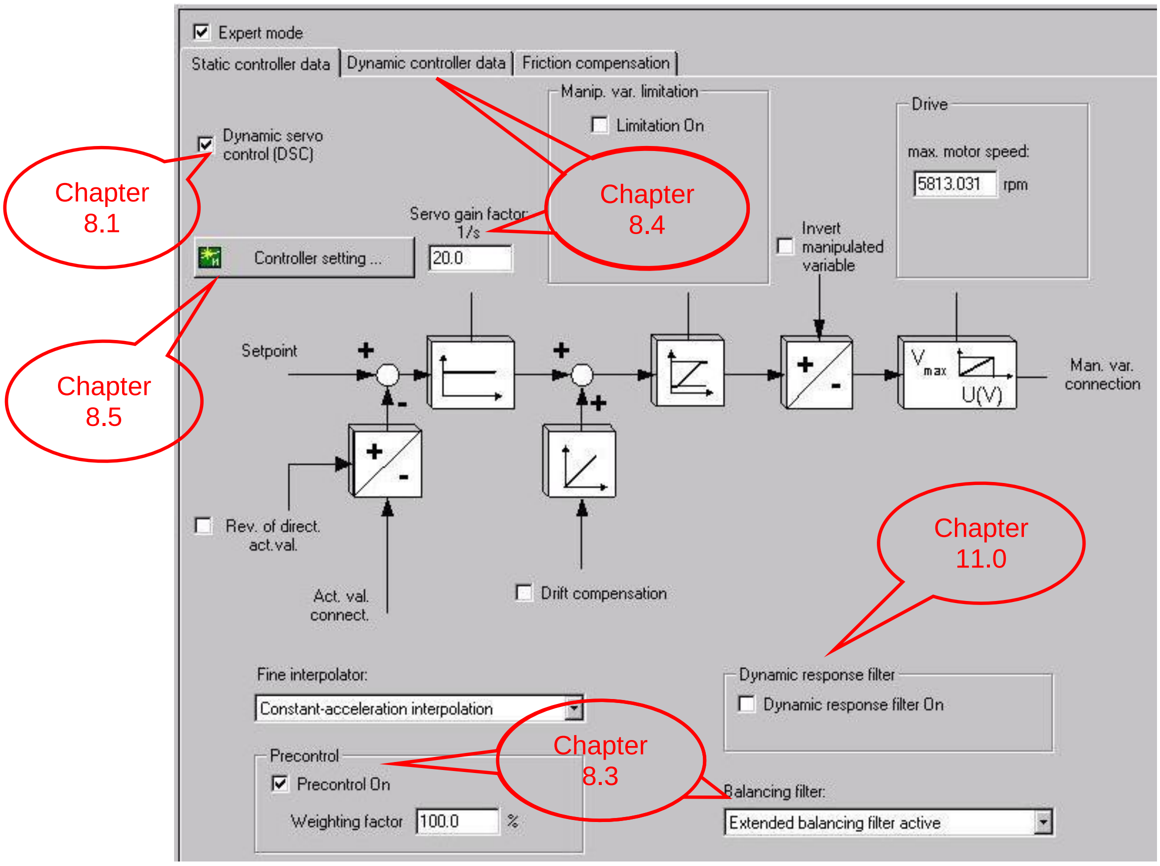
<u>The most important position controller parameters:</u>

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

<u>and the option:</u>

- DSC Dynamic Servo Control (active per default)

Figure 8-1 menu “closed-loop control” in SIMOTION



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

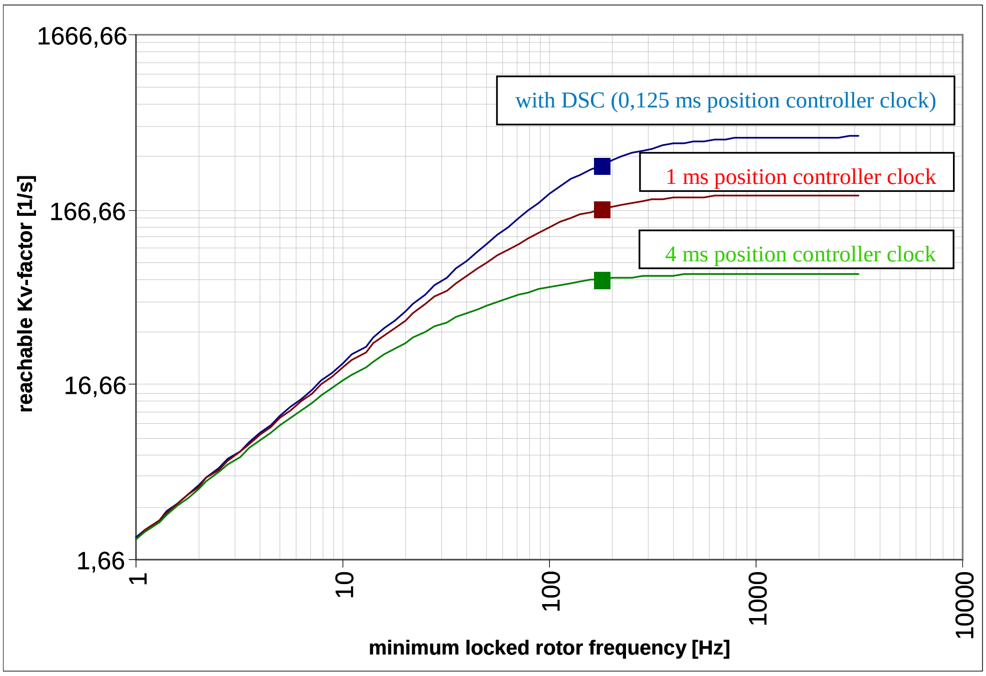
Use DSC especially for dynamic applications!

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 more the higher the minimum locked rotor frequency of the systems is.

Figure 8-2 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.

8.2 Unit of the position controller gain factor (Kv)

Attention

There is a difference between the servo gain factor unit of the SIMOTION 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:

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

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

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

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

The result is a conversion factor of 16.6:

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

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

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

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

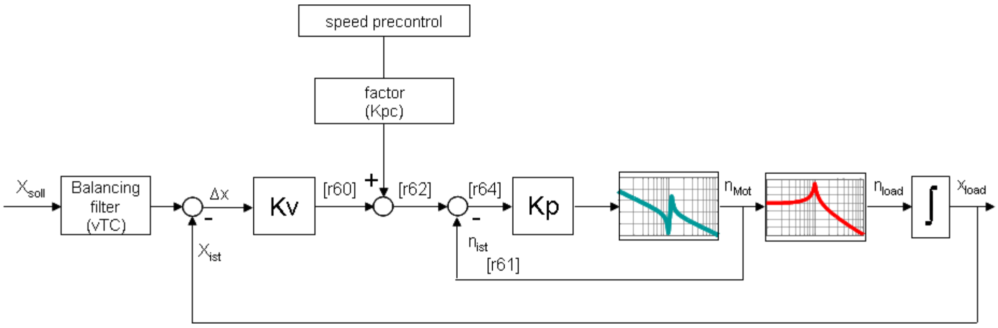
(see also: chart, chapter 8.1)

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 up directly on the position controller output. The speed controller input is available faster, because the known speed setpoint can by-pass the position controller.

Figure 8-3 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.

To activate the speed pre-control, set the checkbox „Pre-control On“ in the closed-loop control menu.

Note To do a fine-tuning of the speed pre-control, a balancing filter can be used.

In the closed-loop control menu there are three balancing filter modes available:

- Balancing filter not active [balanceFilterMode=OFF]
- Balancing filter active [balanceFilterMode=MODE_1]
  (a PT1 filter is used as the balancing filter)
- Extended balancing filter active [balanceFilterMode=MODE_2]
  (digital FIR (finite-duration impulse response) filter)

Note	The extended balancing filter (balanceFilterMode=MODE_2) is recommended.

The balancing filter is a simplified model of the speed control loop. It is used to prevent the position controller from overriding the manipulated velocity variable during the acceleration and deceleration phases.

This is accomplished by delaying the position command value of the position controller by the balancing time with reference to the velocity pre-control.

To adjust the balancing filter, go to the register **„Dynamic controller data“**.

(Activate the checkbox “Expert mode” in the closed-loop control menu to see the dynamic controller data.)

<u>There are three time constants available:</u>

- tTC Current control loop equivalent time (here not relevant)
- **vTC Speed control loop equivalent time (for balancing filter)**
- pTC Position control loop equivalent time (here not relevant)

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.

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 measuring (Figure 8-13) a creeping in into the final position is noticeable!

vTC ideal: The system deviation equals 0. Consequently, the controller output without pre-control [r60] equals 0 as well.

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

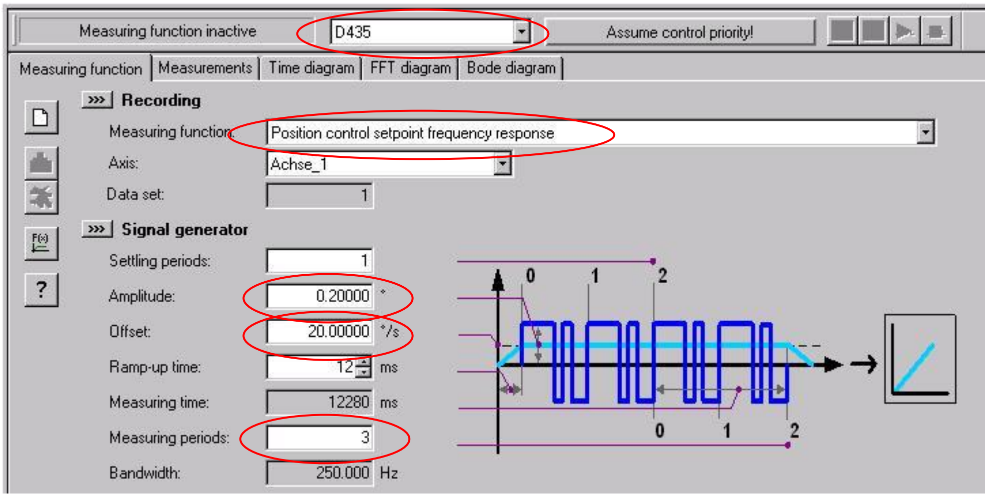
8.4 Position controller parameter

NOTE In this chapter, the position controller optimization is described for SIMOTION.

8.4.1 Servo gain factor (Kv) optimization (frequency domain)

- Deactivate speed pre-control: Kpc = 0%
- Balancing time: vTC = 0ms

Figure 8-4 position controller setpoint frequency response



Device selection: D4xx

Measuring function: “Position control setpoint frequency response”

Amplitude: -default-

→ Too big amplitude may affect the measuring result negatively! (Limitations can be reached)

→ Check sound during measurement: audible but not abnormal

Offset: **Offset in °/s > Amplitude in °/s**

→ to avoid reverse rotation

Measuring periods: ca. 3

→ More measuring periods increases the accuracy (averaging)

→ Affects the measuring time

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

Use the chart from chapter 8.1 to estimate the servo gain factor in preparation of the optimization.

Figure 8-5 position control setpoint frequency response (Kv too low)

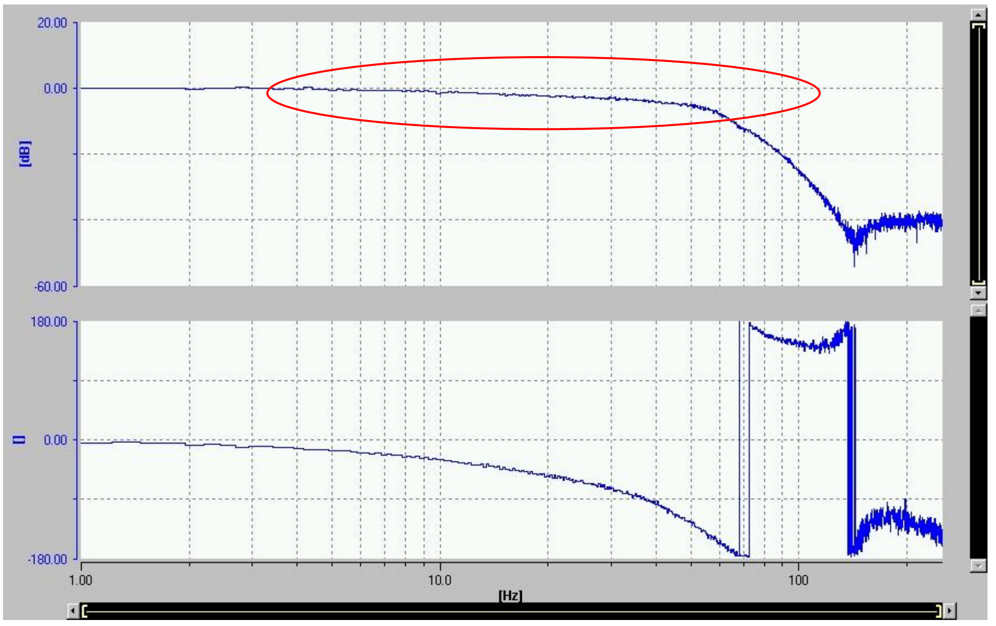


Figure 8-6 position control setpoint frequency response (Kv ideal)

Amplitude response should stay close to 0dB until phase tilt.

NOTE

The position controller is often optimized according to the optimum amount.

Since in many position-controlled applications no overshoot is permissible, no increase in the amplitude should be seen in the frequency range.

8.4.2 Determination of balancing time vTC (time domain)

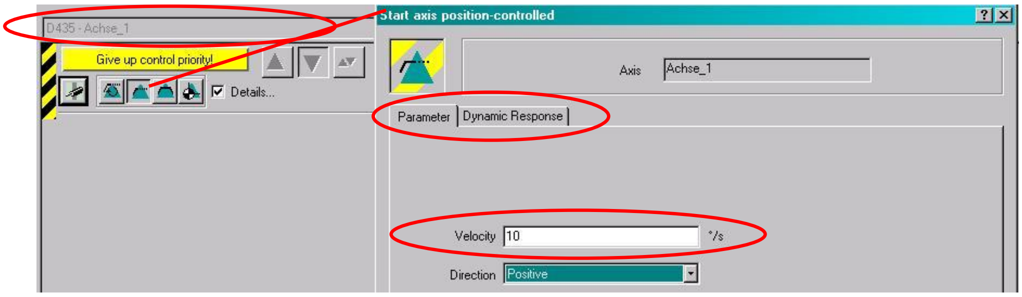
Set the following parameter at the beginning of the optimization:

• Speed pre-control	Kpc	=	100%	
• Balancing time	vTC	=	0ms	(start value)
• Servo gain factor	Kv	=	„optimized value“	

Attention **Do not use the measuring functions „position control ramp“ and „final controlling element jump“ for balancing time optimization of oscillatory systems, as speed set point jumps are included in these measuring functions. The optimization could be affected negatively because of the infinite accelerations.**

Specify a trapezoidal velocity profile with the control panel instead. The significant signals must be traced with the device trace.

Figure 8-7 control panel



Adjust the velocity profile by clicking on the button “Position-controlled traversing of the axis”

<u>Tab „Parameter“:</u>

Setting of the movement speed

Entry in °/s

$$\boxed{[^\circ/s] = \left[\frac{1/\min}{60s}\cdot 360^\circ\right]}$$

<u>Tab “Dynamic response“:</u>

Choose the velocity profile: “trapezoidal” with an endless jerk or “smooth” with the possibility of jerk limiting.

Note The jerk is the derivative of the acceleration and defines the change of acceleration respectively deceleration. Decreasing the jerk, the corners of the acceleration profile getting smoothed.

Attention **Pay attention to torque limitation (negative/positive) during the following measurements. The torque limit can be reached as a result of a too high acceleration or jerk value.**

To check the torque limit setting, go to “open-loop/closed-loop control” → “torque limitation” in the drive.

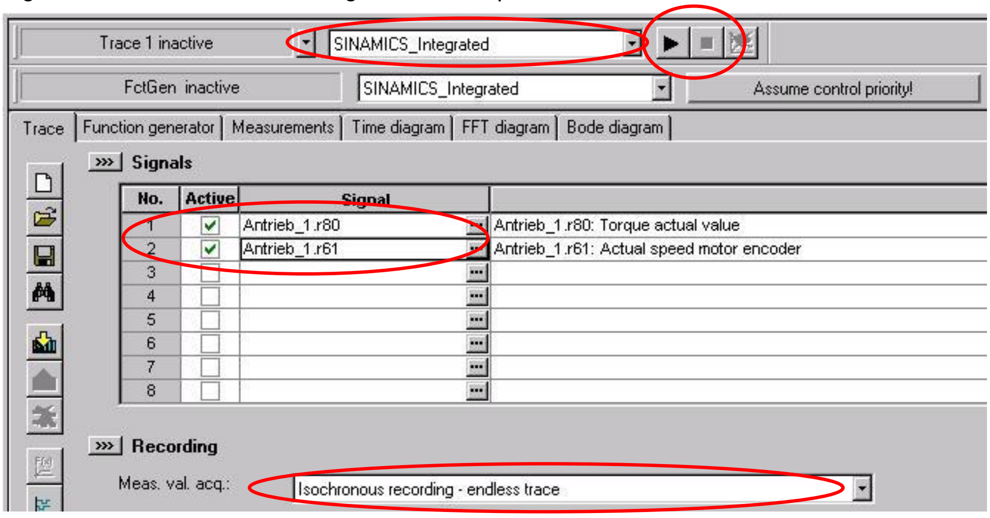
Before starting the measurement for balancing time optimization, the velocity profile has to be defined with consideration of torque limitations.

Note The torque actual value cannot be recorded straight away with the SIMOTION trace. Because of this, the balancing time optimization is described for the SINAMICS trace in this document.

With activated technology data block, the torque actual value is available in SIMOTION. In that way all signals can also be recorded in the SIMOTION trace.

Trace the signals „torque actual value“ [r80] and “actual speed motor encoder” [r61] with the device trace (device: SINAMICS_Integrated).

Figure 8-8 device trace function generator: torque actual value



Note: **Recording: “isochronous recording – endless trace“**

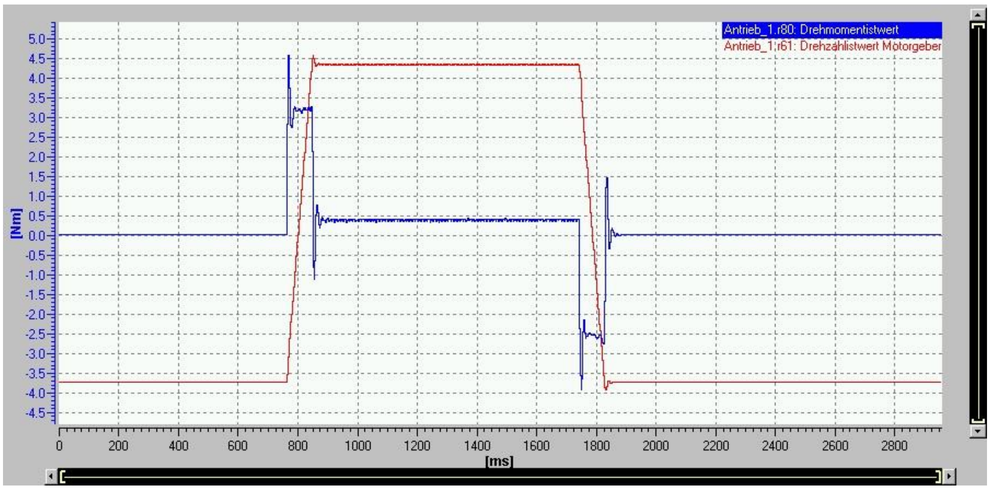
To start/stop the recording press the "Play/Stop" button at the top of the device trace window.

During the recording, the specified velocity profile must be traversed with the control panel. (The function generator is not used!)

You can approximate the torque limits by adapting the parameters velocity, acceleration and jerk.

Note	It's recommended to keep approx. 10% distance to the adjusted torque limit!

Figure 8-9 torque actual value (blue)



In the test configuration the torque limit is 5Nm. Thus a maximum value of 4.5Nm is tolerable.

After defining the velocity profile, the measurement for balancing time optimization can be performed.

Significant parameters are:

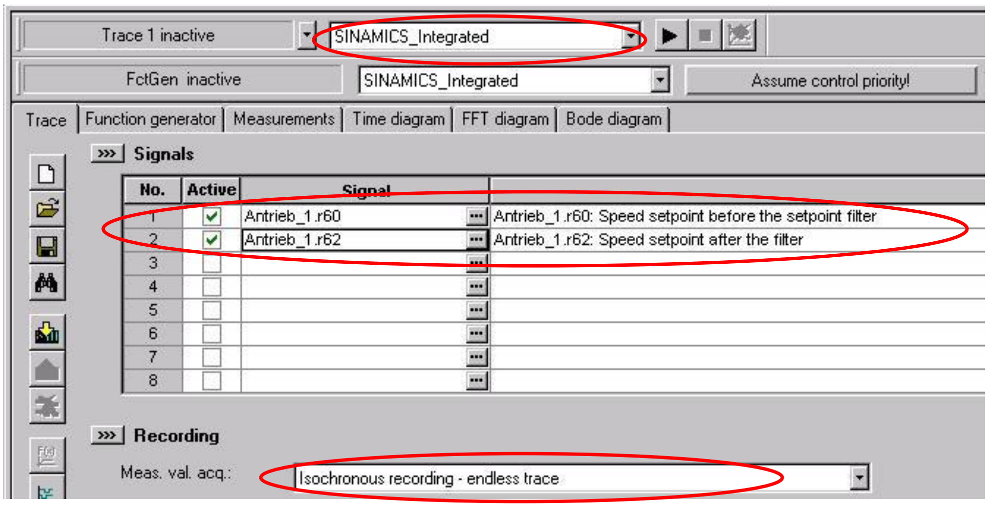
- [r60] Speed setpoint before the setpoint filter [rpm]
- [r62] Speed setpoint after the filter [rpm]

There are two criteria to optimize the balancing time:

- **quick reach of speed setpoint [r62] without overshooting**
- **speed setpoint, without pre-control value [r60], close to 0**

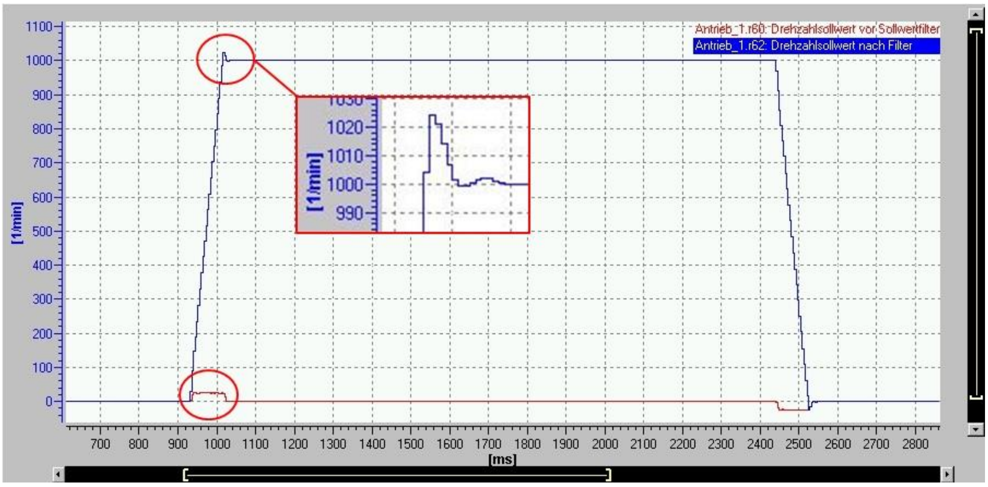
Trace the signals [r60] and [r62] with the device trace:

Figure 8-10 device trace function generator: speed setpoint



Note: Recording: “isochronous recording – endless trace“

Figure 8-11 measurement 1: vTC clearly too short



The blue curve shows the position controller output including the pre-control value (signal [r62]).

The trace shows a distinct overshoot of the speed command value.

Proportional to the speed overshoot, there is an overshoot of the position setpoint. However, use the speed command value to detect any overshoots because the evaluation by position is more difficult.

The red curve shows the position controller output before adding the pre-control value (signal [r60]).

If speed pre-control is inactive (Kpc = 0%) the signals [r60] and [r62] are congruent.

If speed pre-control is active (Kpc = 100%) signal [r60] should equal to 0.

(The position controller serves as disturbance controller only)

If the time constant is not chosen optimally, the position controller "helps" at the beginning of the acceleration and delay phases (additionally to the speed pre-control). Because of this, the red curve deviates from 0 when accelerating and decelerating.

With the help of both criteria the short balancing time is noticeable.

Figure 8-12 measurement 2: vTC too short

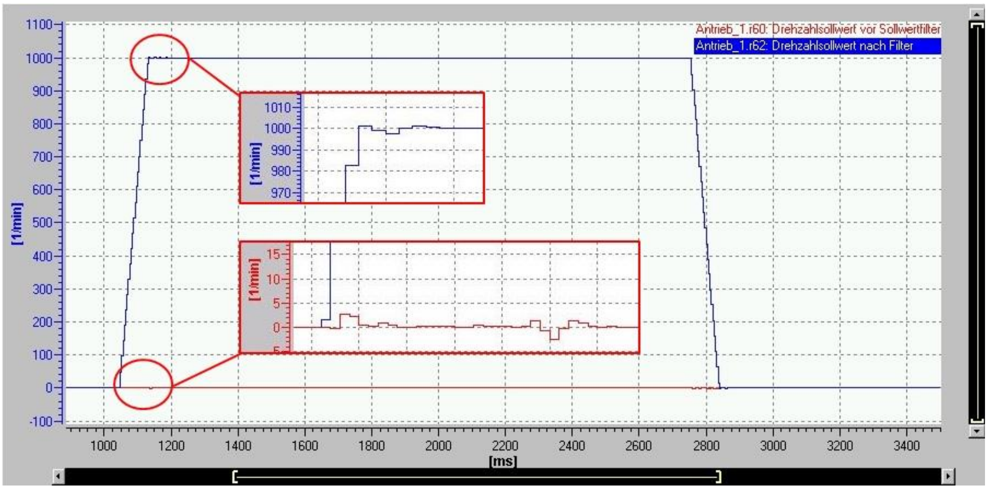
The too short balancing time can be also recognized with vTC = 1ms (overshoot and deviation).

Figure 8-13 measurement 3: vTC too long

If vTC is too long (extreme example), the command value is reached very slowly (blue curve, zoom).

Because of negative system deviation between command value and actual value, the position controller reacts against the speed pre-control (red curve).

Figure 8-14 measurement 4: vTC ideal



Measurement 4 shows the position controller output is nearly 0. If the balancing time is ideal, the speed command value is reached quickly without overshooting.

The evaluation of the speed command value is hard, even when using the zoom, because the threshold between quickly and creeping reach of the final position is difficult to identify).

Because of this, the parameter [r60] (position controller output without pre-control signal) is more suitable. Especially for fine adjustment of the balancing time.

Approximate the ideal balancing time step by step by evaluating the signal [r60].

The following trace shows, that even a minimal change of the balancing time has consequences:

Figure 8-15 measurement 5: vTC minimal too long

It's hard to identify an overshoot of the speed setpoint [r62] (blue) caused by the minimal too big balancing time.

The position controller output without pre-control [r60] (red) shows a larger deviation compared to measurement 4 with vTC = 2.1ms.

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 Figure 9-1).

NOTE

Siemens motors:

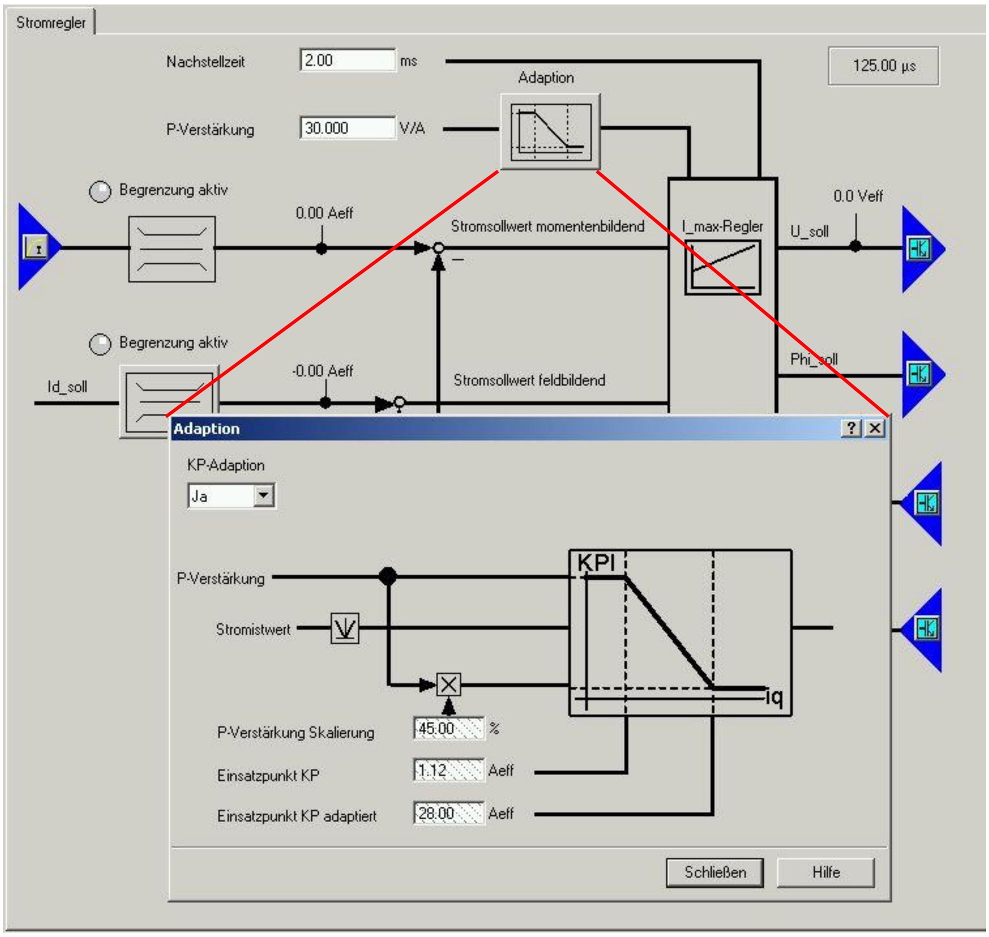
The current controller adaption is active per default. The DriveCliQ data sheet provides the correct settings.

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!

Figure 9-1 Current controller adaption window

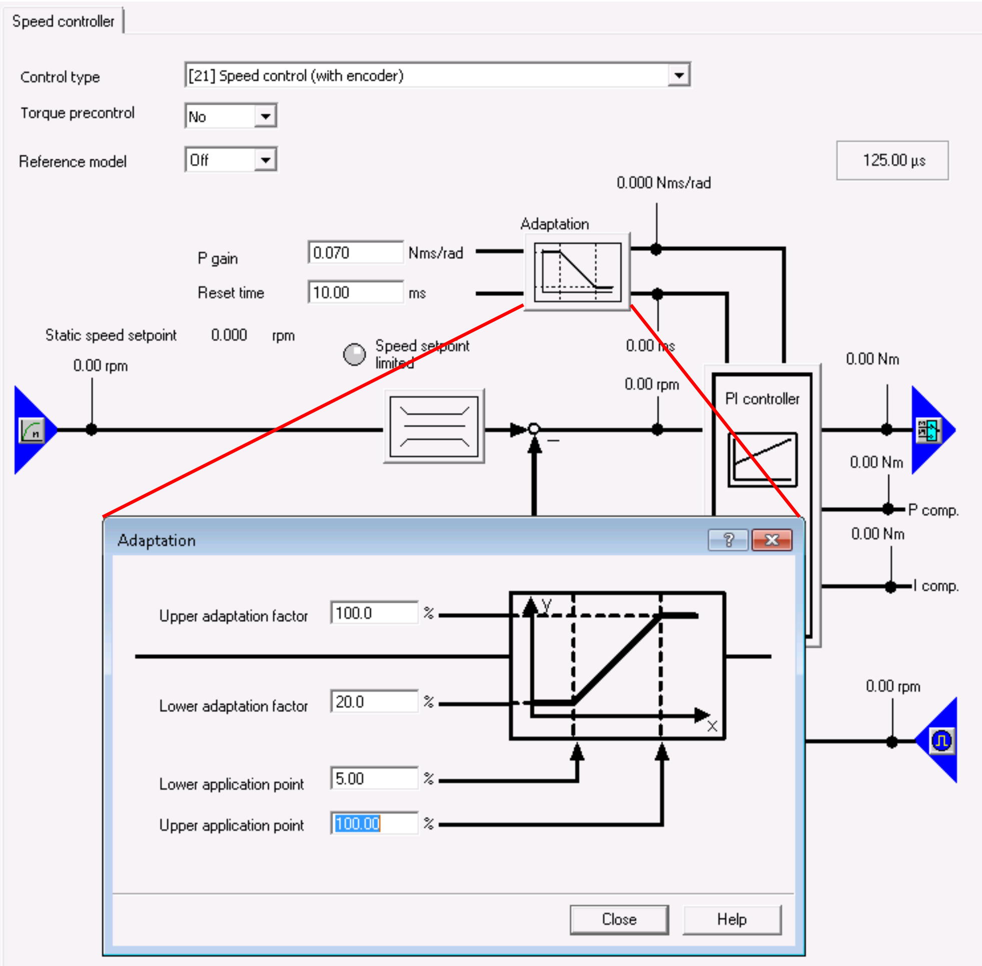


9.2 Speed controller adaption

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 Speed controller adaption window



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.

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

Adaption during machine standstill

The new location of a resonance frequency (and thus filter frequency) which has changed due to a change of the load is being calculated after measuring the inertia. After that the filter will be changed using acyclic write command to the drive.

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

The most 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 Fuction Friction Characteristic

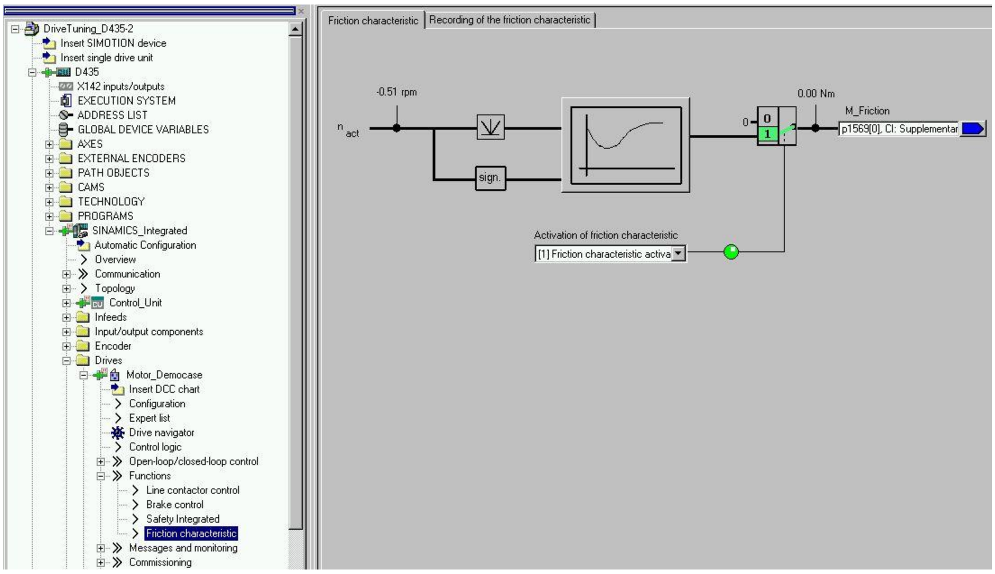
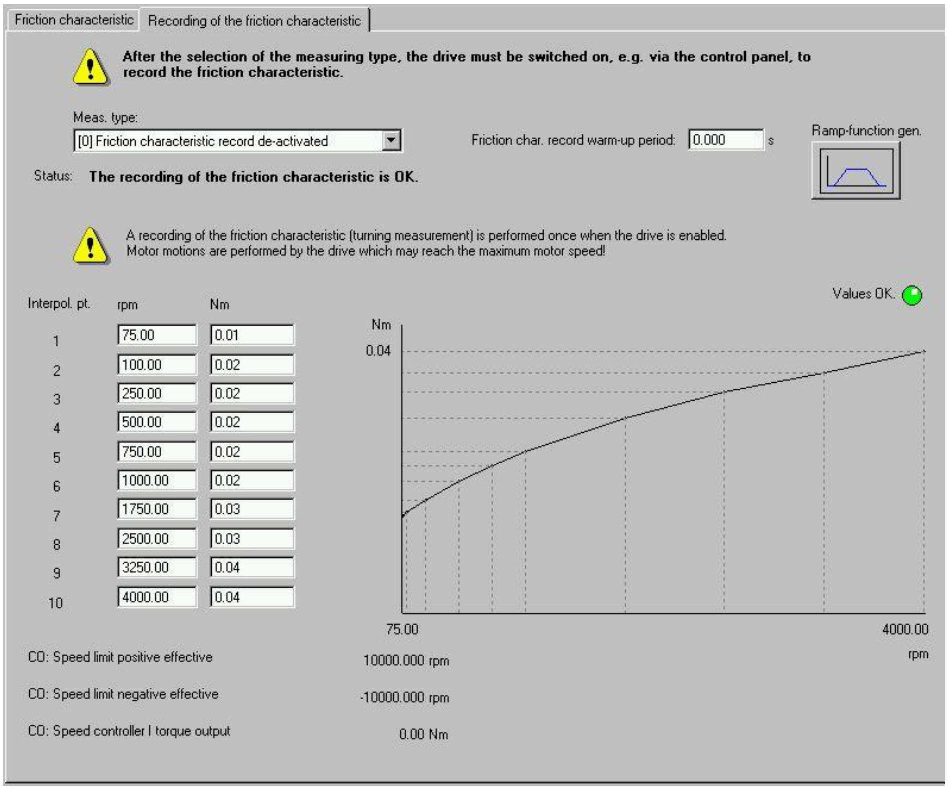


Figure 10-2 Friction characteristic recording



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.

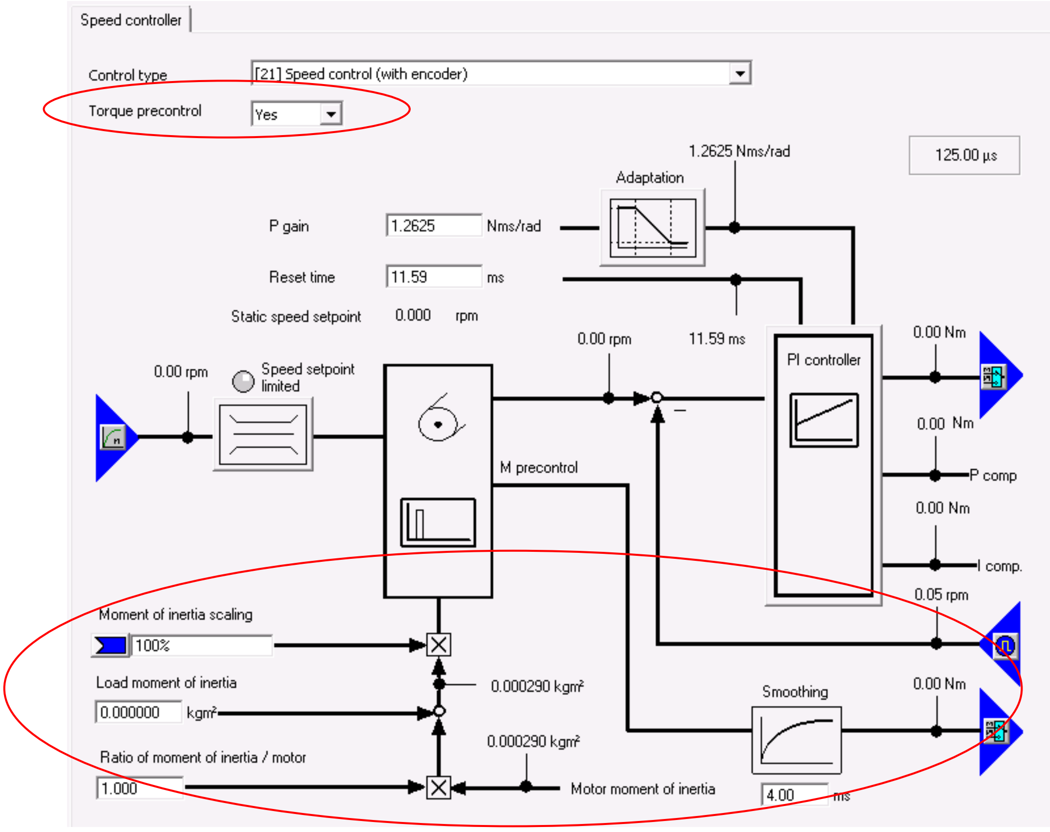
NOTE The acceleration between the speed levels is relatively high! Sensitive mechanic should be disconnected before the measurement.

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.

10.2 Acceleration torque

Figure 10-3 Acceleration torque pre-control in the drive



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.

In the screenshot shown above, the torque pre-control in the drive sincludes the position controller output in the torque feedforward calculation. Usually this is not intended.

10.3 DSC Spline

An advanced form of torque pre-control using SIMOTION is DSC with Spline.

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:

- Linear fine interpolation and pre-control of the torque
- Extended support for highly dynamic motions
- Process response is determined by the lower current controller equivalent time

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

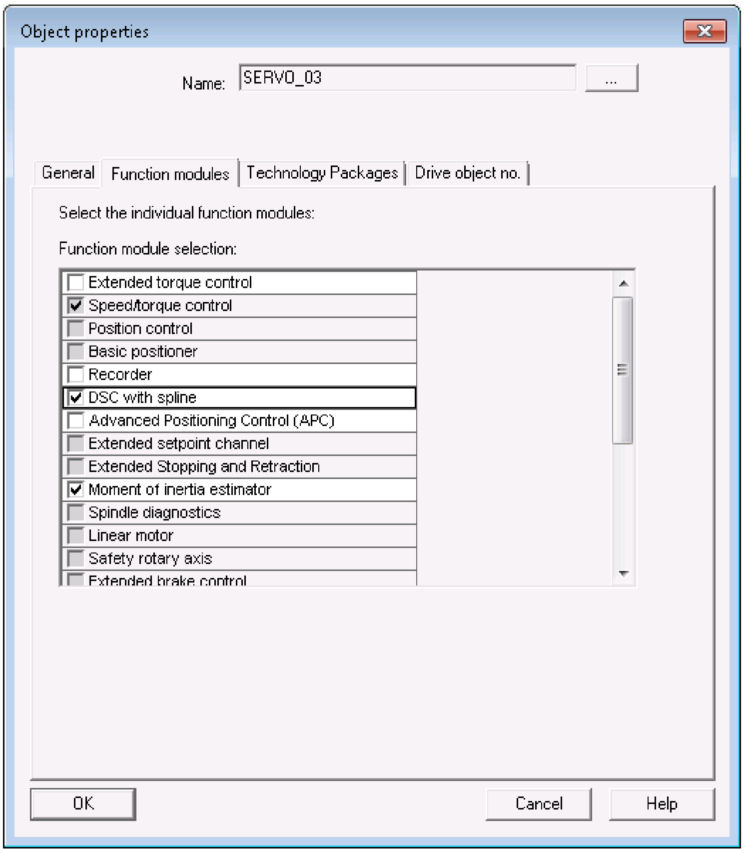
- Telegrams 125 and 126 must be supported by the drive
- Consistent setpoints

  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)

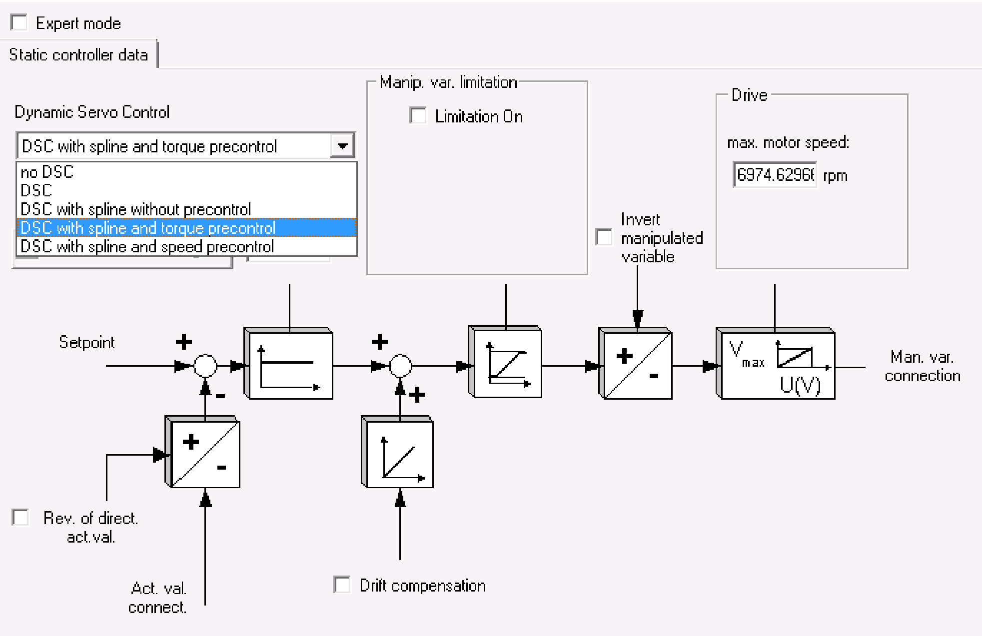
To use DSC Spline, the function module "DSC with Spline" must be activate in the drive.

Figure 10-4 Activation of the Spline function module in the drive



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

Figure 10-5 Activation Spline pre-control in the axis



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.

<u>Additional required settings:</u>

- 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 variable. The motor moves to compensate for 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.

Irrespective of the method used, any mechanical oscillation must be able to be measured

using the measuring system assigned to the particular axis. This is the reason that the

following methods are available when using APC.

1. APC is set just using motor variables (motor encoder, current).
2. APC is deployed together with a direct measuring system.
3. APC is deployed 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

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.

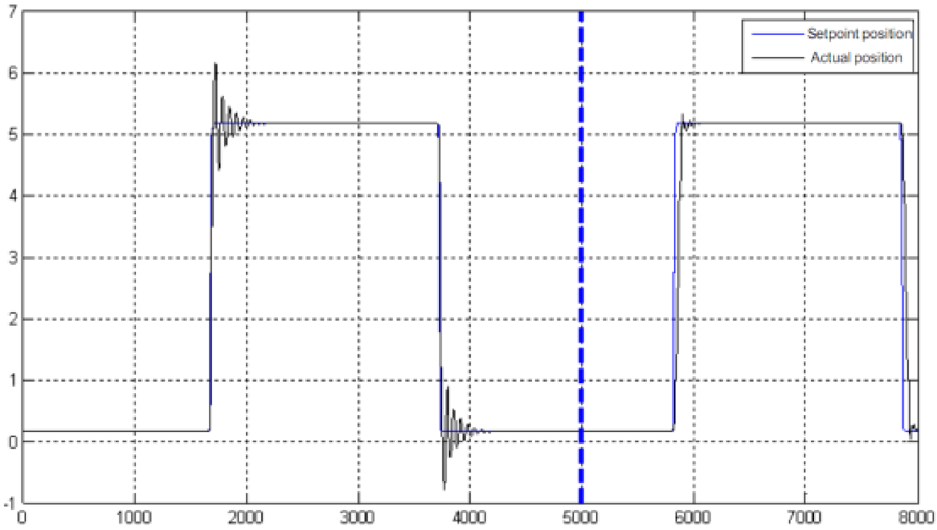
This leads to a vibrationless positioning, less stress on the material, noticeable improvement in smoothness and finally to trouble-free operation and higher machine cycle rates.

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 10-6 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

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

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

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 (e.g. delta-picker)

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 dynamics axes through a PT2 filter.

Axes coupled through fix mechanic

Motors which are driving one mechanic together (e.g. gantry, delta picker, …) 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 16.3 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).

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).

NOTE The handling toolbox provides a library which uses dynamic models of the different kinematics for calculation of necessary torques to drive a defined path. Following, the calculated torque is used for pre-control in the control loop. In this way the workload of the speed control loop command response can be reduced.

For detailed information see chapter 10.7 Further pre-control types

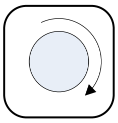
12 Torque motors

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.

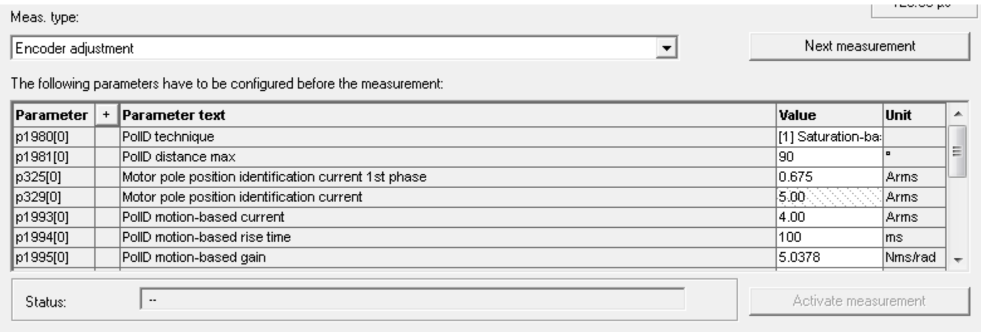
NOTE Always invert (or do not invert) p410.0 and p410.1 together. Both parameters should have the same value!

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 "Commissioning" > "stationary/turning measurement". Choose "encoder adjustment" as measuring type:

Figure 12-1



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

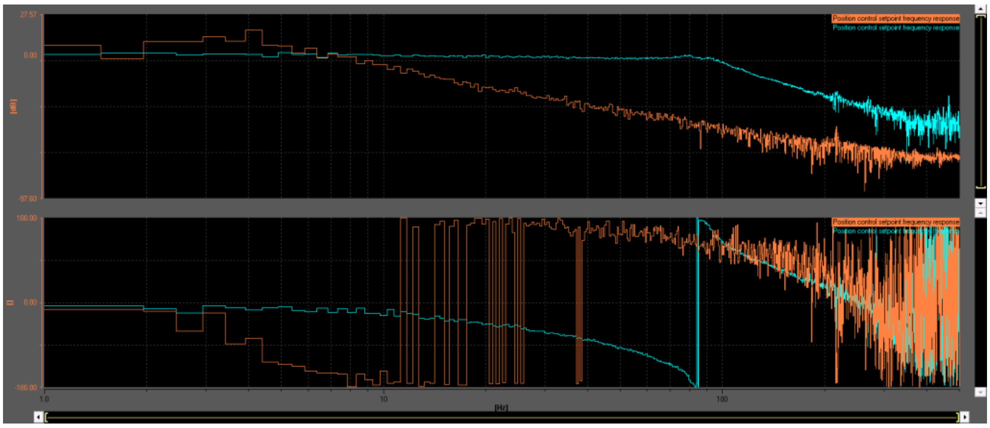
Due to the high stiffness and small damping, it can be necessary to reduce the measuring amplitude. This is especially necessary, if the gain factor is very high due to high load inertia.

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.

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



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 & Automatic Servo Tuning with S120

13.1 One-Button-Tuning (OBT)

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.

This is a drive-internal function. Therefore, no external engineering tool is required. OBT can be started via drive parameter in the expert list using an engineering system or writing the respective parameter via acyclic write commands during program runtime. For instance, with a button on a user HMI.

OBT can be selected with the parameter p5300 and will be executed with the next enable of the drive.

<u>OBT configuration:</u>

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!**

<u>Traversing distance:</u>

The maximum traversing distance during the measurement can be limited using the parameter p5308.

<u>Dynamic factor:</u>

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

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

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

NOTE Due to several advantages the OBT is preferred compared to Automatic Servo Tuning!

13.2 Automatic Servo Tuning

The Automatic Servo Tuning is available for S120 drives in STARTER/SCOUT as well as in TIA Portal/Startdrive.

Speed controller

In SCOUT/STARTER, press the button  to start the automatic controller setting. In TIA Portal/Startdrive go to the window "Commissioning" -> "Automatic Servo Tuning".

Features of the automatic controller setting:

- System identification using FFT analysis
- Automatic setting of current setpoint filters, e.g. for damping resonances
- Automatic setting of the controller (gain factor Kp, integral time Tn)

Attention	**The automatic controller stetting sets current setpoint filters with endless notch depth. In this way the phase tilt is much bigger compared to a finite notch depth of manual tuning.**

Note	To improve the result of the automatic controller setting fit the notch depth to a proper (endless) value.

Position controller

Just as automatic controller setting of the speed controller, there is the possibility to optimize the position controller automatically.

To start the automatic controller setting in SCOUT, press the button


in the closed-loop control menu of a specific axis.

In TIA Portal go to TO menu "commissioning" -> "Tuning".

Attention	**Only the proportional gain factor Kv will be optimized!** **Speed pre-control and balancing are not set.**

14 Optimization in TIA Portal/Startdrive

There are no frequency-based measuring functions available in TIA Portal/Startdrive.

S120 drives can be optimized with Automatic Servo Tuning using the Startdrive wizards or with One-Button-Tuning.

For more details see chapter One Button Tuning & Automatic Servo Tuning with S120

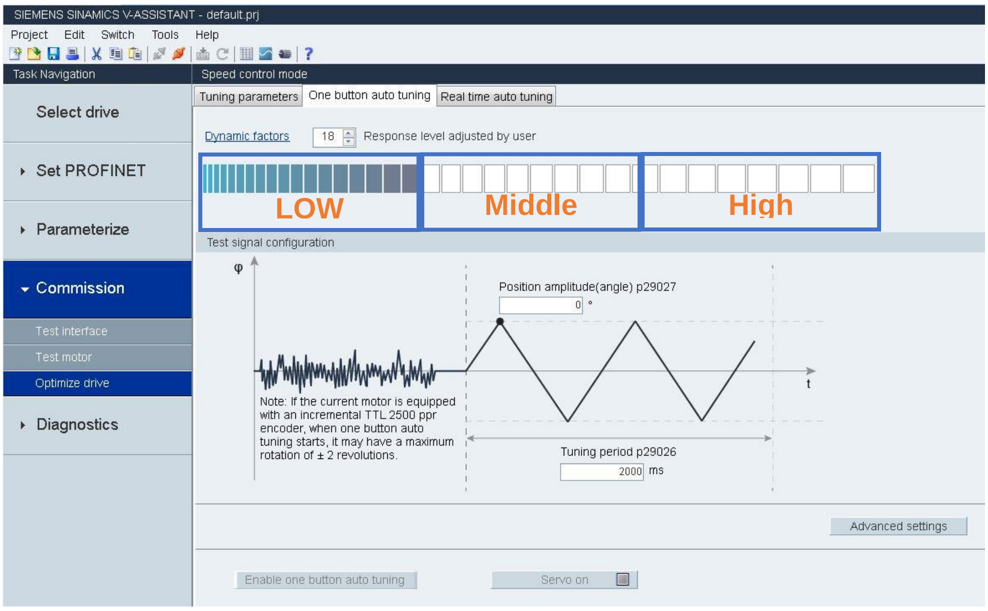
15 Optimization of other drives

15.1 V90

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

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

Figure 15-1 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.

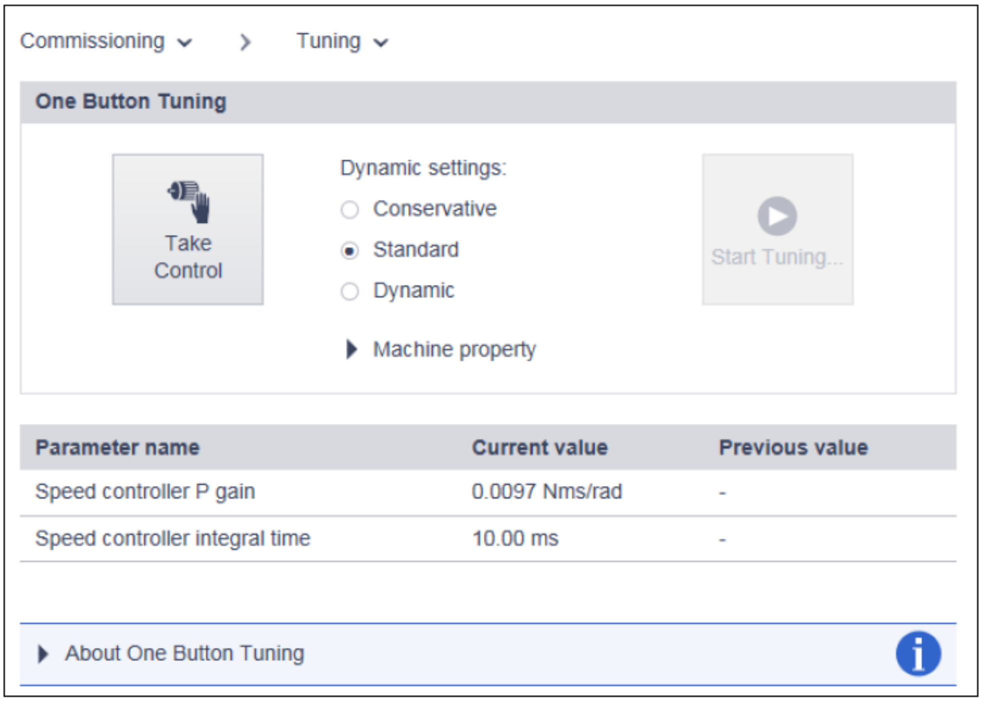
NOTE In the "Diagnostics" menu, the user can analyze the control loop using frequency responses like known from STARTER/SCOUT. A manual tuning is possible.

NOTE For detailed information see SINAMICS V90 PROFINET, SIMOTICS S-1FL6 Operating Instructions
https://support.industry.siemens.com/cs/ww/en/view/109757719

15.2 S210

S210 drives are being configured and optimized using the integrated web server.

Figure 15-2 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

https://support.industry.siemens.com/cs/ww/en/view/109760645

16 Further Optimization Methods

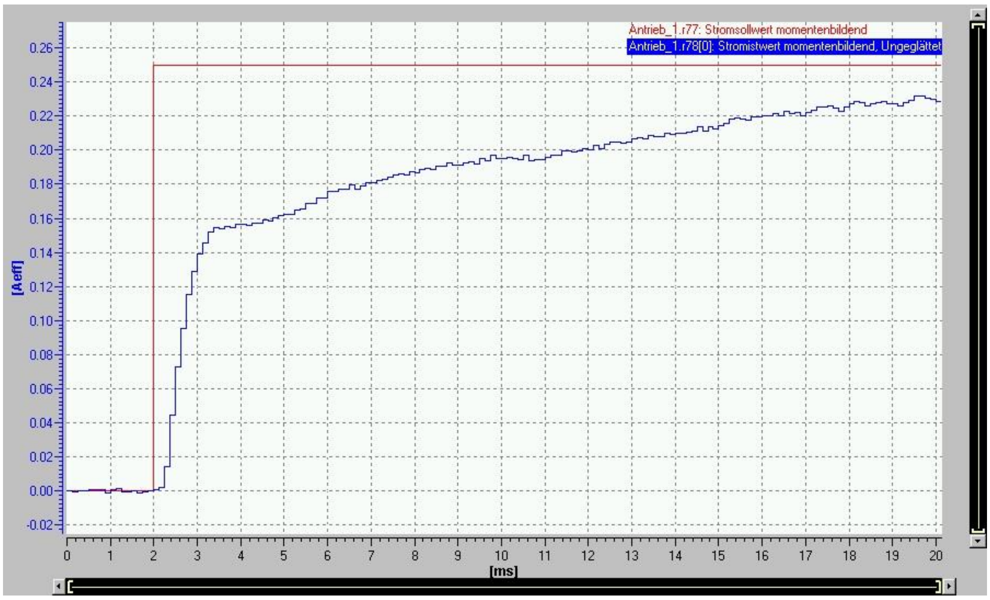
16.1 Current controller setpoint jump

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 which of these frequencies could later excite vibrations.

Measuring function: Current controller setpoint jump (after current setpoint filter)

Figure 16-1 current controller setpoint jump



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!**

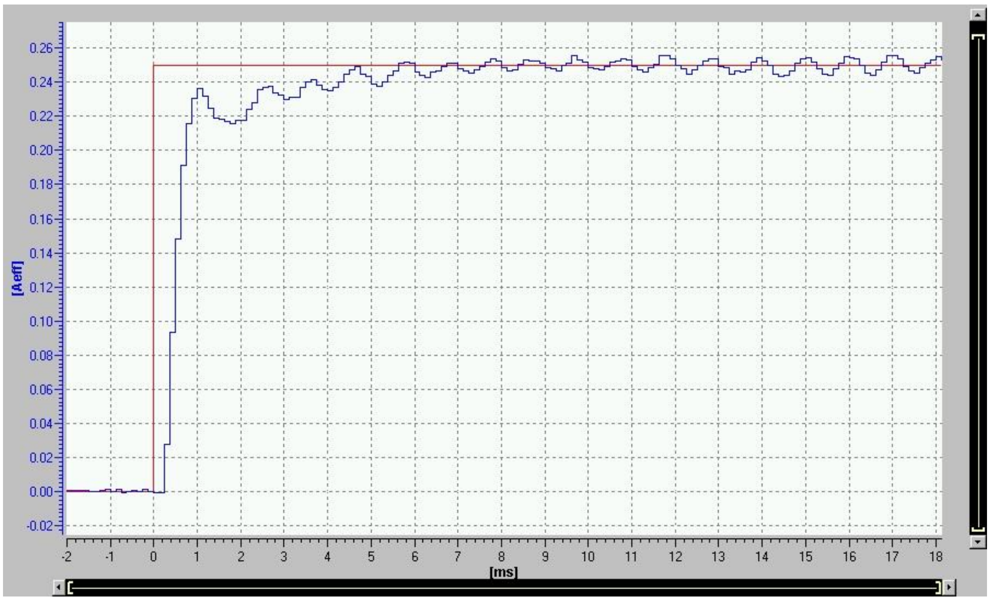
Figure 16-2 current controller setpoint jump

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.

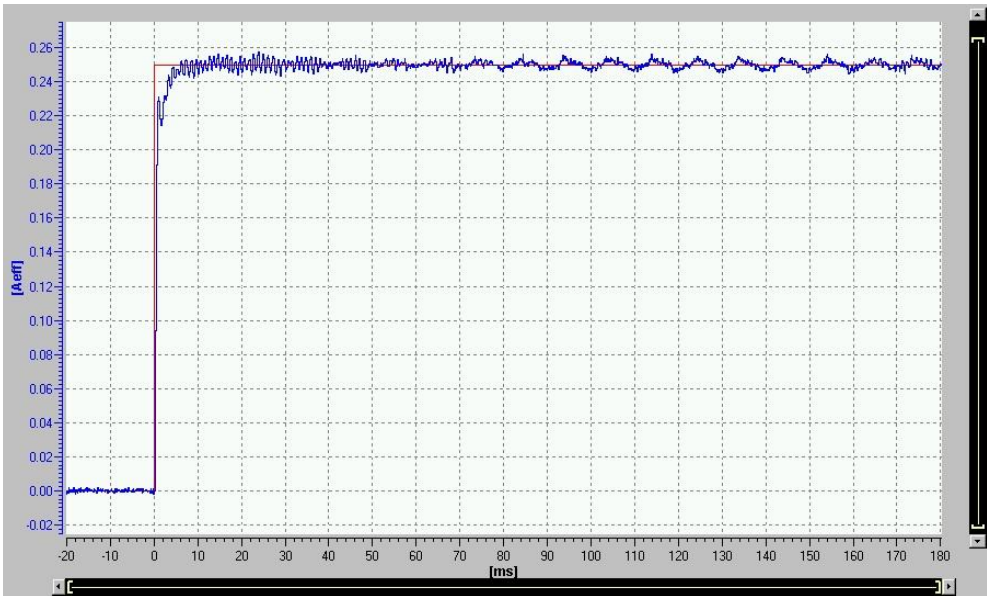
→ **reduce integral time**

Figure 16-3 current controller setpoint jump (Measuring time: 10ms)



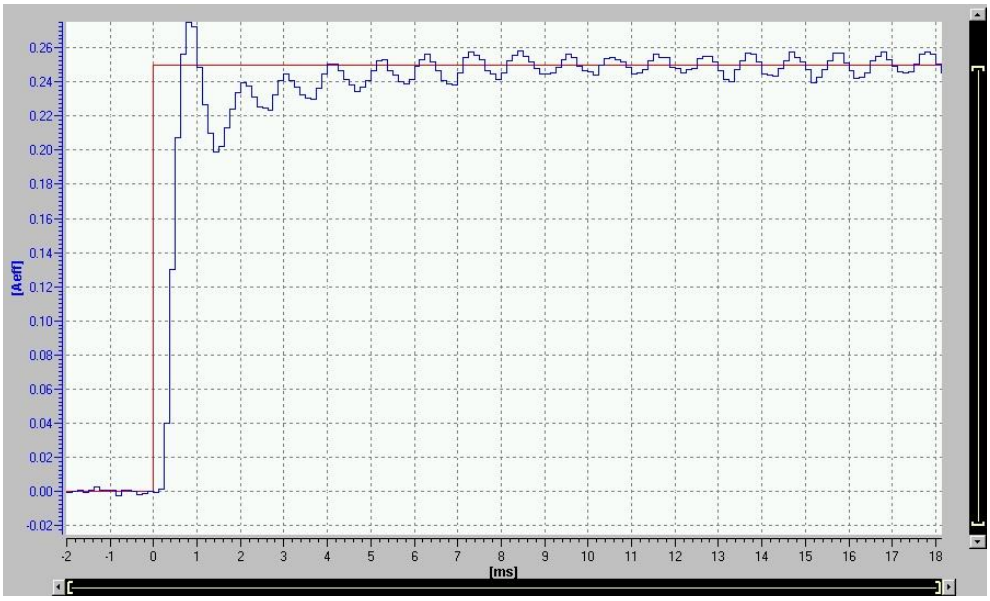
No more persistent system deviation.

Figure 16-4 measuring time: 100ms



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

Figure 16-5 current controller setpoint jump (measuring time: 10ms)



Attention	**Overshoot not bigger than 14%!**

Note	Current controller setpoint jump also can be used for Kp-adaption with third-party drives.

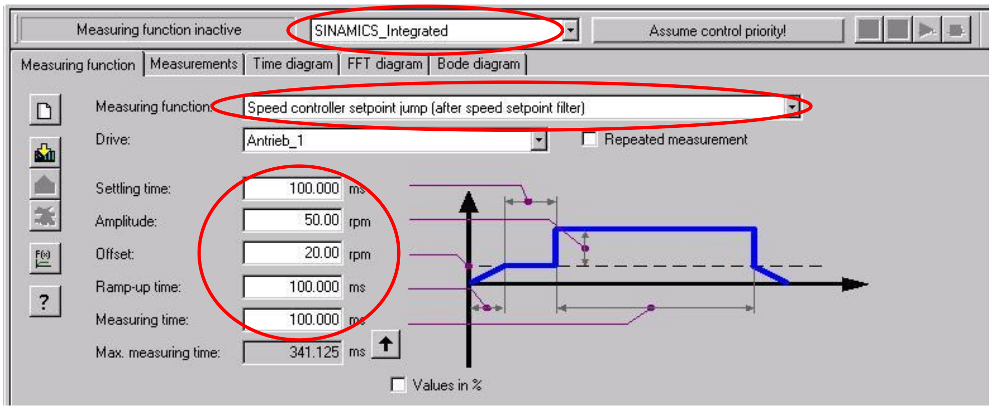
16.2 Speed controller setpoint jump

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 which of these frequencies could later excite vibrations.

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

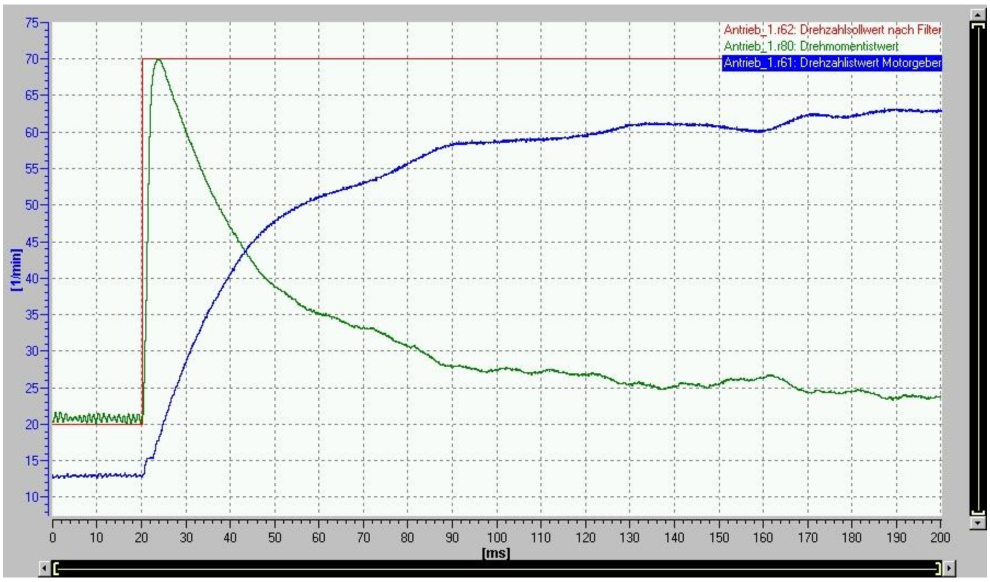
Figure 16-6 speed controller setpoint jump



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:

Figure 16-7 speed controller setpoint jump



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!**

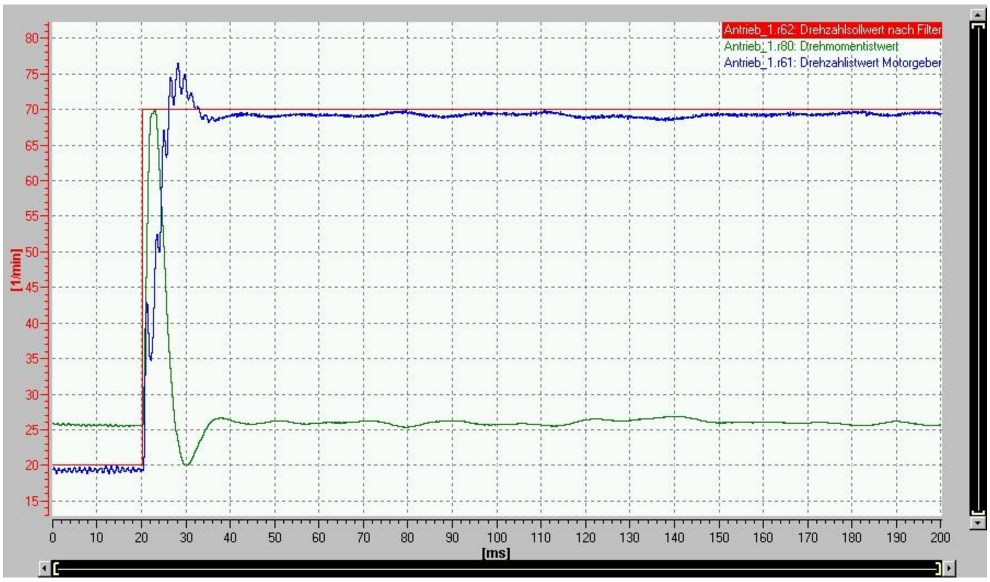
Tracing the torque actual value is not required mandatorily, however it should be noticed.

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

Figure 16-8 speed controller setpoint jump

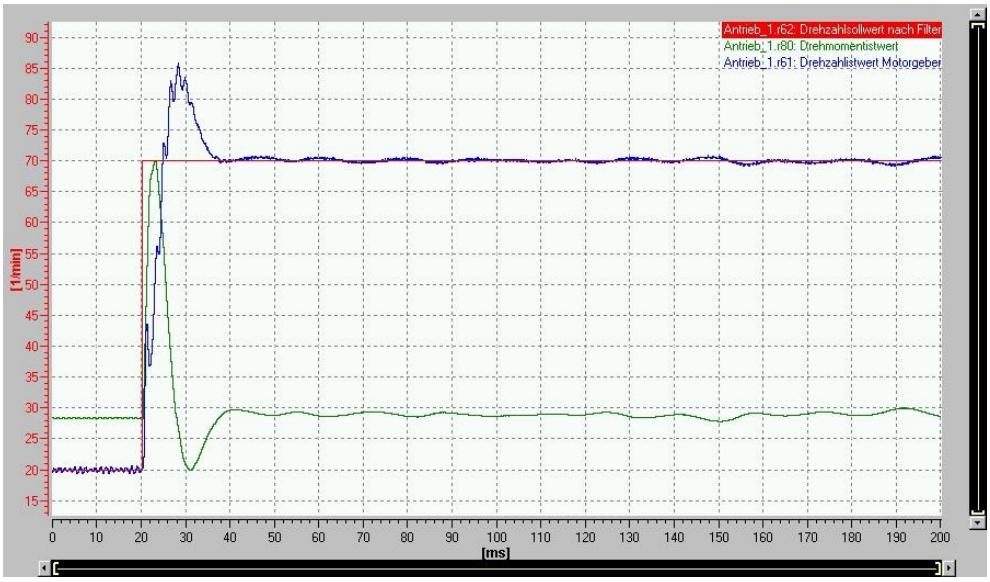


The result of raising Kp is a smaller system deviation and a quicker rise time.

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

→ **reduce integral time**

Figure 16-9 optimized speed controller

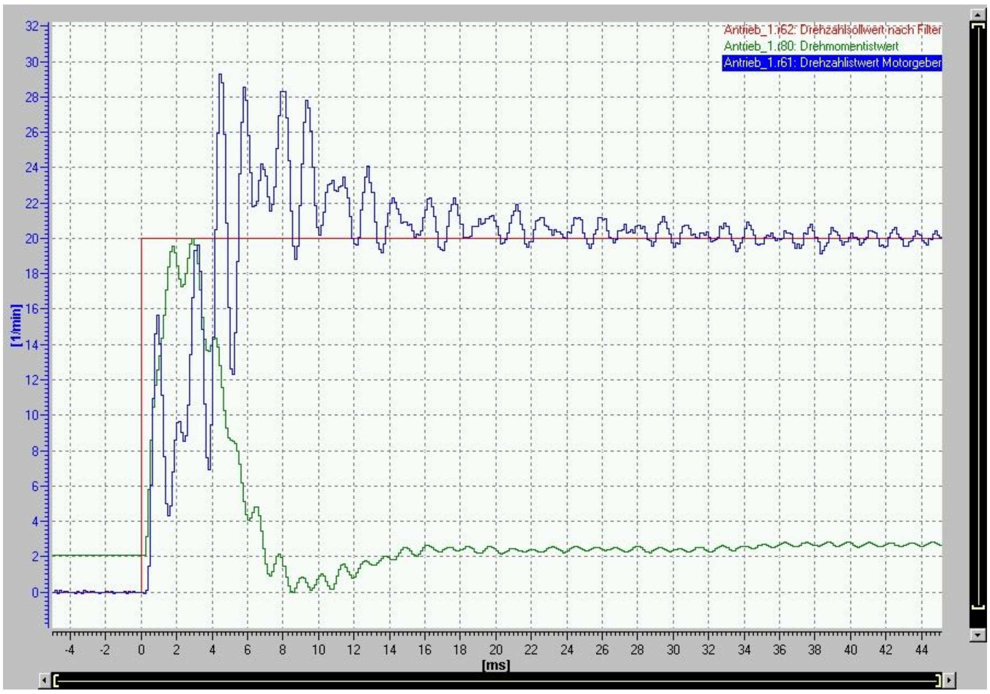


Symmetric optimum: One-time overshoot up to 43%

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

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

Figure 16-10 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!

16.3 Measuring functions during program runtime

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.

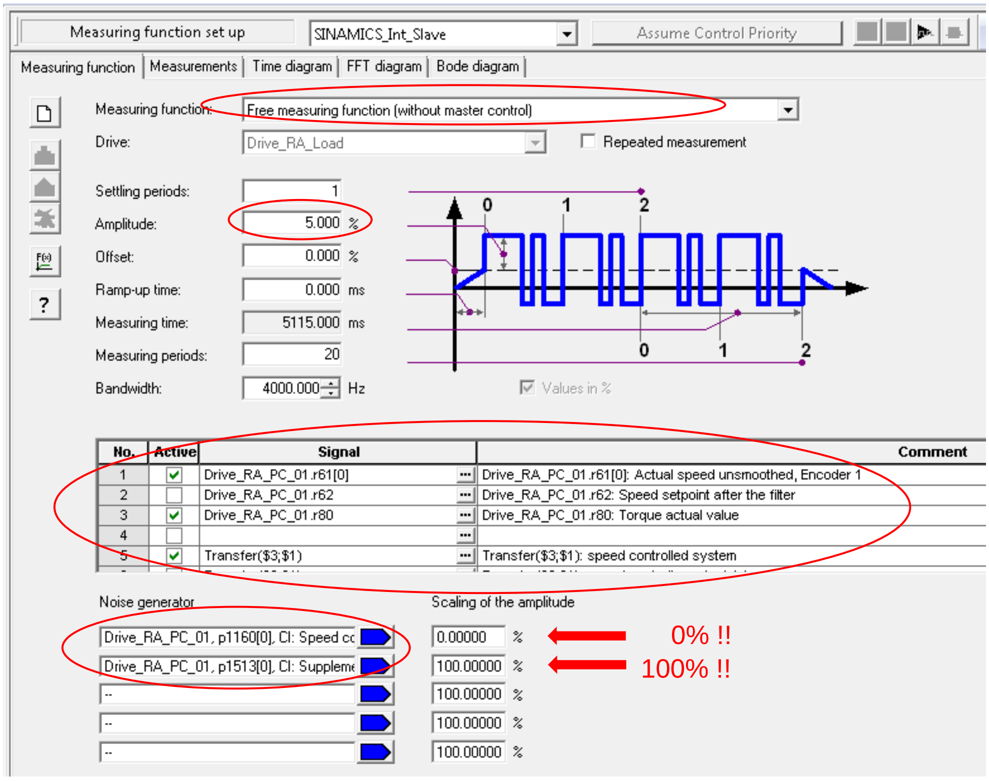
For example, another passive axis is in contact with the driven axis (e.g. printing cylinder and passive impression cylinder).

The following described measuring functions add a noise signal to the basic motion of a higher prior controller.

16.3.1 Speed Controlled System

The following settings must be made:

Figure 16-11 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"

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".

NOTE It is essential to ensure that the noise signal is applied to the additional torque input p1531.

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

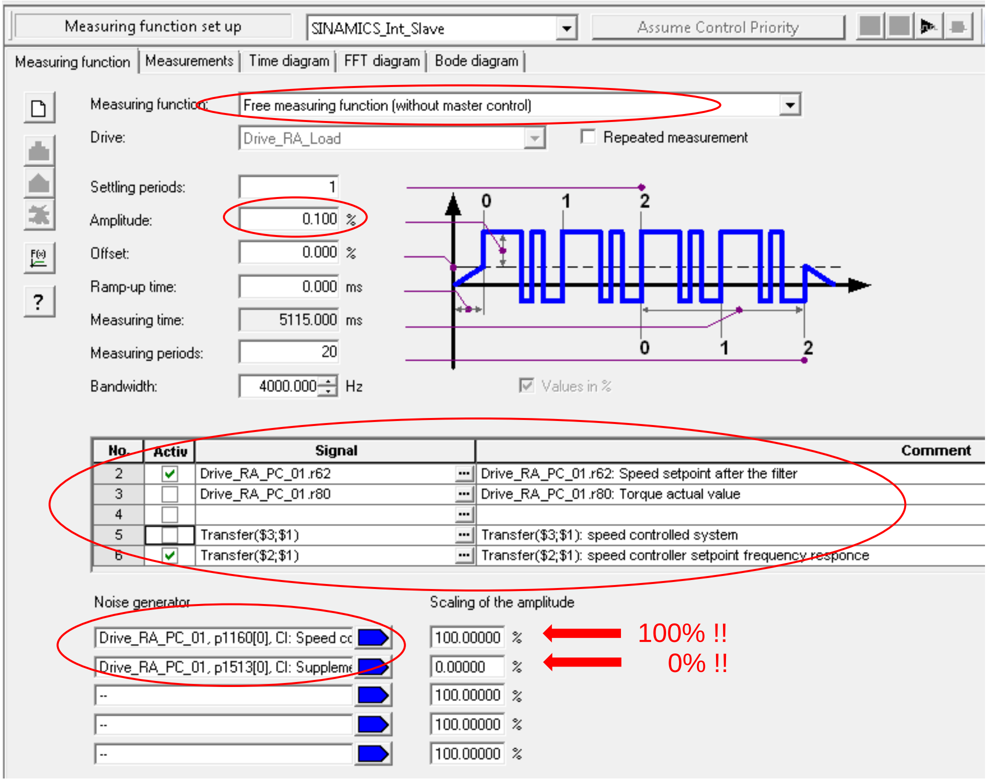
NOTE It is important to adjust the amplitude level to the frequency response to be measured. In particular, when the speed controller setpoint frequency response is recorded after the sped controlled system.

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

16.3.2 Speed Controller Setpoint Frequency Response

The following settings must be made:

Figure 16-12 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)

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 p1531 (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!

16.4 Inverse filtering of locked rotor frequency

Attention	**The following described methods should only be applied by experienced users!**

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.

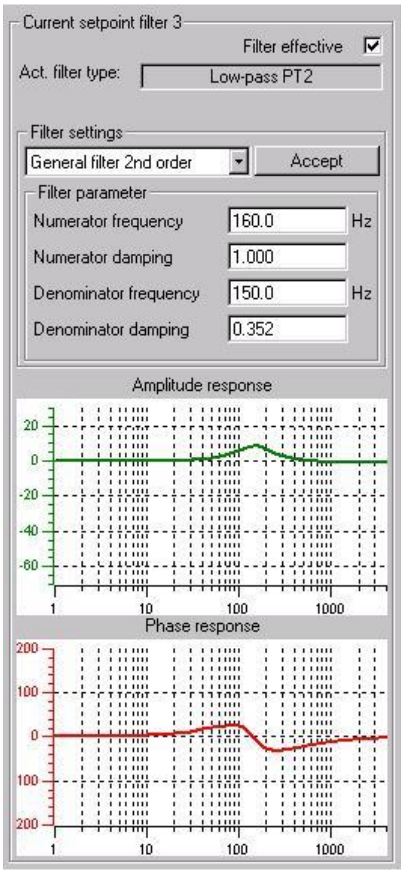
After setting these values, change the filter type to „General filter 2nd order".

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 16-13Filter settings



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

Proportional gain factor Kp = 1.0 for both measurements.

Figure 16-14 open control loop with filter (blue) and without filter (green)

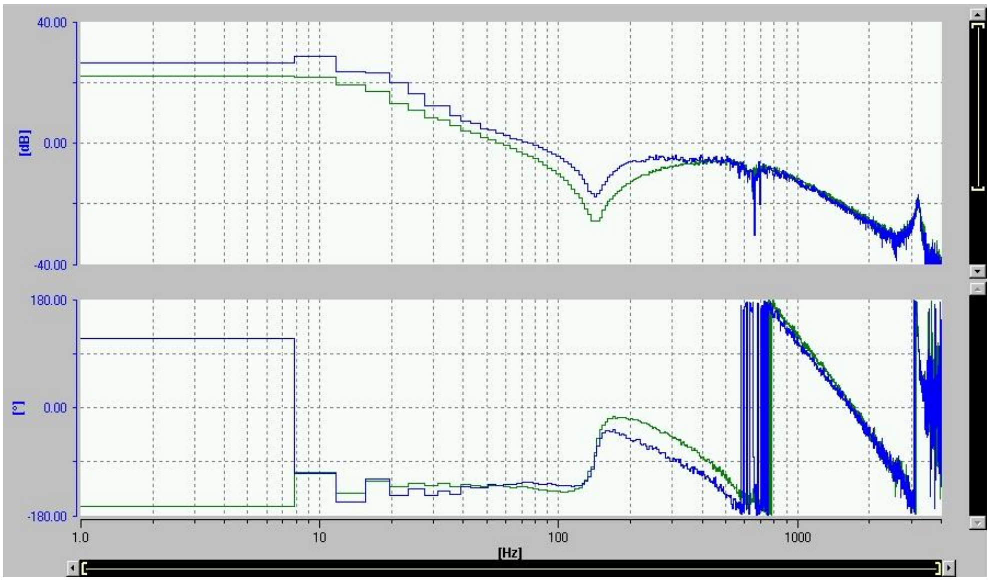
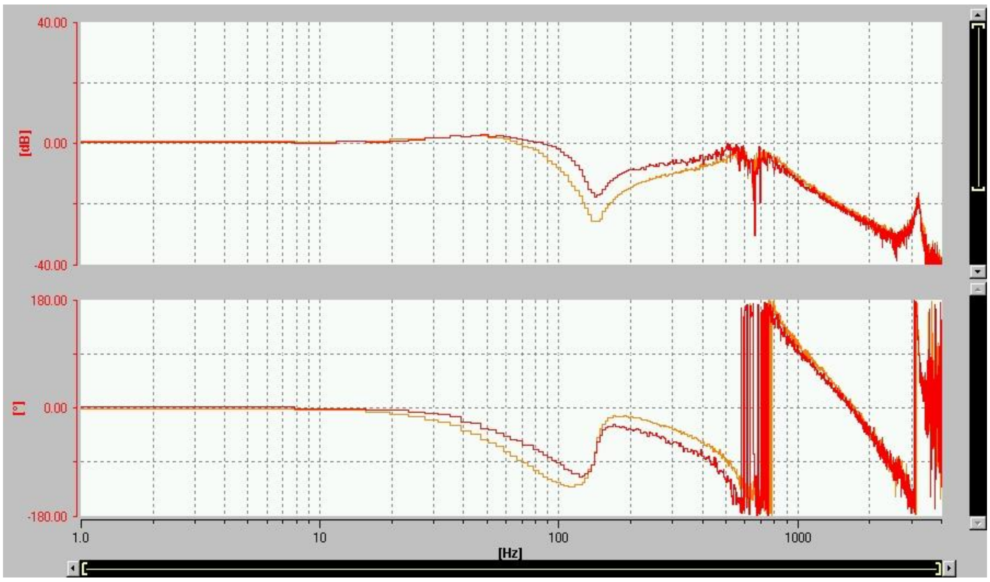


Figure 16-15 closed control loop with filter (red) and without filter (orange)



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

Furthermore, the controller bandwidth could be increased (in this case ca. 30%).

→ The control loop is more dynamic.

16.5 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 16-16) 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.

Figure 16-16 Open speed control loop

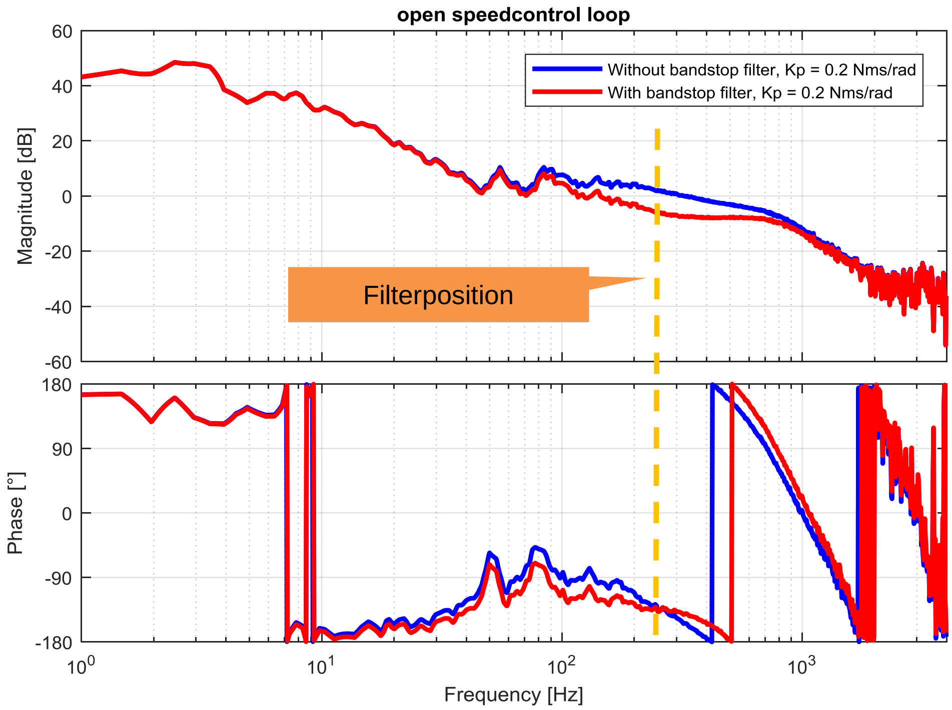
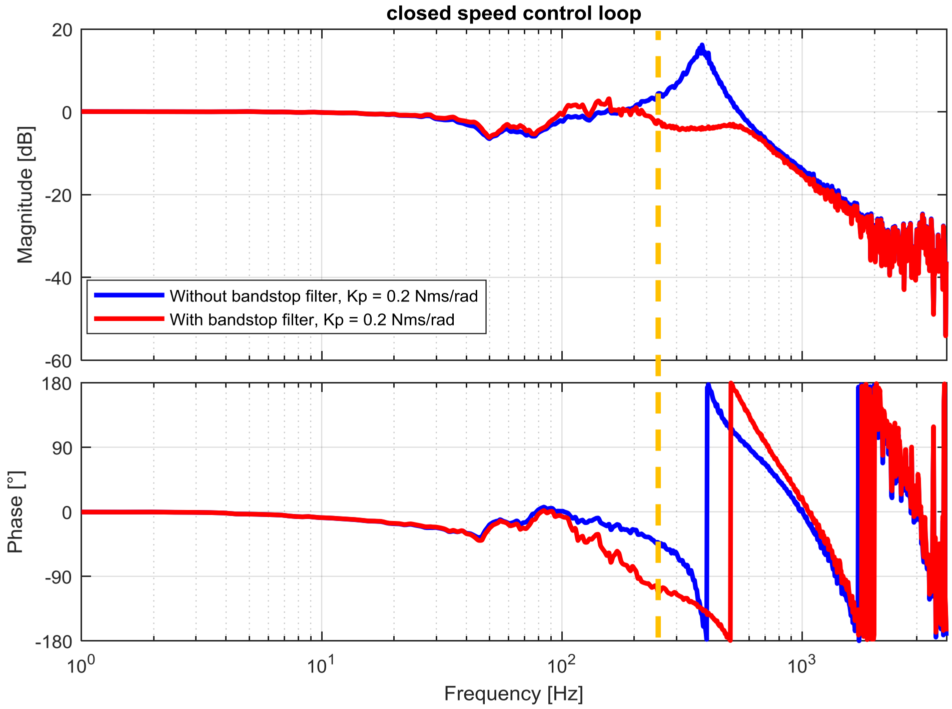


Figure 16-17 Closed speed control loop



16.6 PT1 Low-pass

The default current setpoint filter (low pass PT2) with 70% attenuation (0.7) can be used when many resonance frequencies need to be damped.

At a filter frequency of 200Hz for instance, the amplitude falls off with 40dB / decade starting from 200Hz. However, it has the disadvantage that it costs relatively much phase (the phase tilts to -180 °).

If this is too much, for example because the resonances are not so pronounced, you can also generate a PT1 low-pass filter by parameterization.

To obtain the same filter frequency with a PT1, the characteristic frequency must be set to 2000Hz and the damping to 500% (5).

With this parameterization, the phase also falls off starting from 200Hz, but only with 20dB / decade. The phase only rotates to -90 °.

17 Appendix

17.1 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

SITRAIN – Training for Industry

With our globally available training courses for our products and solutions, we help you achieve with practical experience, innovative learning methods and a concept that's tailored to the customer's specific needs.

For more information on our offered trainings and courses, as well as their locations and dates, refer to:
www.siemens.com/sitrain

Service offer

Our range of services includes the following:

- 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

17.2 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

17.3 Links and literature

Table 17-1

	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

17.4 Change documentation

Table 17-2

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