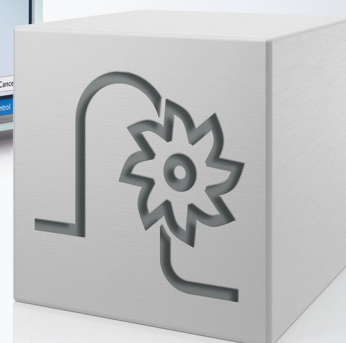
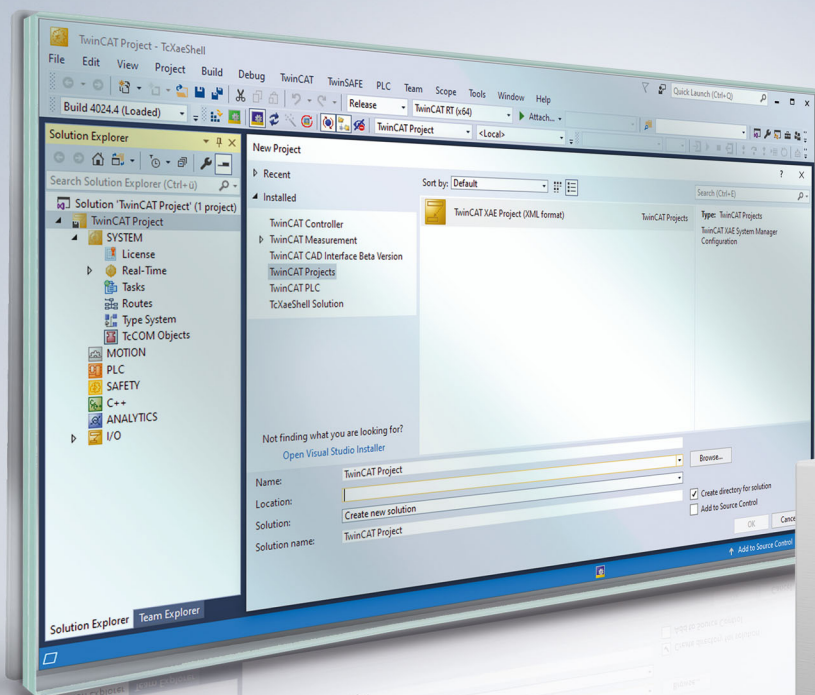


Functional description | EN

TF5200 | TwinCAT 3 CNC

FIR-Filter



Notes on the documentation

This description is only intended for the use of trained specialists in control and automation engineering who are familiar with the applicable national standards.

It is essential that the documentation and the following notes and explanations are followed when installing and commissioning the components.

It is the duty of the technical personnel to use the documentation published at the respective time of each installation and commissioning.

The responsible staff must ensure that the application or use of the products described satisfy all the requirements for safety, including all the relevant laws, regulations, guidelines and standards.

Disclaimer

The documentation has been prepared with care. The products described are, however, constantly under development.

We reserve the right to revise and change the documentation at any time and without prior announcement.

No claims for the modification of products that have already been supplied may be made on the basis of the data, diagrams and descriptions in this documentation.

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EP1590927, EP1789857, EP1456722, EP2137893, DE102015105702

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General and safety instructions

Icons used and their meanings

This documentation uses the following icons next to the safety instruction and the associated text. Please read the (safety) instructions carefully and comply with them at all times.

Icons in explanatory text

1. Indicates an action.

⇒ Indicates an action statement.

DANGER

Acute danger to life!

If you fail to comply with the safety instruction next to this icon, there is immediate danger to human life and health.

CAUTION

Personal injury and damage to machines!

If you fail to comply with the safety instruction next to this icon, it may result in personal injury or damage to machines.

NOTICE

Restriction or error

This icon describes restrictions or warns of errors.

Tips and other notes

This icon indicates information to assist in general understanding or to provide additional information.

General example

Example that clarifies the text.

NC programming example

Programming example (complete NC program or program sequence) of the described function or NC command.

Specific version information

Optional or restricted function. The availability of this function depends on the configuration and the scope of the version.

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1 Overview



This function is an additional option requiring a license.

Task

Machine vibrations can have a negative impact on the machining results of a machine tool.

The FIR filter function (Finite Impulse Response filter) achieves the following:

- Smooths setpoint curves at axis level.
- Reduces the excitation of machine vibrations.
- Is simple and reliable to use by specifying a maximum permitted tolerance.

Improves surface finish especially in free-form surface machining.



This function is available as of CNC Build V3.1.3075.02

Programming and parameterisation

The function can be parameterised and enabled

- both in the axis lists
- and in the #FILTER programming command in the NC program,

provided a filter type (P-AXIS-00586) is configured for the particular axis.

Mandatory note on references to other documents

For the sake of clarity, links to other documents and parameters are abbreviated, e.g. [PROG] for the Programming Manual or P-AXIS-00001 for an axis parameter.

For technical reasons, these links only function in the Online Help (HTML5, CHM) but not in pdf files since pdfs do not support cross-linking.

2 Description

FIR axis filters provide the user with the possibility of smoothing the axis setpoint curves for drives to minimise machine excitation.

Various filters are selectable as FIR axis filter:

- Moving average filter
- Gaussian filter
- Windowed sinc filter
- Time delay filter

Parameterisable filters are effective with:

- Linear axes.
- Rotary axes without modulo calculation, i.e. those that have a limited motion range (see P-AXIS-00015).
- Rotary axes with modulo handling, i.e. with endless rotation.



Only one filter per axis can be enabled at a time. A filter is only effective when a filter order > 0 and a filter type are assigned.

2.1 Operating principle

FIR filters (Finite Impulse Response filters) are discrete filters with an impulse response of finite length. These filters have the advantage that they are always stable and so cannot excite themselves to vibrate.

Precisely one of these axis filters can be enabled for each axis and then acts on the setpoint signal of that axis.

As shown in Figure [Step response of axis setpoint filter \[► 10\]](#), filters have a smoothing effect on the filtered signal (here: step response). Depending on the filter used, the signal curve or smoothing has a different characteristic. However, smoothing also causes a deviation from the original setpoint curve.

So, using a filter also entails a certain error or distortion in the axis affected. At corners and curvatures on a programmed contour, such an error may lead to contour deviations.

Refer to the subsection [Contour deviation \[► 15\]](#) for more information on deviations and how they can be limited.

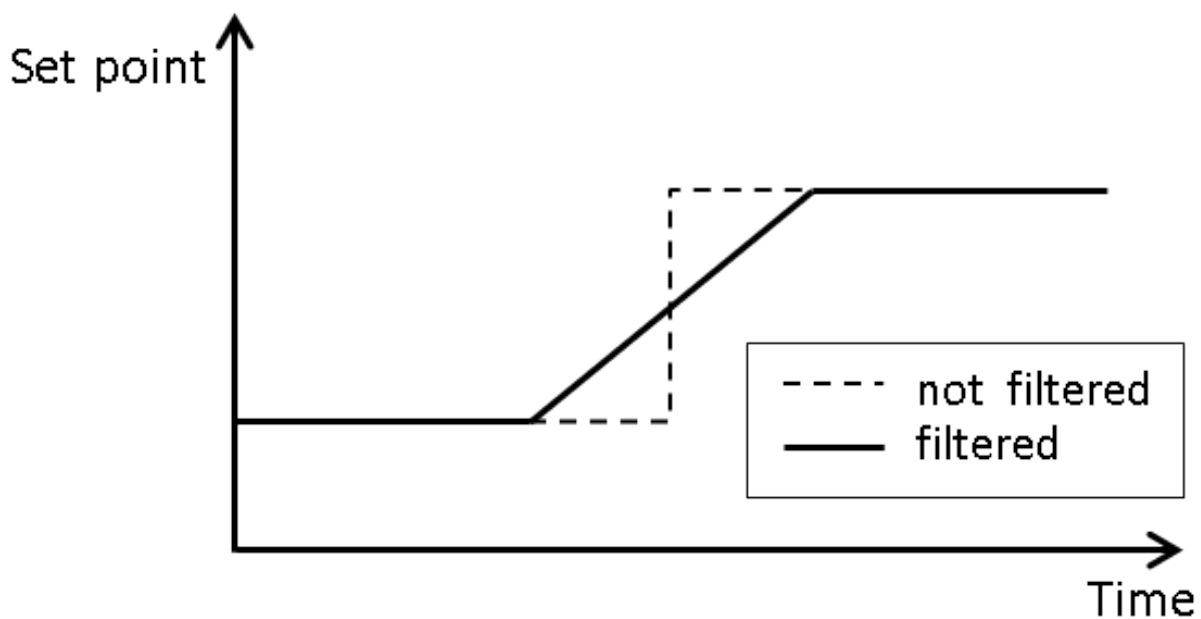


Fig. 1: Step response of axis setpoint filter



Using an axis setpoint filter leads to an axis error compared to the unfiltered setpoint signal

and this results in a contour deviation.

2.2 Filter types

2.2.1 Moving average filter

The FIR moving average filter is a symmetrical non-causal time series moving average filter. It acts like a low-pass filter within the frequency band: With a low-pass filter, all frequencies below a certain cut-off frequency pass through the filter. Higher frequencies above this cut-off frequency are attenuated or are not passed through at all. High frequencies are filtered out.

The degree of signal smoothing can be adjusted by specifying a filter order. The higher the order, the stronger the filter effect.

The filter core corresponds to a rectangle, see Fig. "Filter core of moving average filter" below. The resulting characteristic filter curve (step response) is depicted in Fig. "Step response of moving average filter".

The examples are calculated with order 40.

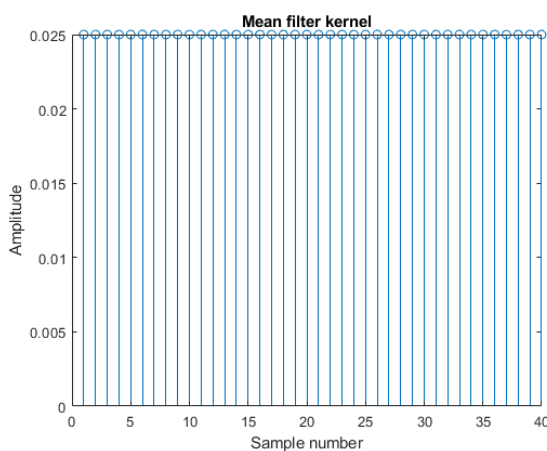


Fig. 2: Filter core of moving average filter

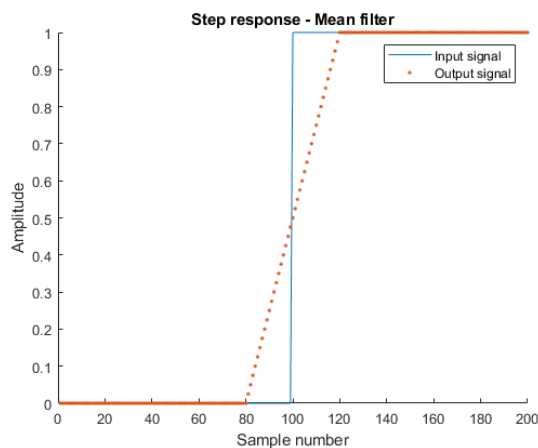


Fig. 3: Step response of moving average filter

2.2.2 Gaussian filter

A FIR Gaussian filter is a symmetrical non-causal time series moving average filter with a Gaussian curve instead of a rectangle as filter core. Like the moving average filter, it acts as a low-pass filter within the frequency band.

The degree of signal smoothing can be adjusted by specifying a filter order. The higher the order, the stronger the filter effect.

The filter core corresponds to a Gaussian curve, see Fig. "Filter core of Gaussian filter". The resulting characteristic filter curve (step response) is depicted in Fig. "Step response of Gaussian filter".

The examples are calculated with order 40.

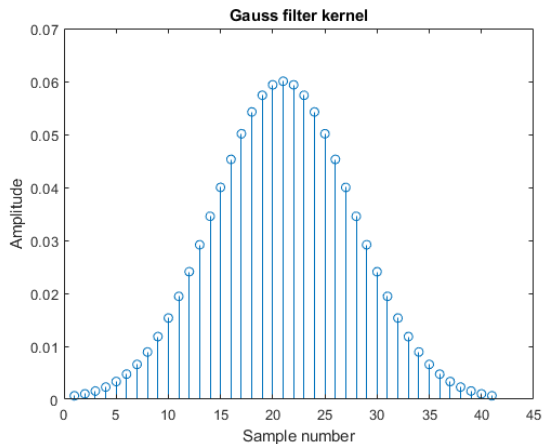


Fig. 4: Filter core of Gaussian filter

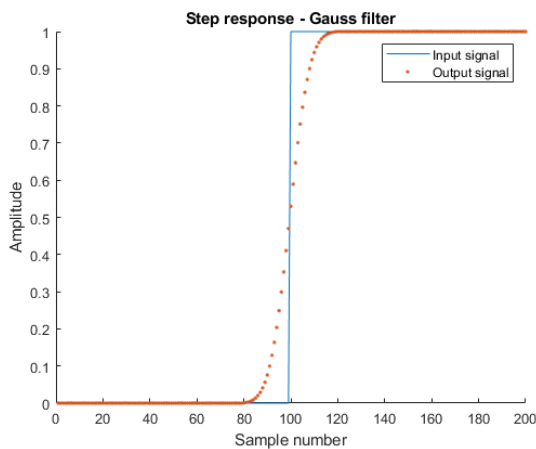


Fig. 5: Step response of Gaussian filter

2.2.3 Windowed sinc filter

The FIR windowed sinc filter is a symmetrical non-causal filter. It acts within the frequency band as an “ideal” low-pass filter.

The filter engagement frequency is specified in the frequency parameters. The degree of signal smoothing can be adjusted by specifying a filter order. The higher the order, the stronger the filter effect.

The filter core corresponds to a windowed sinc function, see Fig. “Filter core of windowed sinc filter”. The resulting characteristic filter curve (step response) is depicted in Fig. “Step response of windowed sinc filter”.

The examples are calculated with order 40 frequency 100 Hz.

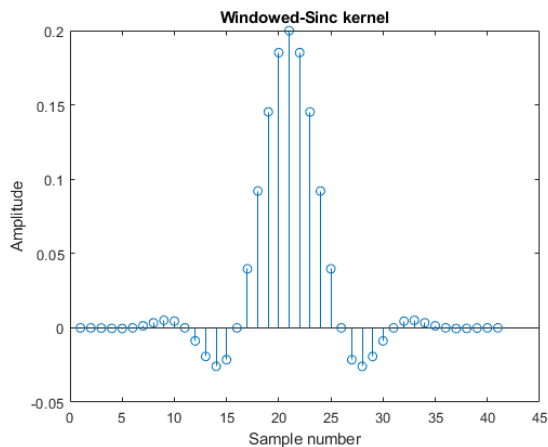


Fig. 6: Filter core of windowed sinc filter

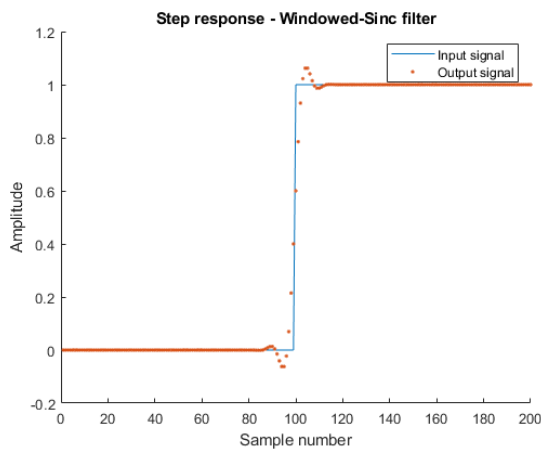


Fig. 7: Step response of windowed sinc filter

2.2.4 Time delay filter

A time delay filter delays signals in time without changing the signal curve. One application, for example, is to compensate for dead times in the drive train, if this is not identical in all axes.

The delay time can be configured in axes either in cycles in the parameter order (P-AXIS-00587) or in μs in the parameter order_time (P-AXIS-00591). Alternatively, it is also possible to program delay time in the NC program parameters ORDER or ORDER_TIME. The maximum number of possible delays is 100 cycles or $100 \cdot \text{NC cycle time in } \mu\text{s}$.

Another possible application is to synchronise axes when FIR filters are used.

If a FIR filter is used in only one axis and not in the other axes of an axis group, the axes will run asynchronously in time. To obtain synchronous axes despite this, time delay filters can be used in the other axes.

Time delay filter to synchronise axes

Axis with configured moving average filter:

```
filter_fir.enable      1
filter_fir.type        1 (moving average filter)
filter_fir.order       20
filter_fir.share       100
```

Required settings in other axes to obtain synchronous axes:

```
filter_fir.enable      1
filter_fir.type        4 (time delay filter)
filter_fir.order       10
filter_fir.share       100
```

The adjusting filter order of the time delay filter is obtained from half the filter order of the filter used:

$\text{filter_fir.order} / 2$

If the filter order is an odd number, the adjusting filter order of the time delay filter is obtained from:

$(\text{filter_fir.order} + 1) / 2$

2.3 Contour deviation

An axis error (see [Operating principle \[► 10\]](#)) always occurs when an axis filter acts on the axis setpoints of an axis and this leads to contour deviations. The tolerance monitoring function (see [Tolerance monitoring \[► 16\]](#)) can be used to monitor and limit axis errors caused by axis filters.

As opposed to conventional low-pass filters, it is possible with FIR axis filters to travel parallel paths in opposite directions and obtain a good workpiece surface at the same time.

In general, these deviations have no effect on motion control applications.

2.3.1 Estimation of contour deviation

Contour deviations caused by the use of FIR axis filters are influenced by 3 factors, provided identical filters are used in every axis of an axis group:

1. Cycle time
2. Filter order
3. Traverse feed rate

The following simple ratios apply:

- Double cycle time = double error
- Double feed rate = double error
- Double filter order = double error

The graphic below is generated for a cycle time of 1ms and an F1000 feed rate at a 90° corner using a moving average filter. With different marginal data, the filter orders must be updated according to the ratios above.

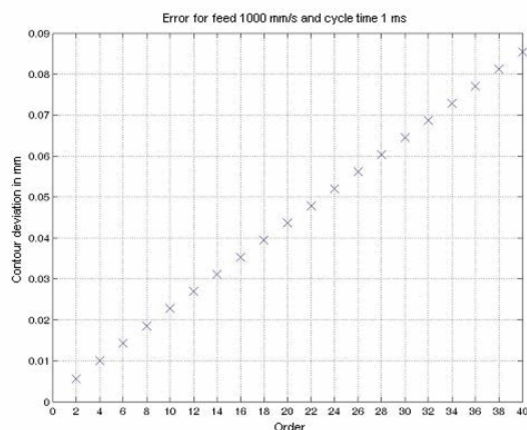


Fig. 8: Contour error per filter order at a 90° corner

2.3.2 Limiting axis errors and contour deviation

The following options are available to influence an axis error or contour deviation:

- Adapt the influencing factors (cycle time, feed rate, filter order) as described in [Estimation of contour deviation \[► 15\]](#).
- Adapt the filter parameters for all axes of an axis group (if settings are different).
- Activate tolerance monitoring (see [Tolerance monitoring \[► 16\]](#)).

2.3.2.1 Tolerance monitoring

Tolerance monitoring provides a simple and reliable method for handling filters.

The automatic monitoring of axis errors only intervenes if axis errors become excessive when axis filters are used.

The user must specify the maximum permitted tolerance in the NC program.

To depict the operating principle of tolerance monitoring, the figure below presents a comparison of contours of a motion “without filter” (blue curve top right), ‘with filter’ (red curve) and ‘with filter and tolerance monitoring’ (green curve in a corner of the program. The program of the example used here is a programming example taken from the Section [Programming \[► 21\]](#).

An moving average filter with an order of 40 is used as filter. The specified tolerance is 0.001mm.

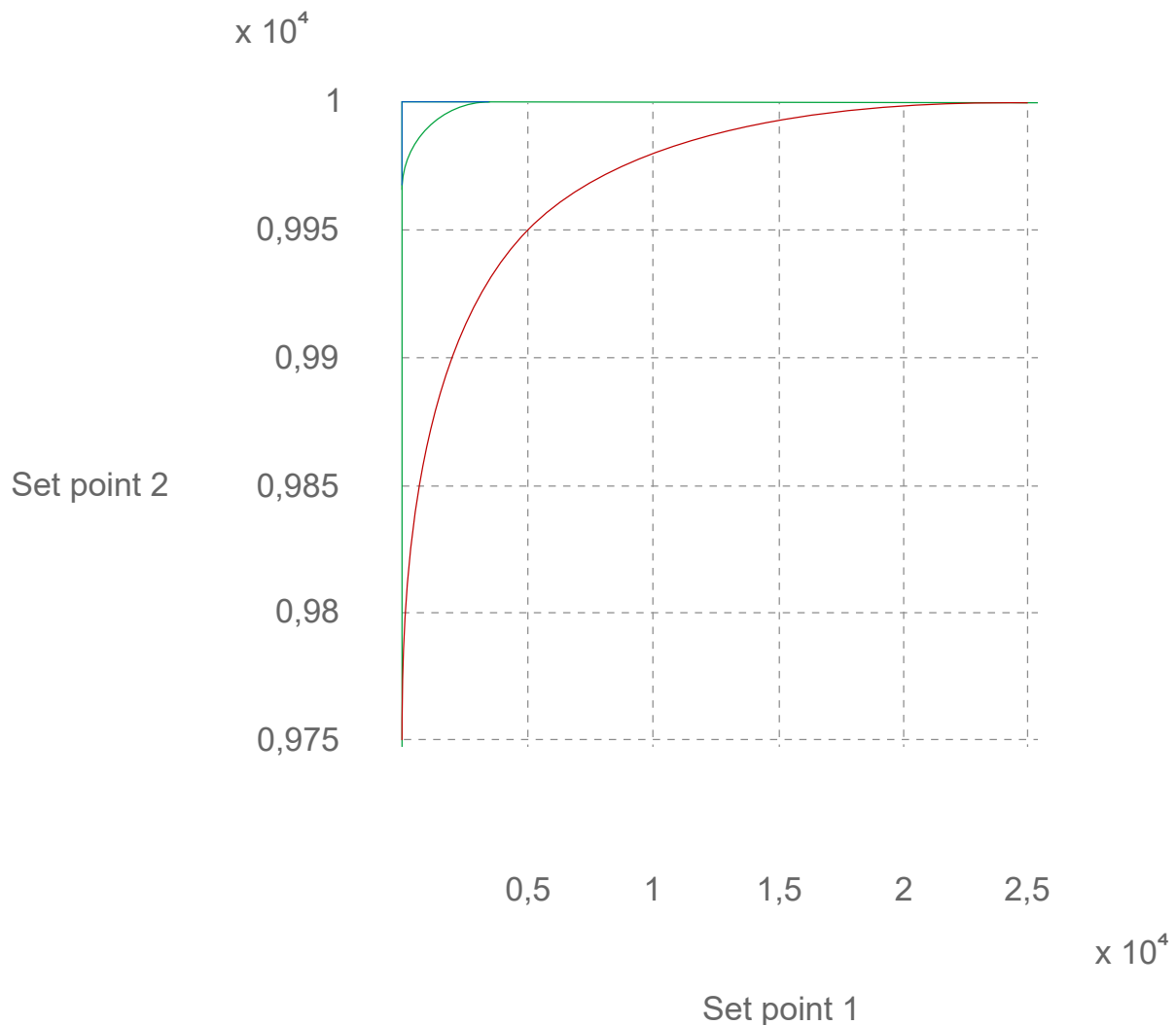


Fig. 9: Comparison with contour in corner for motion

Blue	without filter
Red	with filter
Green	with filter and tolerance monitoring

Functionally, an intervention by tolerance monitoring ensures that the path velocity is only reduced at the relevant points in the program ([Operating principle \[► 10\]](#)). Reducing path velocity is based here on the axis with the largest anticipated axis error in the particular situation. The velocity is reduced until the axis error no longer exceeds the tolerance limit. Moreover, it should also be ensured that the size of any reduction is only as small as required to limit the machining velocity of the program as little as possible. To depict the function of tolerance monitoring, the figure below shows the path velocity with (green curve) and without (red curve) tolerance monitoring. The ramps with reduced velocities caused by tolerance monitoring (green curve) are easily visible at the program corners.

The tolerance monitoring of FIR filters is intended to obtain the best possible balance between machining velocity and accuracy while at the same time minimising the excitation of the machine to vibrate.

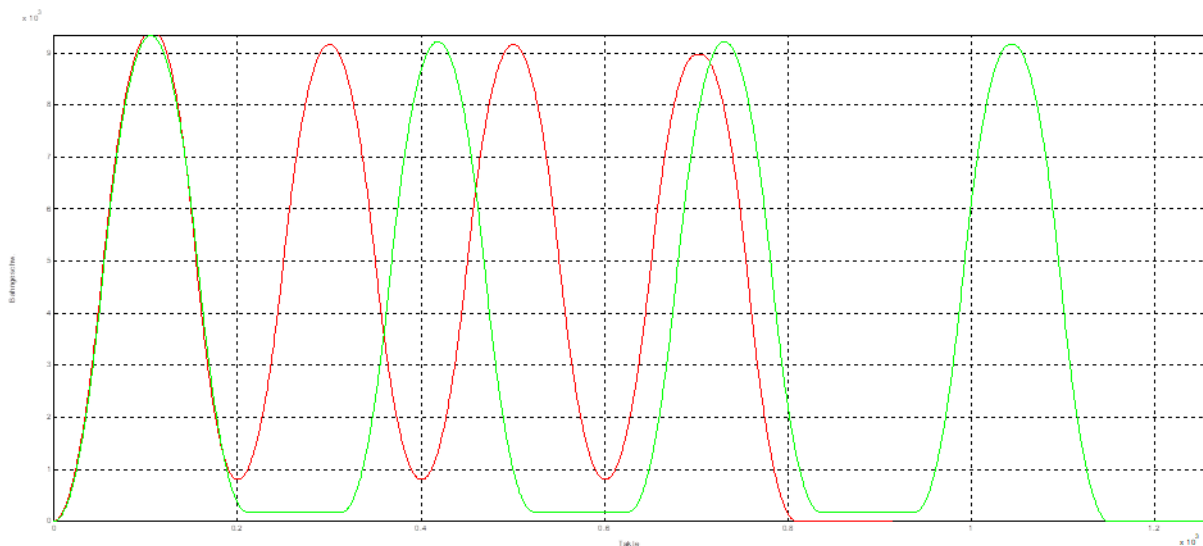


Fig. 10: Comparison of path velocity with (green) and without (red) tolerance monitoring

- i** Deviation or axis error and machining velocity have a uniform behaviour. Less deviation = lower machining velocity; more deviation = higher machining velocity. As a result, tolerance monitoring generally entails a longer machining time.
- i** Tolerance monitoring monitors the axis errors of all axes and not the contour deviation.
- i** Tolerance monitoring always monitors the current axis setpoint curve. This means that any path adaptations, for example an activated contouring mode, are also included in the filtered setpoint curves. The specified tolerance then always refers to the already modified setpoint curve, i.e. it is added.

Maximum contour deviation is dependent on the machine kinematics. Since tolerance monitoring only monitors the maximum error per axis, the contour error may vary. This results from interaction between the individual axes. As an example, this can be determined as follows for simple kinematics:

- Cartesian axes in 2D motion: $\text{max. contour deviation} = \text{tolerance} * \pm(\text{tolerance} * \sqrt{2})$
- Cartesian axes in 3D motion: $\text{max. contour deviation} = \text{tolerance} * \pm(\text{tolerance} * \sqrt{3})$

3 Enabling FIR filters

A condition for the use of this function is the correct parameterisation of axis-specific filter parameters. Parameter settings can be made in 2 ways:

- Axis-specific in the axis lists.
- Identically for all axes in the #FILTER command in the NC program.

i If the axes in an axis group are configured with different axis filters or filter parameters, this will result in an asynchronous axis behaviour. It is therefore recommended to always use the same configuration for the axis filters within an axis group.

Requirements for the use of filters:

- One filter type (P-AXIS-00586) must be configured in the given axis..
- The filter order must be specified with a value greater than 0; this can be assigned in
 - parameter P-AXIS-00587 or P-AXIS-00591 in the axis parameters or
 - in the NC program with `#FILTER [▶ 21][ORDER=.. or ORDER_TIME=..]`.

Time of enable

FIR axis filters can be enabled in 2 ways:

1. Program-specific and time-specific across all axes by NC programming.
2. Permanently and axis-specific in the axis lists.

A mixed form is also possible, for example the filters can have a permanent axis-specific preconfiguration in the axis lists and be flexibly enabled or disabled in the NC program.

4 Restrictions – special features

The [FIR filters \[► 9\]](#) and the Vibration Guard are different independent functions with similar objectives. Both functions smooth the axis setpoint signal to avoid exciting the machine to vibrations. FIR filters achieve this in the broadband. On the other hand, the Vibration Guard filters specific critical frequencies selectively.

NOTICE

It is only possible to use FIR filters and the Vibration Guard simultaneously under certain conditions.

The following combinations are **not** possible and will result in the output of an error message:

- Configuring an FIR filter in one axis and at the same time activating the Vibration Guard in the same axis.
- It is **not possible within an NC program** to program both [#FILTER \[► 21\]](#) and [#VIB GUARD](#) commands (Error ID 22060).
- If [#FILTER \[► 21\]](#) commands are used, the Vibration Guard may not be activated in the axis lists.
- If [#VIB GUARD](#) commands are used, no filter types may be configured in the axes.

It is permitted to use:

- **an FIR filter in one axis and the Vibration Guard in another axis** but only if activation takes place exclusively in the axis lists. In this case, neither [#FILTER](#) nor [#VIB GUARD](#) commands can be used.

Axis exchange commands

Axis exchange commands disable FIR filters.

Axis exchange commands disable FIR filters that may be enabled at that time. If the filters should remain enabled after axis exchange, they must be re-enabled by a corresponding [#FILTER \[► 21\]](#) command.

If the FIR filters were only enabled in the axis lists (P-AXIS-00573), the filters remain enabled even after axis exchange.

5 Programming

Syntax:

#FILTER [ON | OFF] [ORDER=.. ORDER_TIME=.. SHARE=.. AX_DEV=.. FCUT=.. ACC_FACT=.. QUALITY=..]

ON	Enable FIR filter.
OFF	Disable FIR filter.
ORDER=..	Specify filter order
ORDER_TIME=..	Specify filter order over time in [μs]
SHARE=..	Define the degree of effectiveness (analogous to P-AXIS-00590) of the filter in [%] value range 0 – 100 default value = 100
AX_DEV=..	Specify the tolerance for tolerance monitoring in [mm, inch *]. Default value = 0 (no tolerance monitoring). *with active P-CHAN-00439
FCUT=..	Specify the cut-off frequency (analogous to (P-AXIS-00585) of the filter in [Hz] default value = 30
ACC_FACT=..	Increase the path velocity at block transitions with FIR filter enabled. The greater the value setting, the less the velocity is reduced at the block transition. This requires a valid setting of P-AXIS-00013 (a_trans_weight) for the axes. Value range = 1.0 – 10.0 Default value =: 1.0
QUALITY=..	Specify the filter quality of the filter core curve value range: 0 < QUALITY <= 1 default value = 1.0 Parameter available as of V3.1.3075.04



The #FILTER ON/OFF command enables or disables all the FIR filters of the axes in the channel.

It is possible to use FIR filters on all axes. It is also possible to use different filters for each axis by axis-specific configuration in the axis lists.

FIR filters can be globally enabled or disabled and reparameterised across all axes in the NC program during machining (see [Programming example](#) [► 22]).



Tolerance monitoring can only be configured and activated in the NC program.

Tolerance monitoring is programmed by the parameter AX_DEV. It ensures that every axis remains within the specified tolerance [mm, inch].

Tolerance monitoring always monitors all axes and therefore can only be controlled globally in the NC program.

Tolerance monitoring is only active if AX_DEF was specified with a corresponding tolerance.

NC program with 90° corner

Program with a simple square contour. Traverse feed rate=4000mm/min, slope type=TRAPEZ (non-linear) and tolerance (AX_DEV)=0.001mm.

Setting in the axis lists:

- filter_fir.type 1
- filter_fir.order 40

The contour is traversed 3 times:

1. first with filter and tolerance monitoring
2. only with filter
3. finally as reference without filter enabled.

```
N010 G00 G90 X0 Y0 Z0
N020 #SLOPE [TYPE=TRAPEZ]
(Contour with filter and tolerance monitoring)
N030 #FILTER ON [AX_DEV=0.001]
N040 G01 X0 Y1 F4000
N050 G01 X1 Y1
N060 G01 X1 Y0
N070 G01 X0 Y0
(Contour only with filter)
N080 #FILTER ON
N090 G01 X0 Y1 F4000
N100 G01 X1 Y1
N110 G01 X1 Y0
N120 G01 X0 Y0
(Contour without filter or tolerance monitoring)
N130 #FILTER OFF
N140 G01 X0 Y1 F4000
N150 G01 X1 Y1
N160 G01 X1 Y0
N170 G01 X0 Y0
N180 M30
```

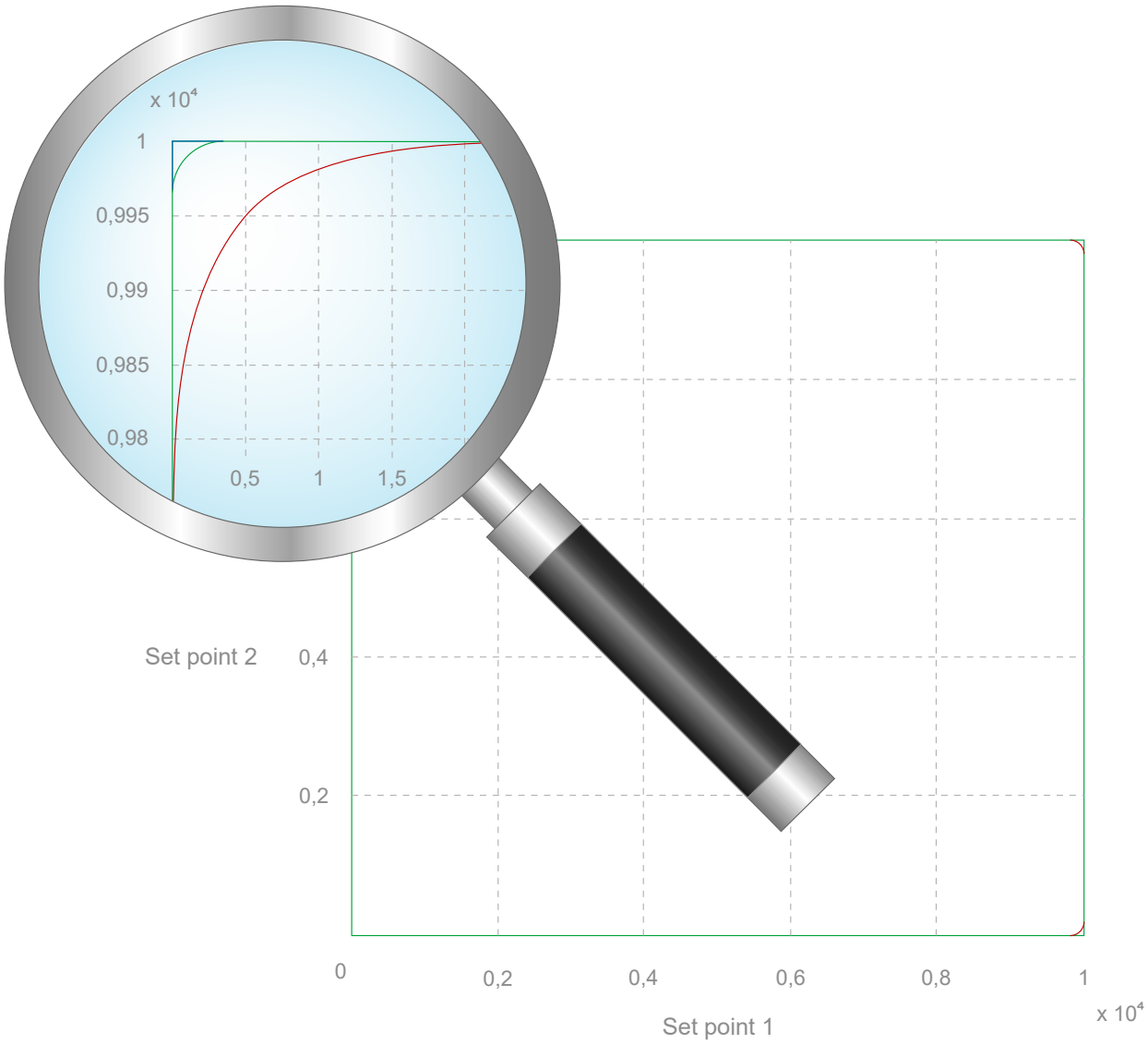


Fig. 11: 2D contour programming example

6 Parameters

6.1 Overview

ID	Axis parameters	Description
P-AXIS-00573	enable	Enable axis-specific FIR filter
P-AXIS-00585	fcut	Cut-off frequency of the FIR filter
P-AXIS-00586	type	FIR filter type
P-AXIS-00587	order	Filter order
P-AXIS-00590	share	FIR filter share factor
P-AXIS-00591	order_time	Filter order in time [μ s]
P-AXIS-00593	quality	Filter quality

Description	Axis parameters	Programming parameter
FIR filter type	filter_fir.type	-
Filter enable	filter_fir.enable	ON
Filter disable	-	OFF
Order of the filter	filter_fir.order	ORDER
Filter order in time [μ s]	filter_fir.order_time	ORDER_TIME
Filter share	filter_fir.share	SHARE
Cut-off frequency of the FIR filter	filter_fir.fcut	FCUT
Limit value for tolerance monitoring [mm, inch]	-	AX_DEV
Path velocity at block transitions	-	ACC_FACT
Filter quality	filter_fir.quality	QUALITY

6.2 Description

P-AXIS-00573 Enable axis-specific FIR filter	
Description	This parameter controls the general enabling/disabling of the filter function.
Parameter	filter_fir.enable
Data type	BOOLEAN
Data range	0: Filter is disabled 1: Filter is enabled
Axis types	T, R, S
Dimension	T: ---- R,S: ----
Default value	0
drive types.	----
Remarks	The filter function is only enabled if a valid filter type (P-AXIS-00586) is selected, otherwise the filter is disabled. Alternatively, the filter can also be enabled or disabled with the NC command #FILTER ON/OFF. The parameter is available as of V3.1.3075.00

P-AXIS-00586 Type of axis-specific FIR filter	
Description	The parameter defines the FIR filter type
Parameter	filter_fir.type
Data type	UNS32
Data range	0 – No filter 1 – Moving average filter 2 – Gaussian filter 3 – Windowed sinc filter 4 – Time delay filter
Axis types	T, R, S
Dimension	T: ---- R,S: ----
Default value	0
drive types.	----
Remarks	The filter function is only enabled if a valid filter type is selected, otherwise the filter is disabled. The parameter is available as of V3.1.3075.00

P-AXIS-00587 Order of axis-specific FIR filter	
Description	This parameter defines the order of FIR axis filters. The filter is off when order = 0. In order to use a configured filter effectively, it is absolutely necessary to specify order > 0.
Parameter	filter_fir.order
Data type	UNS32
Data range	$0 \leq \text{order} \leq 200$ (*)
Axis types	T, R, S
Dimension	T: ---- R,S: ----
Default value	0
drive types.	----
Remarks	Alternatively, filter effectiveness can be achieved by assigning a valid value in P-AXIS-00591 or by programming a filter order in the NC program.

	<p>(*) The data range of the filter type (P-AXIS-00586) time delay filter is $0 \leq \text{order} \leq 100$</p> <p>The parameter is available as of V3.1.3075.00</p>
--	---

P-AXIS-00591 Order of axis-specific FIR filter in time	
Description	<p>Alternatively to P-AXIS-00587, this parameter specifies the order of the FIR filter.</p> <p>If this parameter is smaller than the NC cycle time, the filter is disabled. This parameter is used only if P-AXIS-00587 was not configured and no filter order was programmed by the NC program.</p>
Parameter	filter_fir.order_time
Data type	UNS32
Data range	$\text{NC cycle time} \leq \text{order_time} \leq 200 * \text{NC cycle time (*)}$
Axis types	T, R, S
Dimension	T: μs R,S: μs
Default value	0
Drive types	----
Remarks	<p>(*) The data range of the filter type (P-AXIS-00586) time delay filter is $\text{NC cycle time} \leq \text{order_time} \leq 100 * \text{NC cycle time}$</p> <p>The parameter is available as of V3.1.3075.00</p>

P-AXIS-00590 FIR filter share factor	
Description	<p>This parameter defines the effectiveness of the FIR filter.</p> <p>When the parameter is assigned:</p> <ul style="list-style-type: none"> share = 0 : no filter effect share = 100 : the filter is 100% effective on axis setpoints (default)
Parameter	filter_fir.share
Data type	UNS32
Data range	$0 \leq \text{order} \leq 100$
Axis types	T, R, S
Dimension	T: % R,S: %
Default value	100
drive types.	----
Remarks	The parameter is available as of V3.1.3075.00

P-AXIS-00585 Cut-off frequency of the FIR filter	
Description	<p>This parameter defines the cut-off frequency of the FIR filter. This parameter is only relevant for FIR filters which consider a cut-off frequency.</p> <p>This is dependent on the filter type of the FIR filter (P-AXIS-00586); the cut-off frequency is only considered with type 3 (windowed sinc filter).</p>
Parameter	filter_fir.fcut
Data type	REAL64
Data range	$1 \leq \text{fcut}$
Axis types	T, R, S
Dimension	T: Hz R,S: Hz
Default value	30
drive types.	----
Remarks	The parameter is available as of V3.1.3075.00

P-AXIS-00593	FIR filter quality	
Description	<p>This parameter influences the shape of the FIR filter core and therefore setpoint smoothing.</p> <p>The quality then specifies the width of the filter core curve. The higher the quality, the wider the filter core curve and the stronger the smoothing effect of the filter.</p> <p>The width of the actual filter core in the shape of the specified order is not affected by bandwidth.</p>	
Parameter	filter_fir.quality	
Data type	REAL64	
Data range	0 < quality <= 1	
Axis types	T, R	
Dimension	T, R: -	S: -
Default value	1.0	
drive types.	----	
Remarks	<p>The parameter is available as of Build V3.1.3075.04 and only acts on filter type 2 (P-AXIS-00586 – Gaussian)</p> <p>The parameter is available as of V3.1.3075.04</p>	

7 Support and Service

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