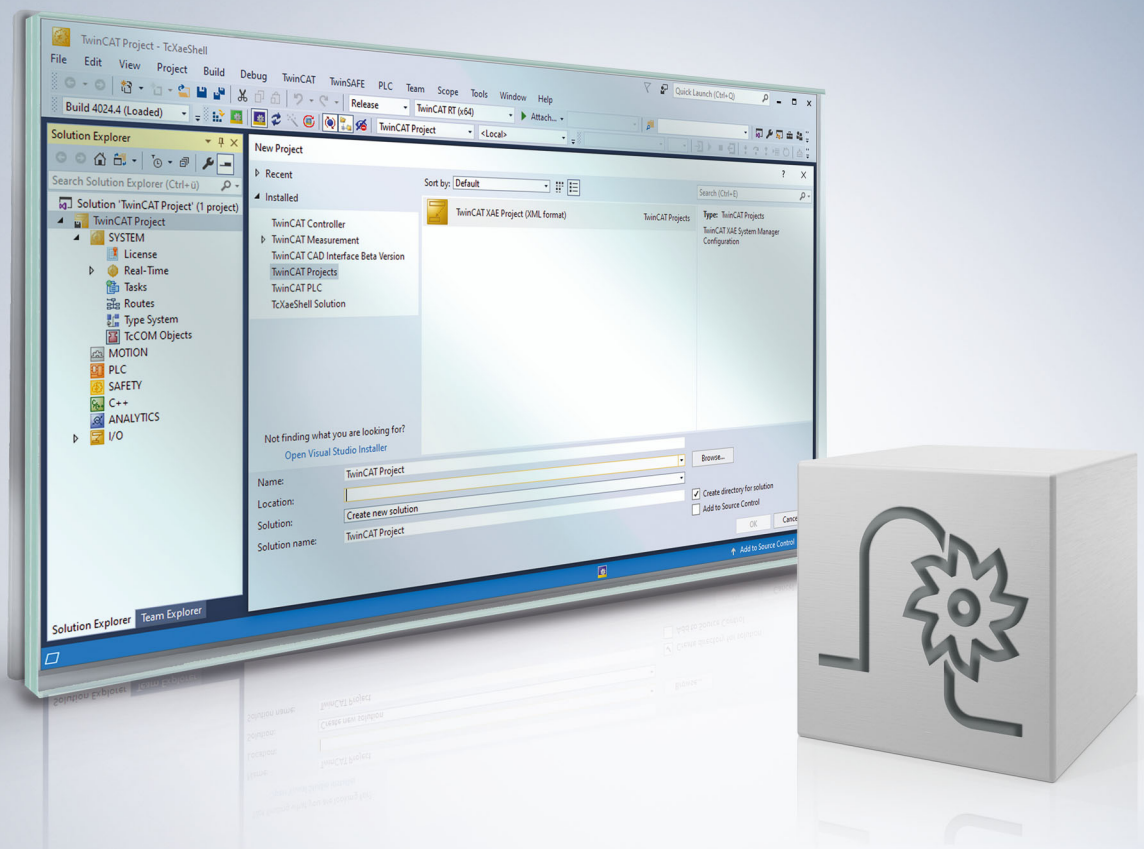
BECKHOFF New Automation Technology

Functional description | EN

TF5200 | TwinCAT 3 CNC

Friction compensation



12/18/2023 | Version: 1.06

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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.

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Icons in explanatory text

1. Indicates an action.

⇨ Indicates an action statement.

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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

Task

Friction effects in the drive train may cause marks or dimensional variations on the workpiece surface at points in the machining process where a change in axis direction occurs (reversing). The purpose of friction compensation is to minimise these effects and enhance machining results.

Characteristics

Friction compensation reduces position lag and improves surface quality. At the same time, it relieves pressure on the speed controller and when activated, it permits the greater use of dynamic parameters and this reduces machining time.

Friction compensation can be activated for SERCOS and CANopen drives. This requires the installation of an additive torque interface (additive current) which requires [▶ 18] configuration.

Parameterisation

The data required for friction compensation is parameterised in the compensation value list [COMP].

Friction compensation is configured by setting the parameter P-AXIS-00522 in the axis parameter list and is active after controller start-up.

Programming

Friction compensation can also be activated/deactivated by the axis-specific NC command **<Axis>[COMP ...]** In the NC program.

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

Friction

Friction basically occurs at points of contact between bodies moving relative to one another. It manifests itself as the force that counteracts the motion.

According to Stribeck, the following friction curves result at different velocities:

- Phase 1: Adhesive friction for standstill (boundary friction)
- Phase 2: Mixed friction, Stribeck friction
- Phase 3: Elastohydrodynamic friction

The constant component of friction at velocity v = 0 results in a surge in frictional force at speed reversal resulting in backlash.

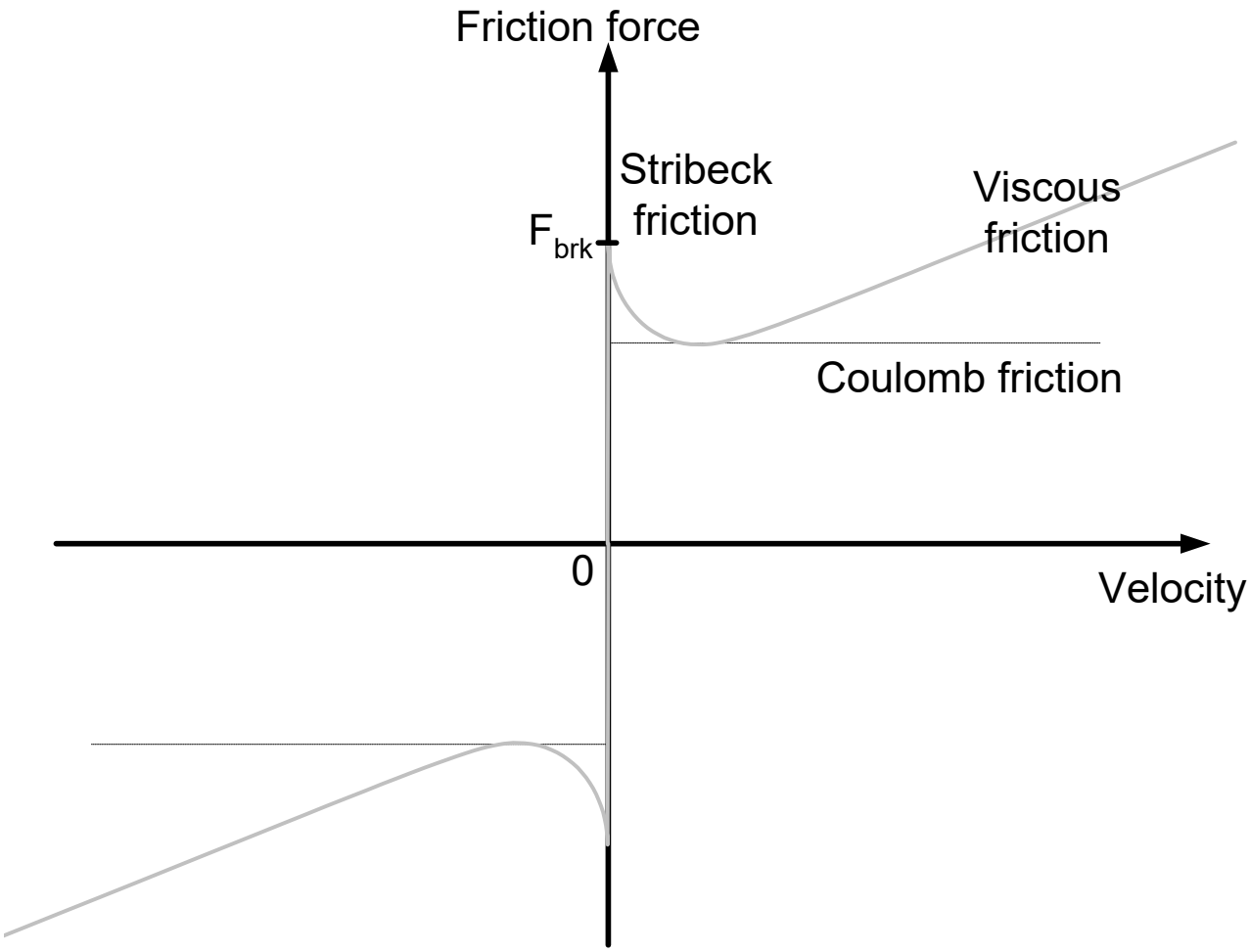

Fig. 1: Theoretical friction curve

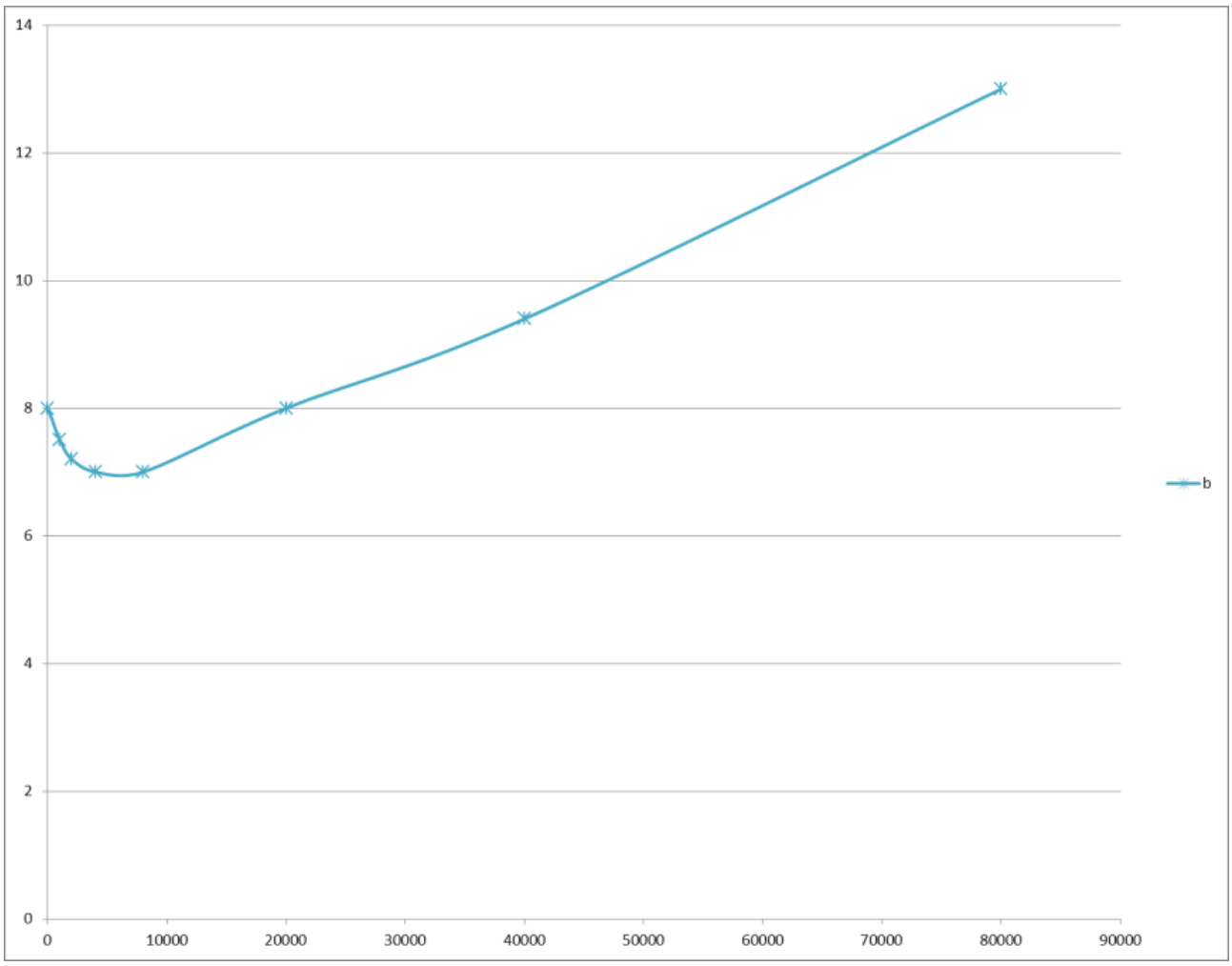

Fig. 2: Measured friction curve

2.1 Additive current dependent on velocity

Additive current

The purpose of friction compensation is to compensate actually existing friction torque by way of an additional torque. It acts in the form of speed-dependent feedforward control of the motor current.

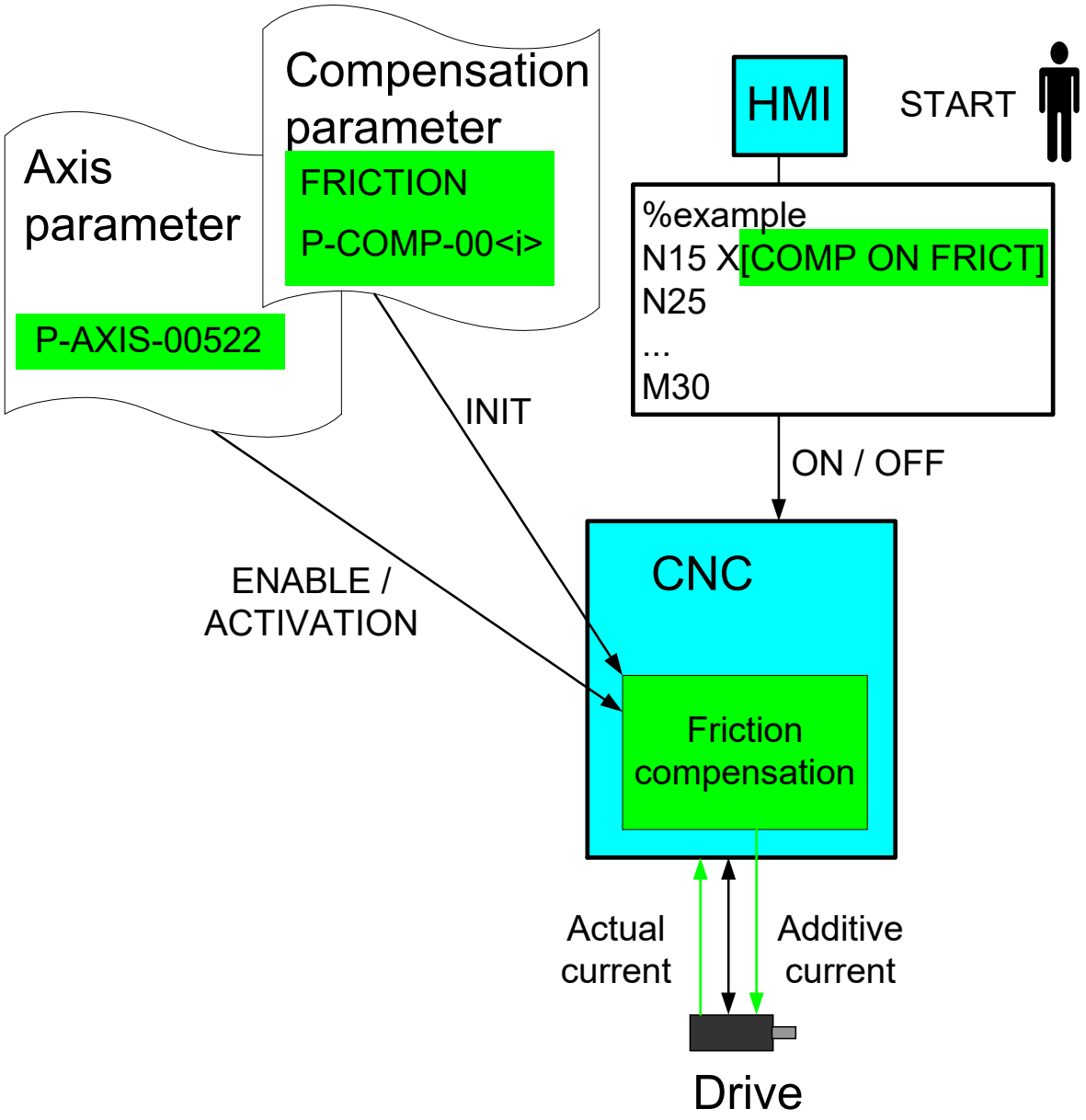

Fig. 3: Principle of friction compensation

It is basically sufficient to command a additive current to the drive on the setpoint side for friction compensation.

However, to determine the characteristic curve for the current and verify compensation, it is also necessary to read the actual current.

Effect

The algorithm compensates for friction during path motions (v≠0) by an additional motor current.

Control loop

The effect of friction compensation on closed-loop control is shown in the figure below.

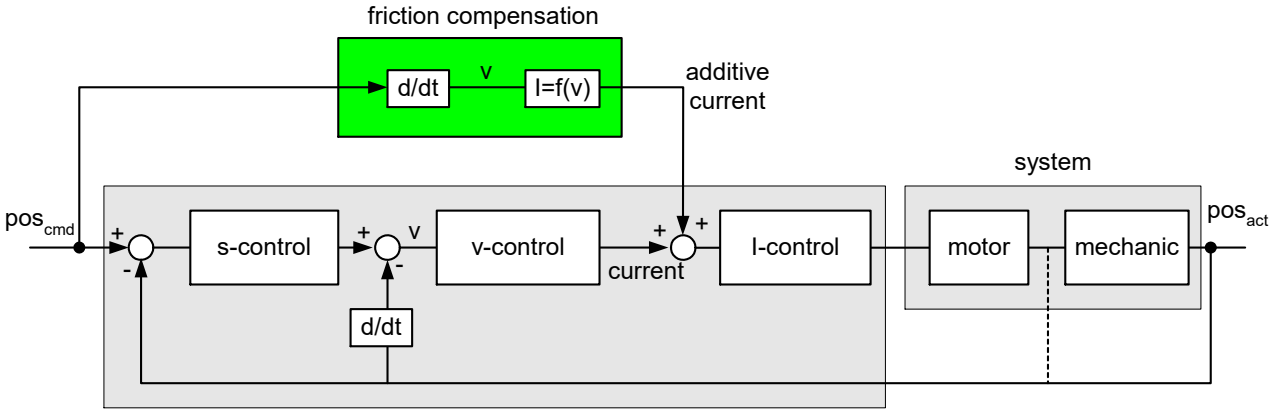

Fig. 4: Add friction compensation to the control loop of an axis

2.1.1 Reverse the motion direction

Reverse and weight the friction curve

In the Stribeck curve model, a jump in feedforward control current occurs in the axis reversal process (velocity zero crossing).

To prevent this discontinuity, the CNC monitors axis reversal. In this case, the friction model may be weighted before and after zero crossing.

- Before zero crossing: time [number of CNC cycles]
- After zero crossing: Path distance covered [0.1 µm]

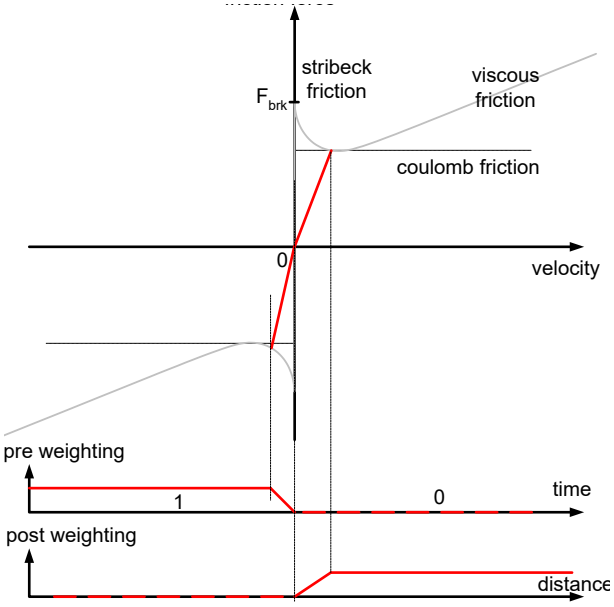

Fig. 5: Weight friction model before/after zero crossing, on reversal from negative to positive velocity

If no reversal takes place, i.e. the axis is only decelerated and continues in the same direction, the friction model is not weighted.

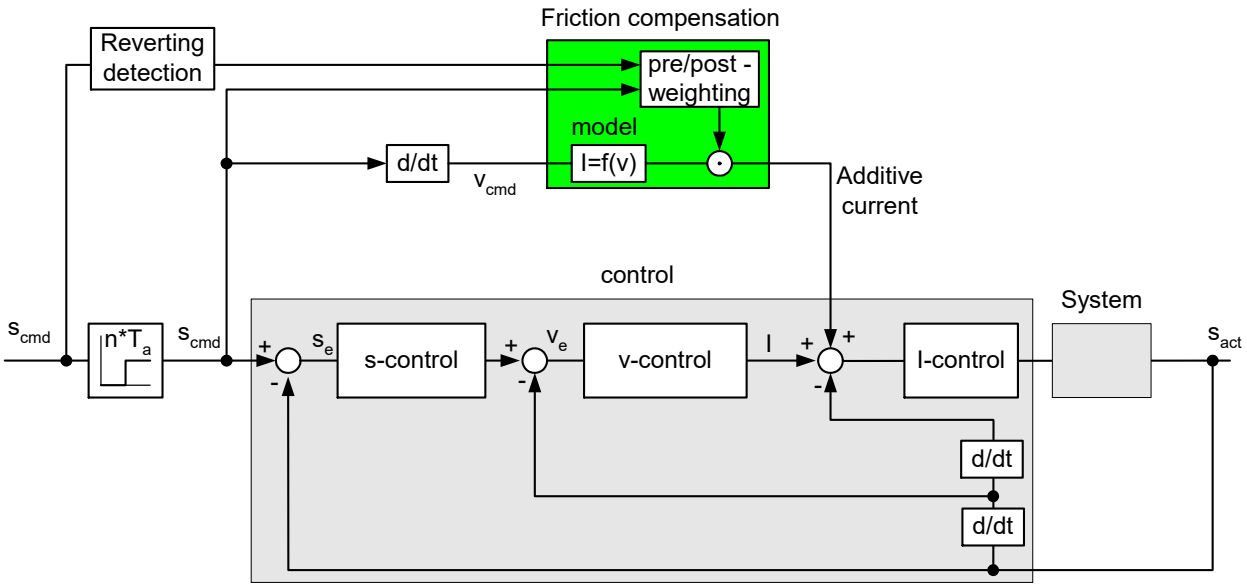

Fig. 6: Add friction compensation to the control loop of an axis

2.2 Parameterisation

Parameterise compensation values

The table for friction compensation must be programmed with ascending velocity and the velocity must be ≥ 0. This is checked when the list is downloaded list and, if applicable, the error message P-ERR-110591 is output.

As of CNC Build V3.1.3079.06, use P-COMP-00062 [▶ 24] to define a maximum number of table entries in the compensation value list. The entries actually used are defined in P-COMP-00042.

Friction compensation parameters are defined in the compensation value list:

- Maximum number of table entries P-COMP-00062 [▶ 24] as of Build V3.1.3079.06
- Friction compensation mode P-COMP-00041
- Number of table elements P-COMP-00042
- Current build-up after direction reversal P-COMP-00043
- Current decay before direction reversal P-COMP-00044
- Scaling factor for compensation values P-COMP-00045
- Table entries for velocity P-COMP-00046
- Table entries for current P-COMP-00047

Friction compensation is only active when the mode (P-COMP-00041) is assigned a value unequal to 0 and P-AXIS-00522 is set.

Only value 3 is permitted for P-COMP-00041

Parameterise friction compensation

```
frict_comp.mode                          3
frict_comp.table_entries                 3
frict_comp.position_delay                30
frict_comp.reversal_lookahead            4
frict_comp.scaling_factor                10
frict_comp.delay_cycles                  9

frict_comp.table[0].in                   0
frict_comp.table[0].out                  0
frict_comp.table[1].in                   316
frict_comp.table[1].out                  3722
frict_comp.table[2].in                   333
frict_comp.table[2].out                  3884
```

Parameter verification

A consistency check takes place when compensation parameters are adopted. If the parameters are not coherent, a related error message is output.

P-ERR-110591 Negative or non-ascending input values

P-ERR-110592 Unknown mode or no values specified

2.3 Select and deselect compensation

Activate/deactivate

By analogy to other compensations, compensation can be activated by a parameter in the axis list or additionally by an NC command.

Enable use/activate

Compensation can only be applied if the parameter P-AXIS-00522 is set (TRUE) in the parameter list and the compensation value list is parameterised.

Behaviour after start-up

When friction compensation is selected, it is active directly after controller start-up regardless of whether homing was executed.

Programming

In every case, compensation can also be activated or deactivated explicitly by the axis-specific COMP command in the NC program.

NOTICE

The COMP command is valid after program end. After activating or deactivating compensation, the operator must also explicitly deactivate or activate it at program end.

2.3.1 Programming

*<axis_name>***[COMP ON** | **OFF FRICT]**

<axis_name>	Name of the axis
COMP	Identifier to select/deselect axis-specific compensation. Must always be programmed as first keyword.
ON	Activates programmed compensation(s)
OFF	Deactivates programmed compensation(s)
FRICT	Keyword for friction compensation

Activates and deactivates friction compensation

```
N15 X[COMP ON FRICT] ;Activates X axis
N25 Y[COMP OFF FRICT] ;Deactivates Y axis
N35 X22 Y33 Z44
N45 X[COMP OFF FRICT] ;Deactivates X axis
N55 M30 ;Program end
```

Error message

If friction compensation must be activated with the COMP command but it was not activated by the parameter P-AXIS-00522, the error message P-ERR-70495 is output.

2.4 Drive parameterisation

Drive telegram

The drive must be fitted with a torque interface to be able to use friction compensation.

SERCOS

The additive torque setpoint must be configured in the cyclic log.

- S-0-0084 Torque feedback value
- S-0-0081 Additive torque command value

CANopen

The related PDOs (process data objects) are similarly configured with CANopen.

- 6077 Torque actual value
- 60B2 Torque offset

3 Determine the parameters for the compensation value list

3.1 Determine parameters manually

Manual determination

Each of the compensation value list parameters can be determined “manually”.

To this end, the associated current (dig_drv.act_torque), e.g. in the scope, must be read off during a motion at constant speed. The motor current during a motion at constant speed is mapped in the figure below. It can be seen that the current is in the opposite direction to the speed.

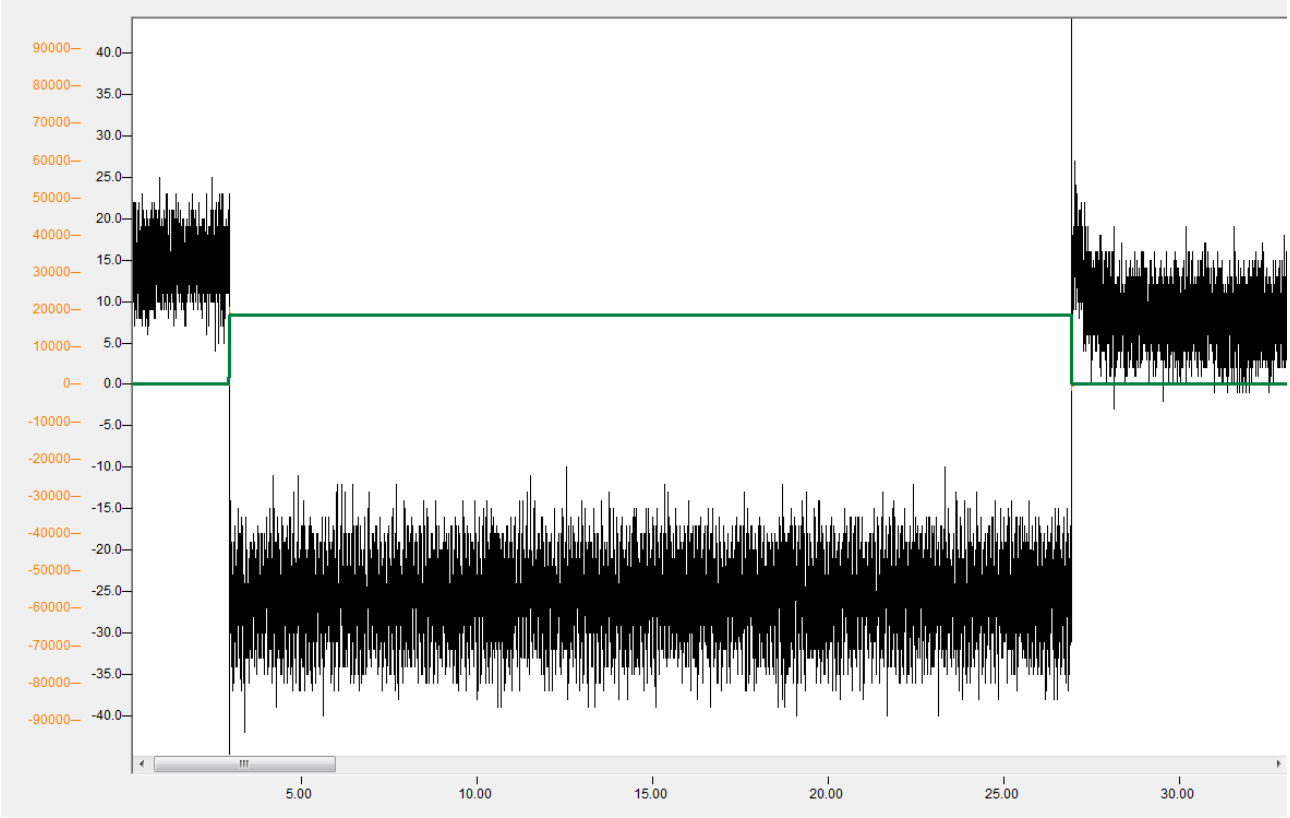

Fig. 7: Constant velocity (green) and associated current (black)

4 Effect of friction compensation

Friction compensation reduces position lag and axis backlash. This boosts accuracy. Furthermore, the speed controllers are relieved, as a result of which the dynamic parameters can be used to a greater extent without impairing the machining result.

The figure below shows the result of a circular transition test with compensation activated and deactivated. Without compensation (blue), clear peaks are visible at the quadrant transitions, which are reduced by compensation (red).

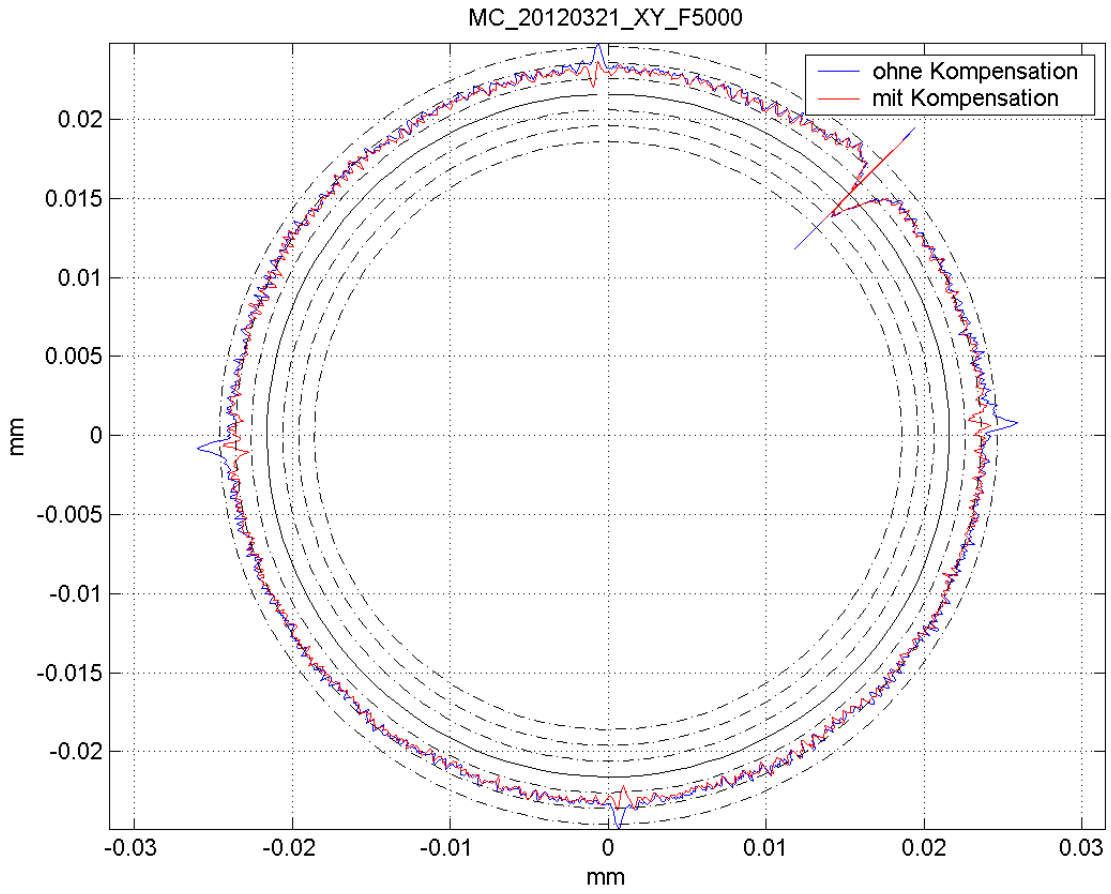

Fig. 8: Circular transition test with and without friction compensation

5 Parameter

5.1 Overview

5.1.1 Axis parameters

ID	Parameter	Description
P-AXIS-00522	lr_param.frict_comp	Activates and deactivates friction compensation

5.1.2 Compensation values

ID	Parameter	Description
P-COMP-00041	Index of the incorrect interpolation point	Friction compensation mode
P-COMP-00042	frict_comp.table_entries	Number of elements in the compensation value table. Maximum of 20
P-COMP-00043	frict_comp.position_delay	Distance over which the motor current is built up during start-up.
P-COMP-00044	frict_comp.reversal_lookahead	Number of cycles during which the motor current is dissipated before a motion reversal.
P-COMP-00045	frict_comp.scaling_factor	Scaling factor for the entries in the compensation list
P-COMP-00046	frict_comp.table[i].in	Velocity
P-COMP-00047	frict_comp.table[i].out	Measured friction (motor current)
P-COMP-00058	frict_comp.delay_cycles	Delay in compensation values after reversal point in cycles
P-COMP-00062	frict_comp.max_points	Max. number of possible table entries

5.2 Description

5.2.1 Axis parameters

P-AXIS-00522	Activation of friction compensation	
Description	This parameter activates the friction compensation.	
Parameter	lr_param.frict_comp	
Data type	BOOLEAN	
Data range	0/1	
Axis types	T, R	
Dimension	T: ----	R: ----
Default value	0	
Drive types	SERCOS, CANopen	
Remarks	If friction compensation must be activated with the COMP command but it was not activated by the parameter P-AXIS-00522, the error message P-ERR-70495 is output.	

5.2.2 Compensation values

P-COMP-00041	Friction compensation mode	
Description	The parameter defines the operation mode for friction compensation. If the parameter is assigned the value 0, friction compensation is deactivated.	
Parameter	frict_comp.mode	
Data type	UNS16	
Data range	0: Deactivate friction compensation 3: Compensation with additive current taking into account the commanded speed	
Axis types	T, R, S	
Dimension	T: ----	R,S: ----
Default value	0	
Remarks	To activate friction compensation, the mode must and P-AXIS-00522 must be set.	

P-COMP-00042	Number of elements in the compensation value table	
Description	This parameter defines the number of entries in the compensation table.	
Parameter	frict_comp.table_entries	
Data type	UNS16	
Data range	0 ≤ table_entries ≤ P-COMP-00062 [▶ 24]	
Axis types	T, R, S	
Dimension	T: ----	R,S: ----
Default value	0	
Remarks	P-COMP-00062 [▶ 24] is available as of Build V3.1.3079.06. The default upper limit is 20.	

P-COMP-00043	Delay value for current build-up
Description	This parameter defines the delay value for current built-up at start-up. Its purpose is to prevent abrupt changes. Current build-up is linear.
Parameter	frict_comp.position_delay
Data type	SGN32
Data range	0 ≤ position_delay ≤ 10
Axis types	T, R, S

Dimension	T: 0.1µm	R,S: 0.0001°
Default value	0	
Remarks		

P-COMP-00044	Reversal look ahead	
Description	This parameter defines the number of cycles over which the motor current decays before motion reversal.	
Parameter	frict_comp.reversal_lookahead	
Data type	UNS16	
Data range	0 ≤ reversal_lookahead ≤ 4	
Axis types	T, R, S	
Dimension	T: Cycles	R,S: Cycles
Default value	0	
Remarks		

P-COMP-00045	Scaling factor for compensation values	
Description	This parameter defines the scaling of all compensation values in the list.	
Parameter	frict_comp.scaling_factor	
Data type	SGN16	
Data range	MIN(SGN16) < scaling_factor < MAX(SGN16)	
Axis types	T, R, S	
Dimension	T: 0.1%	R,S: 0.1%
Default value	1000	
Remarks		

P-COMP-00046	Velocity input variable	
Description	This parameter defines the velocities for which the additional motor currents specified in P-COMP-00047 are to be output to the additive current interface. The values must be entered in ascending order.	
Parameter	frict_comp.table[i].in where i= P-COMP-00042	
Data type	SGN32	
Data range	0 < table[i].in < MAX(SGN32)	
Axis types	T, R, S	
Dimension	T:	R,S: [0.001°/s]
Default value	0	
Remarks		

P-COMP-00047	Measured friction (motor current) – output variable	
Description	This parameter defines the current which is to be additionally output at the additive current interface.	
Parameter	frict_comp.table[i].out where i= P-COMP-00042	
Data type	SGN32	
Data range	MIN(SGN32) < table[i].out < MAX(SGN32)	
Axis types	T, R, S	
Dimension	T: *	R,S: *
Default value	0	
Remarks	* The dimension of the motor current depends on the internal data of the related drive. In CANopen and SERCOS, this value corresponds to the contents of the CNC object *dig_drv.act_torque*.	

P-COMP-00058	Delay time for compensation values

Description	This parameter defines the delay time of all compensation values.	
Parameter	frict_comp.delay_cycles	
Data type	SGN16	
Data range	0 ≤ delay_cycles < 249	
Axis types	T, R, S	
Dimension	T: Cycles	R,S: Cycles
Default value	0	
Remarks		

P-COMP-00062	**Maximum number of table entries for friction compensation**	
Description	This friction compensation parameter (FCT-C25 [▶ 8]) saves the memory space required for a particular number of table entries. The size of the actually used compensation table is defined by `table_entries` (P-COMP-00042) and `table_entries` must be smaller than `max_points`.	
Parameter	frict_comp.max_points	
Data type	UNS32	
Data range	0 <= P-COMP-00062	
Axis types	T, R, S	
Dimension	T: ----	R,S: ----
Default value	20	
Remarks	The parameter value can no longer be changed after start-up or after lists are reloaded. Otherwise error ID 110641 is output. If P-COMP-00062 is not specified (or assigned the value 0), the default value is assigned to P-COMP-00062 for downward compatibility reasons. To avoid the default assignment, memory can be saved for an axis that does not use friction compensation [▶ 8] by assigning the value 1 to P-COMP-00062. This parameter is available as of CNC Build V3.3079.06	

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