Load model

Translation of the "Original Dokumentation"
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Name:	FKT_Load model_en
Version:	

Version: 2018/44	
Change	**Letter symbol**
• iX(-R3) / iC(-R3) / iDT5(-R3) added	STL

Previous version:	2017/04
Product version:	

Product AMK part no.	Firmware Version (AMK part no.)
KW-R06 (O835) KW-R07 (O807) KW-R16 (O872) KW-R17 (O873)	AE-R05/R06 V1.13 2015/21 (205700)
KW-R24 (O901)	AE-R24 V2.03 2015/06 (205587)
KW-R24-R (O954)	AE-R24-R V2.11 2016/46 (206643)
KW-R25 (O902)	AE-R25 V2.03 2015/06 (205588)
KW-R26 (O903)	AE-R26 V2.03 2015/06 (205589)
iX / iC / iDT5	iX V1.07 2015/17 (205688)
iX(-R3) / iC(-R3) / iDT5(-R3)	iX V2.11 2017/05 (206765)
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1 Load model

Supported hardware:	KW-R06 / KW-R16 / KW-R07 / KW-R17 / KW-R24 / KW-R24-R / KW-R25 / KW-R26 / iX / iC / iDT5 / iX(-R3) / iC(-R3) / iDT5(-R3) / ihXT /

The motor torque for the drive is derived from several torques according to 'Newton's laws of physics'. The process torque included in the motor torque is application-specific. Other included torques are moment of inertia, static frictional torque, linear frictional torque and holding torque. These torques can influence the behavior of the dynamics and following error of the machine.

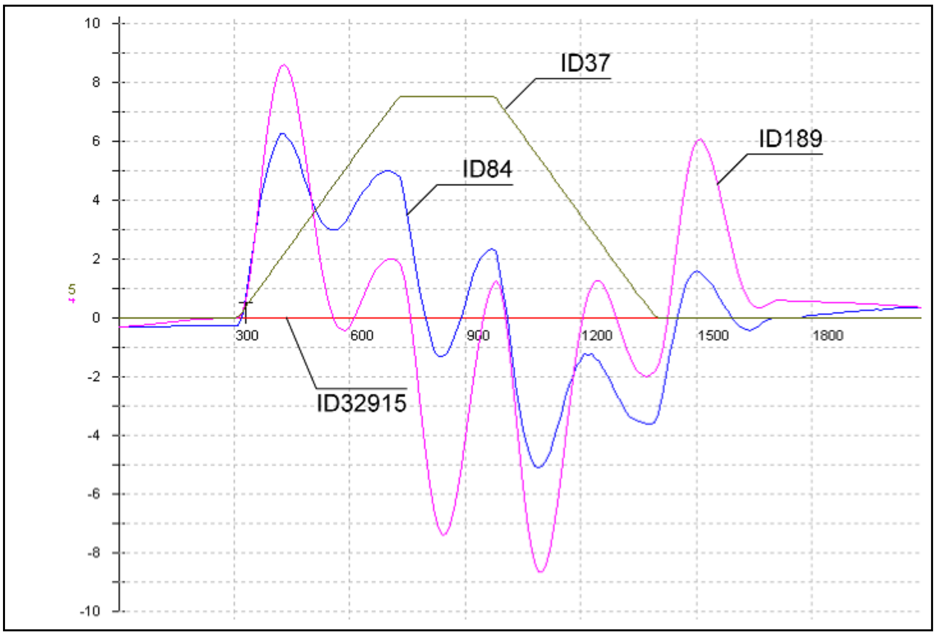
These torques can be pre-controlled using the 'load model' function integrated in the drive firmware. The load model calculates a feed-forward control torque for the current controller from the input torque values and the speed and acceleration values of the movement.

When the parameter settings are optimal, the torque feed-forward control (display value ID32915 'Sum of additive torques') is nearly congruent with ID84 'Torque feedback value'. Thus, the load model relieves the speed control circuit and the controller performance improves. The improved dynamics reduces the position error.

For calculating the feed-forward control torque, the load model requires the input of the torques (ID34221 'Friction torque', ID34222 'Friction torque linear', ID34223 'Holding torque' and ID34224 'Inertia'). These torques can be empirically determined during the commissioning with AIPEX PRO. See 'Determining the torques and optimization' on page 11. In addition to the torques, the speed and acceleration value of the movement is required. These values can calculated by the load model internally or specified externally by PLC (ID37 'Additive velocity command value' and ID194 'Acceleration setpoint').

Initial situation: Movement profile without load model (torque control with feed-forward)

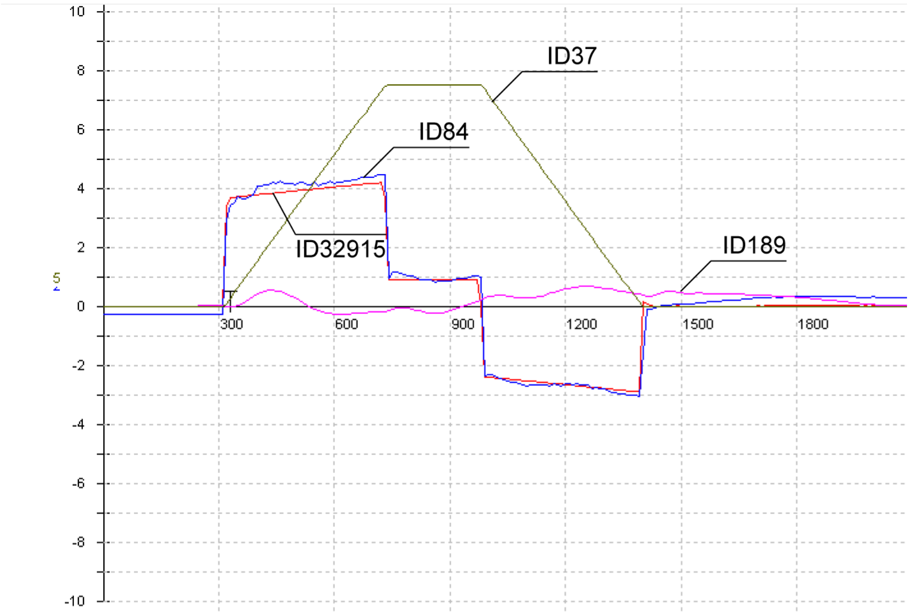
A fluctuating 'Following distance' ID189 can be seen in the recording. No control with feed-forward takes place, ID32915 'Sum of additive torques' is zero.



Recording movement profile with optimized load model

When the torque control with feed-forward is optimally set, ID32915 'Sum of additive torques' is nearly congruent with ID84 'Torque feedback value'. The 'Following distance' ID189 is clearly reduced by this.

The required torque is formed by the torque control with feed-forward.



Summary:

The load model shifts the predominant part of the control from the speed controller by means of the control with feed-forward to the faster current controller. This improves the control dynamics significantly.

In the position control operating mode, the speed can be pre-controlled in parallel to the load model. The dynamics are additionally increased by the speed control with feed-forward.

2 Function

The load model works according to 'Newton's laws of physics' since the following torque equation applies for a drive.

$$M = \Theta\Delta\omega + \sigma(\omega)\,M_{Friction} + \frac{\omega}{\omega_0}M_{Linear} + M_{Stop} + M_{Process\ removal}$$

If moment of inertia (Θ), linear friction (M_{Linear}), static frictional torque ($M_{Friction}$) or holding torque ($M_{Holding}$) are known, these can be parameterized. The torques are calculated in the load model with the associated rotational speeds and then contribute to the improvement of the control performance of the complete system as feed-forward control torque (proportion of ID32915 'Sum of additive torques').

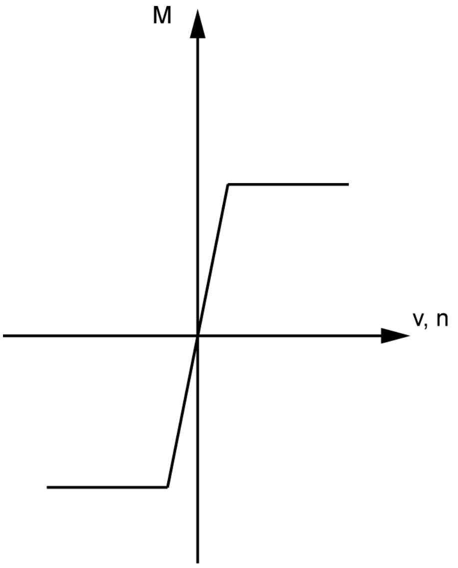
Variable	Meaning	Parameter
M	Torque consumed by the motor	Display ID81 'Torque feedback value'
Θ	Moment of inertia	ID34224 'Inertia'
Δω	Angular acceleration in rad/sec^2	-
σ(ω)	Sign of the angular velocity, absolute	-
ω	Angular velocity in rad/sec2	
ω_0	Reference angular velocity	
$M_{Friction}$	Static coefficient of friction in Nm	ID34221 'Friction torque'
M_{Linear}	Linear coefficient of friction in Nm, based on the reference angular velocity ω_0	ID34222 'Friction torque linear'
$M_{Holding}$	Holding torque (typical for hanging axes)	ID34223 'Holding torque'
$M_{Process\ removal}$	Undefined additional torque that the process requires	-

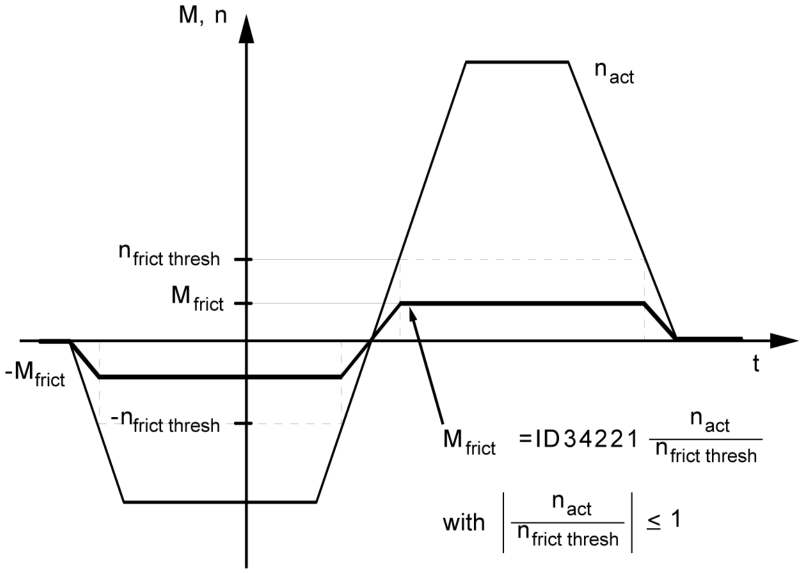
ID34221 'Friction torque'

The parameter 'Friction torque' represents a constant static friction. The torque is fed forward depending on the rotating direction.

The friction torque is fully effective at $n_{act} \geq n_{frict\ thresh}$.

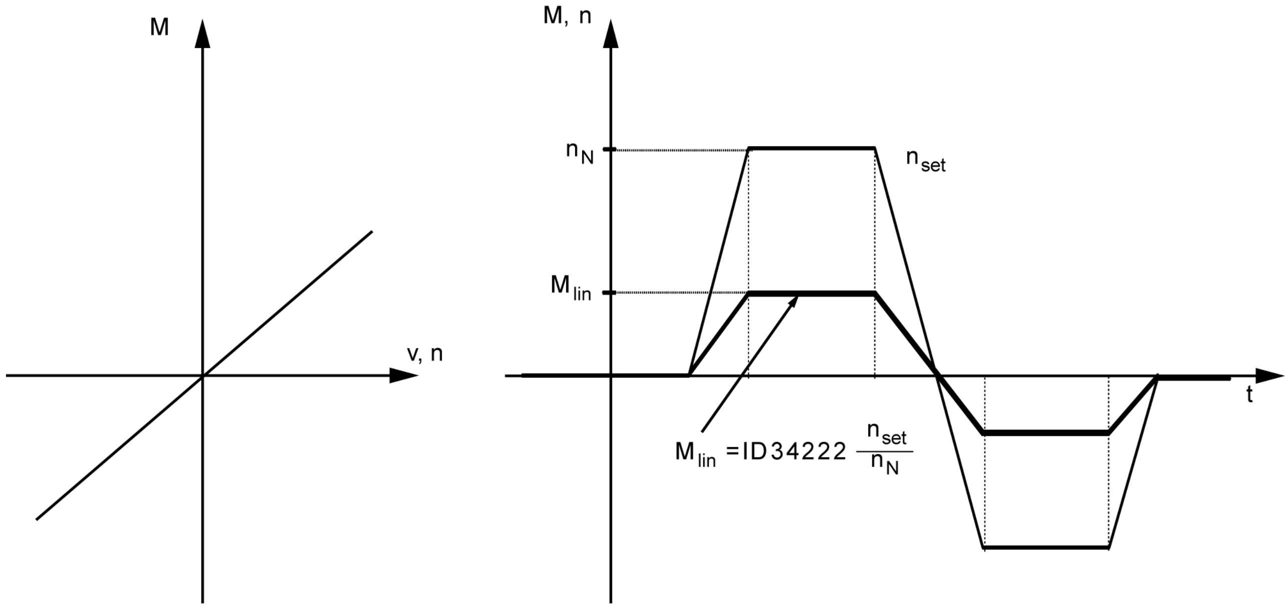
Within the range $n_{act} < n_{frict\ thresh}$, the friction torque is linear.





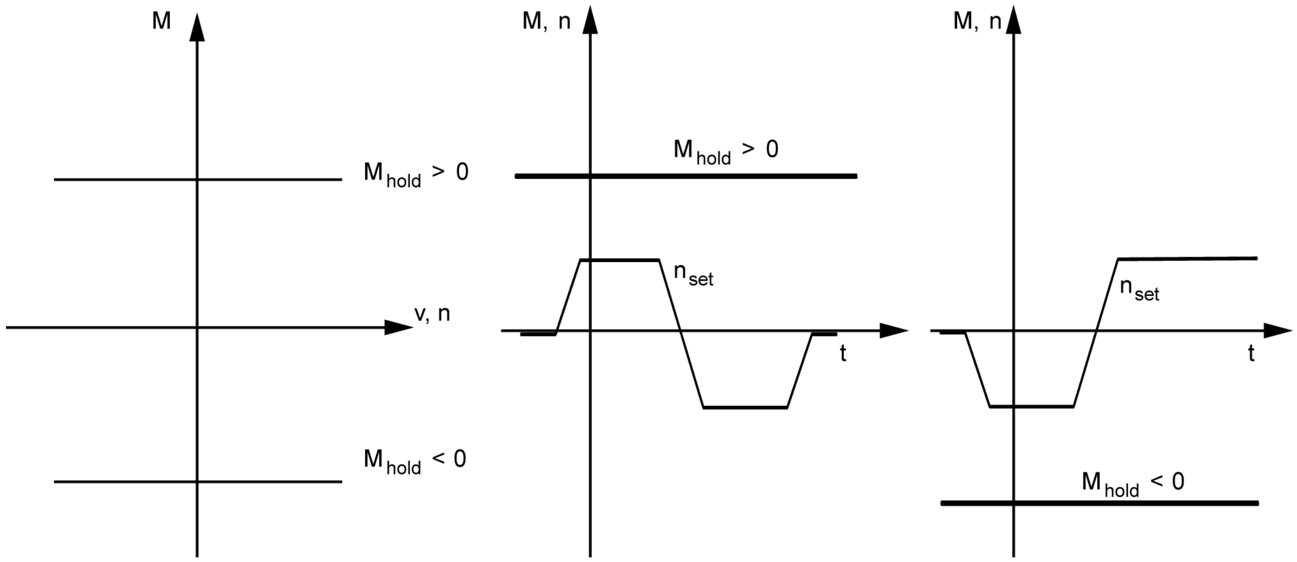
ID34222 'Friction torque linear'

The parameter 'Friction torque linear' represents a fluid friction. Fluid friction is the name of the friction which occurs with perfectly lubricated sliding surfaces. The friction is proportional to the speed with which the surfaces slide on each other.



ID34223 'Holding torque'

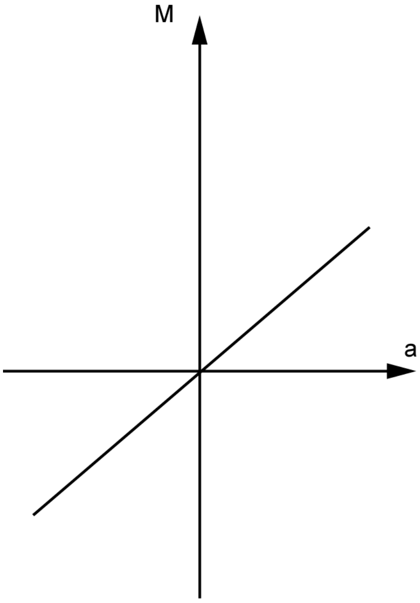
The parameter 'Holding torque' represents a holding torque, a hanging axle for example. The feed forward of the holding torque does not depend on the speed.

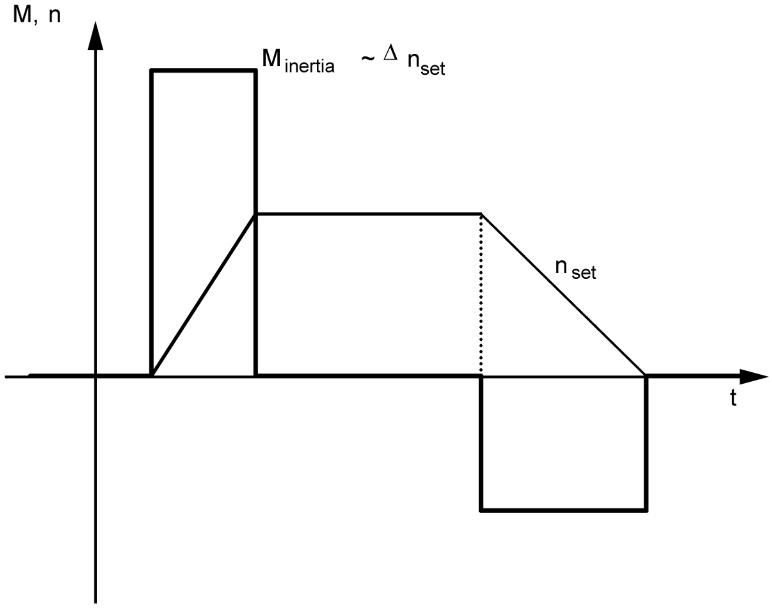


ID34224 'Inertia'

The parameter 'Inertia' represents the motor inertia additional a moment of inertia mounted on the motor shaft.

Inertia takes effect during acceleration and deceleration.





3 Alternatives for specifying speed and acceleration values

The load model requires the speed and acceleration value of the movement for the calculation of the torque feed-forward controller value. These values can be internally calculated or specified externally by PLC (with ID194 'Acceleration setpoint' and ID37 'Additive velocity command value').

Internal calculation of the speed and acceleration values of the movement for the load model:

- The speed and acceleration value of the movement is calculated internally from the 'Velocity control command after ramp' ID32823 and the 'Velocity feedback value' ID40. (Version 1)
- The speed and acceleration value of the movement is calculated internally by differentiating the 'position setpoint' ID47. (Version 2)

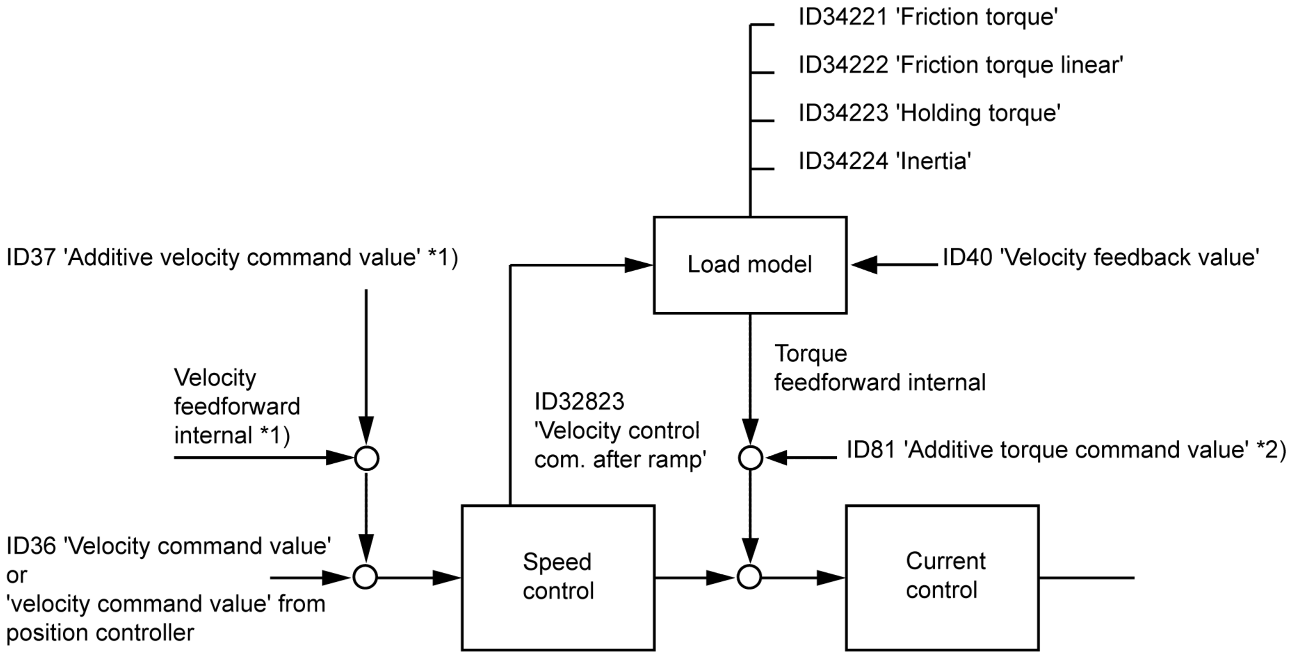
External calculation of the speed and acceleration values of the movement for the load model:

- The speed and acceleration value of the movement is calculated by an external PLC and written to ID194 'Acceleration setpoint' and ID37 'Additive velocity command value' . In addition, the 'Velocity feedback value' ID40 is calculated. (Version 3)
- Do not use for new applications! The speed and acceleration value of the movement is calculated by an external PLC and written to ID81 'Additive torque command value' and ID37 'Additive velocity command value'. In addition, the 'Velocity feedback value' ID40 is calculated. (Version 4)

Detailed depiction of the versions with associated parameterization

Version 1

The speed and acceleration value of the movement is calculated internally from the 'Velocity control command after ramp' ID32823 and the 'Velocity feedback value' ID40.



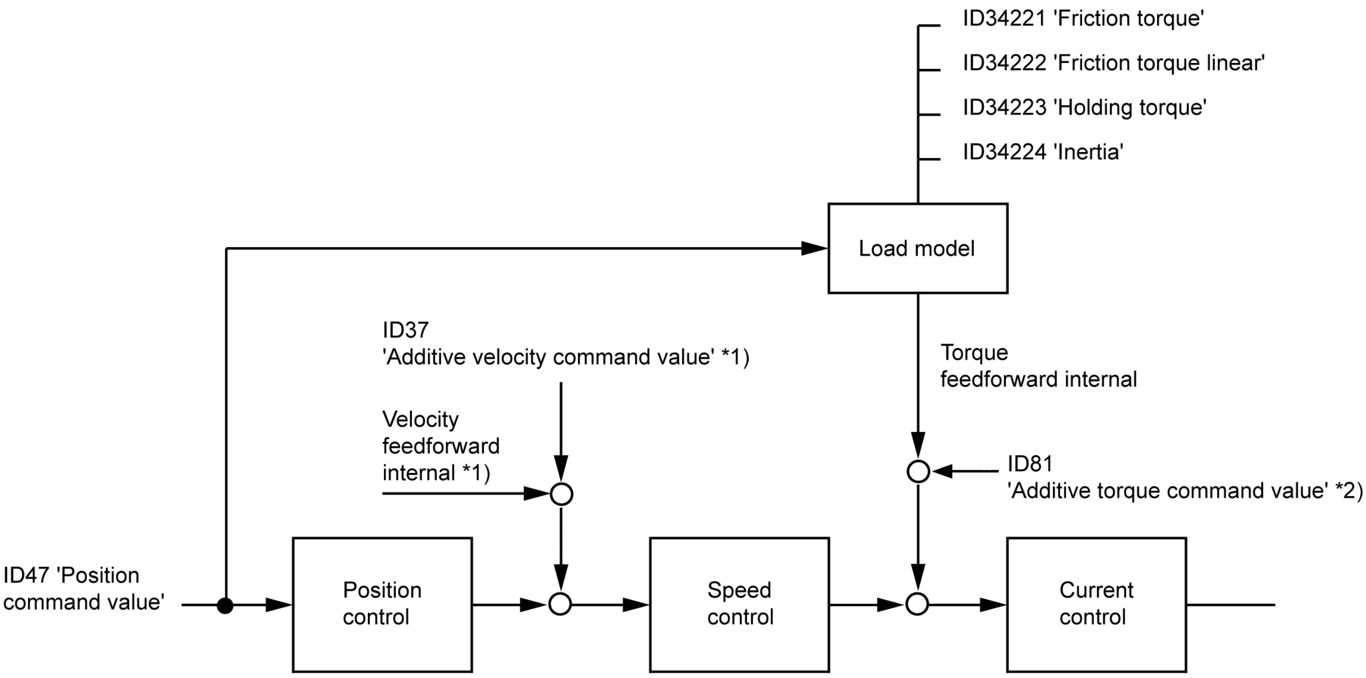
*1) Optional, see FKT_Drehzahlvorsteuerung_en
*2) Optional

Parameterization:

Parameter	Parameter description	Setting	Meaning
ID34225	'Mode feed forward control'	Bit 0 = 0	Load model: Internal source for the acceleration value
		Bit 1 = 0	Load model: Internal source for the speed value
		Bit 2 = 0	(requirement)
		Bit 3 = 0	Speed and acceleration defined according to Bit 0-2
		Bit 16 = 0	Load model active
ID34221	'Friction torque'		[0.01 Nm]
ID34222	'Friction torque linear'		[0.01 Nm]
ID34223	'Holding torque'		[0.01 Nm]
ID34224	'Inertia'		[0.001 kgcm^2]

Version 2

The speed and acceleration value of the movement is calculated internally by differentiating the 'position setpoint' ID47.



*1) Optional, see FKT_Drehzahlvorsteuerung_en
*2) Optional

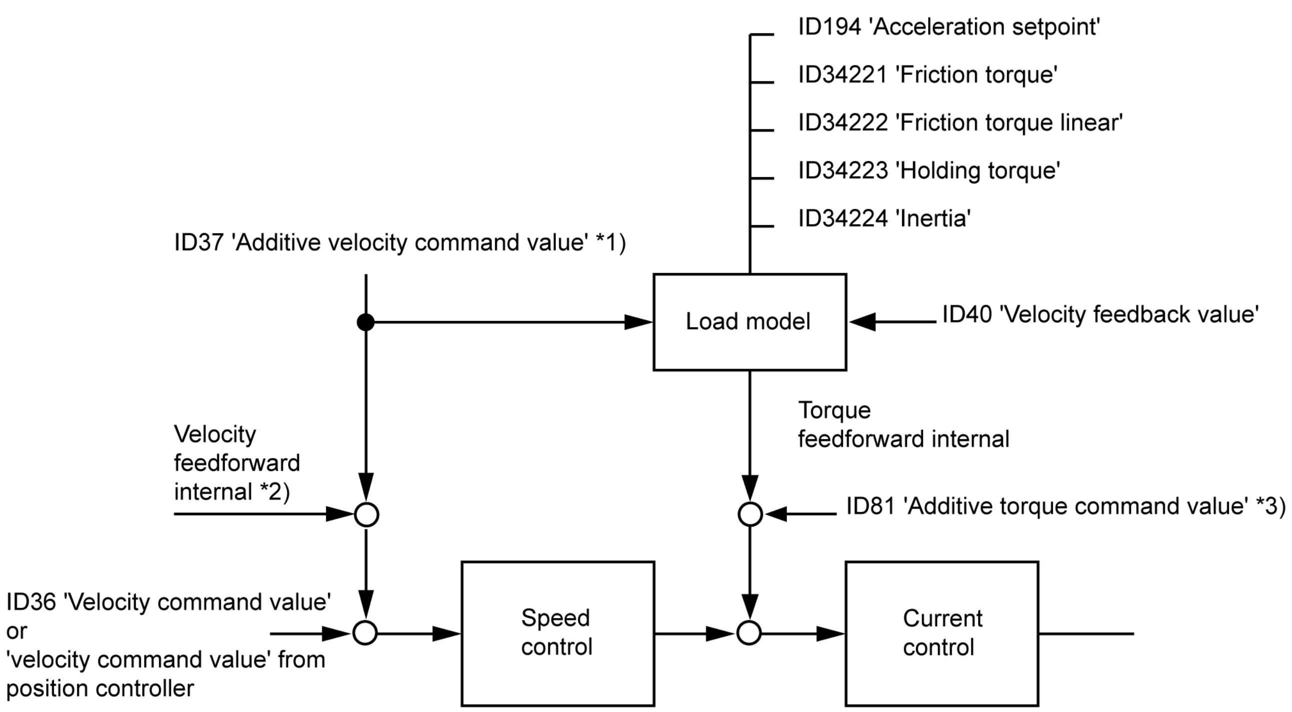
Parameterization:

Parameter	Parameter description	Setting	Meaning
ID34225	'Mode feed forward control'	Bit 0 = 0	(requirement)
		Bit 1 = 0	(requirement)
		Bit 2 = 0	(requirement)
		Bit 3 = 1	Internal source Acceleration and speed value are internally calculated by differentiating the position setpoints.
		Bit 16 = 0	Load model active
ID34221	'Friction torque'		[0.01 Nm]

Parameter	Parameter description	Setting	Meaning
ID34222	'Friction torque linear'		[0.01 Nm]
ID34223	'Holding torque'		[0.01 Nm]
ID34224	'Inertia'		[0.001 $kgcm^2$]

Version 3

The speed and acceleration value of the movement is calculated by an external PLC and written to ID194 'Acceleration setpoint' and ID37 'Additive velocity command value' . In addition, the 'Velocity feedback value' ID40 is calculated.



*1) The additive velocity command value is required for the calculation of the feedforward torque.
In position control, the command value also acts as a velocity feedforward value.
*2) Deactivate
*3) Optional

Parameterization:

Parameter ID	Parameter description	Setting	Meaning
ID34225	'Mode feed forward control'	Bit 0 = 0	(requirement)
		Bit 1 = 1	Load model: External source for the speed value. PLC writes value in ID37 'Additive velocity command value'.
		Bit 2 = 1	Load mode: External source for the acceleration value is written in ID194 'Acceleration setpoint' by PLC.
		Bit 3 = 0	Speed and acceleration defined according to Bit 0-2
		Bit 16 = 0	Load model active
ID37	'Additive velocity command value'		[0.0001 1/min]
ID81	'Additive torque command value'		[0.1 $\%M_N$]
ID194	'Acceleration setpoint'		[0.001 U/s²]
ID34221	'Friction torque'		[0.01 Nm]

Parameter ID	Parameter description	Setting	Meaning
ID34222	'Friction torque linear'		[0.01 Nm]
ID34223	'Holding torque'		[0.01 Nm]
ID34224	'Inertia'		[0.001 kgcm^2]

Version 4:

The speed and acceleration value of the movement is calculated by an external PLC and written to ID81 'Additive torque command value' and ID37 'Additive velocity command value'. In addition, the 'Velocity feedback value' ID40 is calculated.

This version is made available for firmware versions ≤ AER5-6_SW_112_1417_205129. For an external specification, use Version 3 for newer firmware versions.

ID81 'Additive torque command value' is used for specifying the acceleration value with the following scaling:

$$\left[0.0001\ \frac{1}{\min \times \mathrm{ID2} \times 32}\right].$$

In this version, no additional feed-forward control torque ('Additive torque command value') can be specified.

Parameterization:

Parameter ID	Parameter description	Setting	Meaning
ID34225	'Mode feed forward control'	Bit 0 = 1	Load mode: External source for the acceleration value is written in ID81 'Additive torque command value'by PLC.
		Bit 1 = 1	Load model: External source for the speed value. PLC writes value in ID37 'Additive velocity command value'.
		Bit 2 = 0	(requirement)
		Bit 3 = 0	(requirement)
		Bit 16 = 0	Load model active
ID37	'Additive velocity command value'		[0.0001 1/min]
ID81	'Additive torque command value' (used here as acceleration setpoint)		Acceleration scaling $\left[0.0001\ \frac{1}{\min \times \mathrm{ID2} \times 32}\right]$
ID34221	'Friction torque'		[0.01 Nm]
ID34222	'Friction torque linear'		[0.01 Nm]
ID34223	'Holding torque'		[0.01 Nm]
ID34224	'Inertia'		[0.001 kgcm^2]

4 Determining the torques and optimization

The load model requires the input of the torques for the feed-forward control:

- ID34221 'Friction torque'
- ID34222 'Friction torque linear'
- ID34223 'Holding torque'
- ID34224 'Inertia'

If these values are not known, they can be empirically determined, e.g. using the specification of a speed ramp and the AIPEX PRO oscilloscope. See the following example:

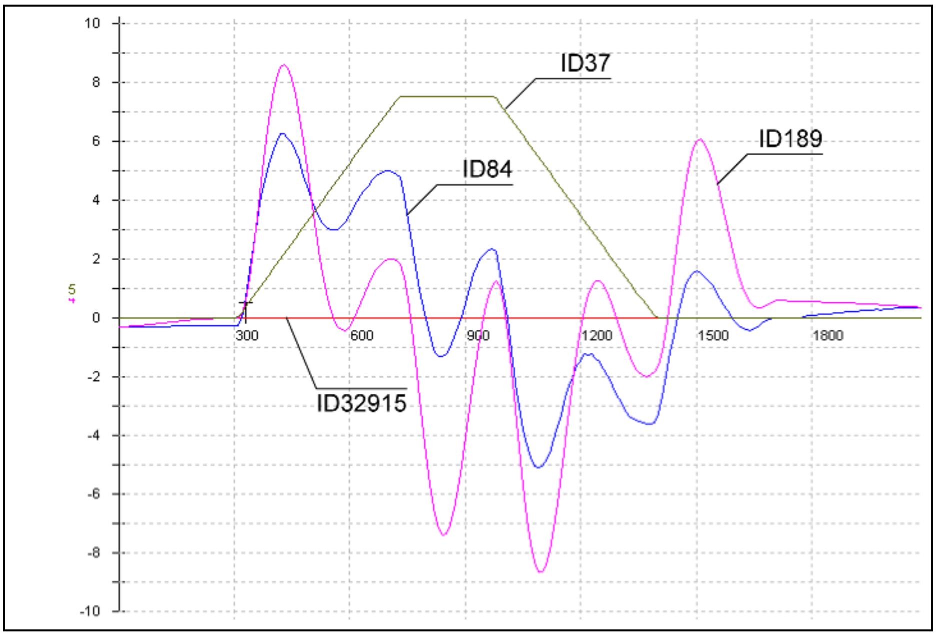
Example moment of inertia and frictional torque

The following signals were recorded with the AIPEX PRO oscilloscope.

Parameter ID	Parameter description	Colors in the following oscillograms
ID37	'Additive velocity command value'	Gray
ID84	'Torque feedback value'	Blue
ID189	'Following distance'	Magenta
ID32915	'Sum of additive torques'	Red

Initial situation: Movement profile without load model (torque control with feed-forward)

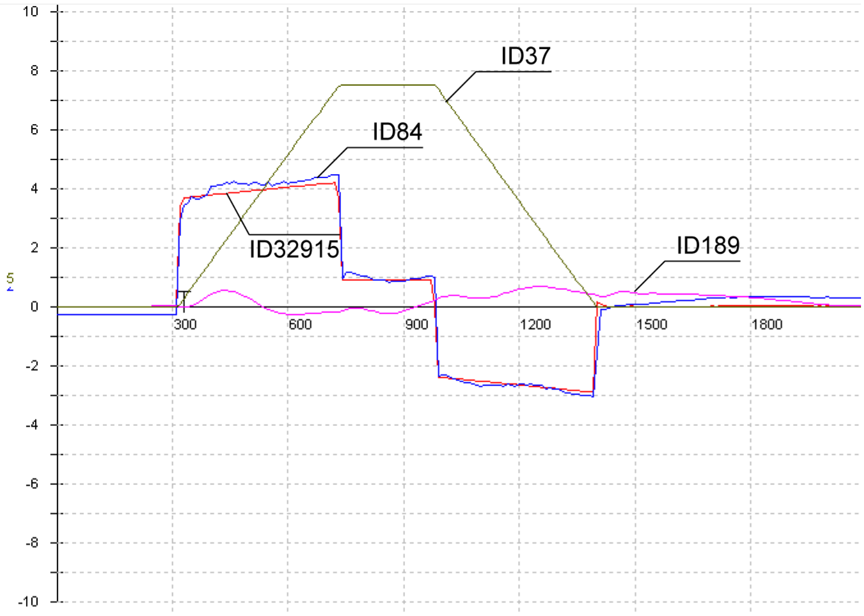
A fluctuating 'Following distance' ID189 can be seen in the recording. No control with feed-forward takes place, ID32915 'Sum of additive torques' is zero.



Recording movement profile with optimized load model

When the torque control with feed-forward is optimally set, ID32915 'Sum of additive torques' is nearly congruent with ID84 'Torque feedback value'. The 'Following distance' ID189 is clearly reduced by this.

The required torque is formed by the torque control with feed-forward.



Summary:

The load model shifts the predominant part of the control from the speed controller by means of the control with feed-forward to the faster current controller. This improves the control dynamics significantly.

Example optimization

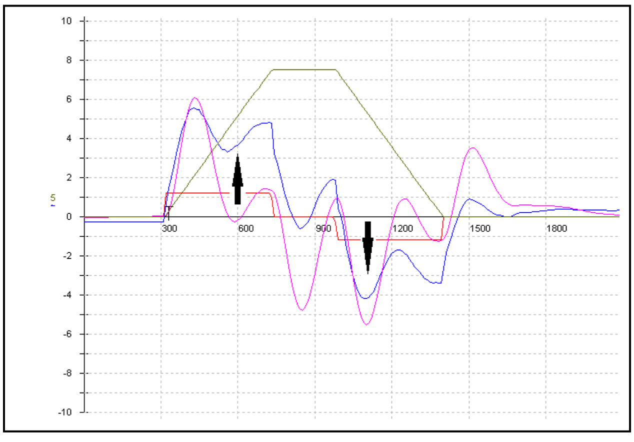
Using the AIPEX PRO oscilloscope, record the above-stated parameters while the drive performs a movement profile with speed ramp.
(the following oscillograms were created with a laboratory model.)

Optimizing the moment of inertia

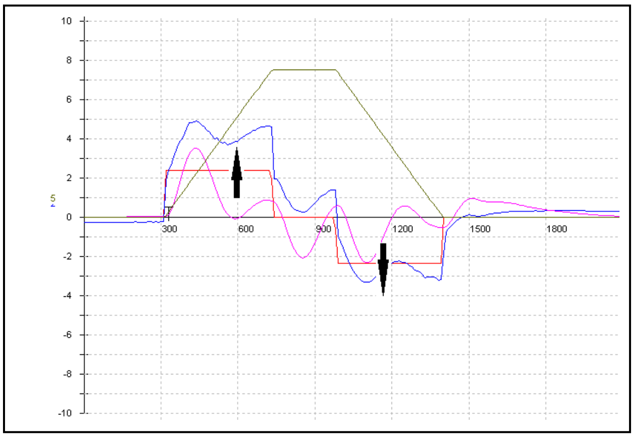
Firstly, the 'Inertia' is determined. The 'Inertia' has an effect in the acceleration phases.
ID34224 'Inertia' is increased until ID32915 'Sum of additive torques' lies just within the curve of ID84 'Torque feedback value'.

ID34224 = 100 kgcm^2

During the acceleration phases, the 'Sum of additive torques' increases, the 'Following distance' reduces, the 'Torque feedback value' becomes smoother.

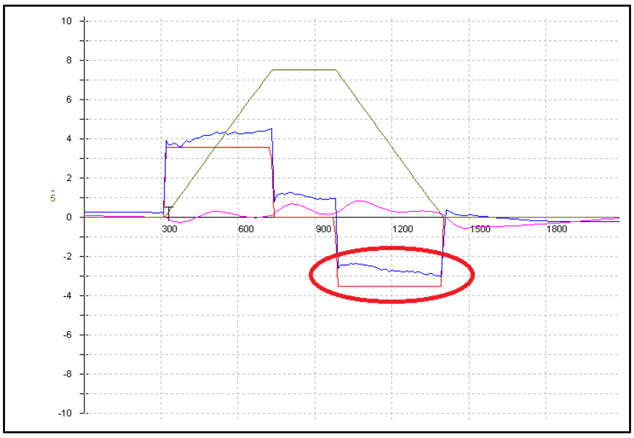


ID34224 = 200 $kgcm^2$



ID34224 = 300 $kgcm^2$

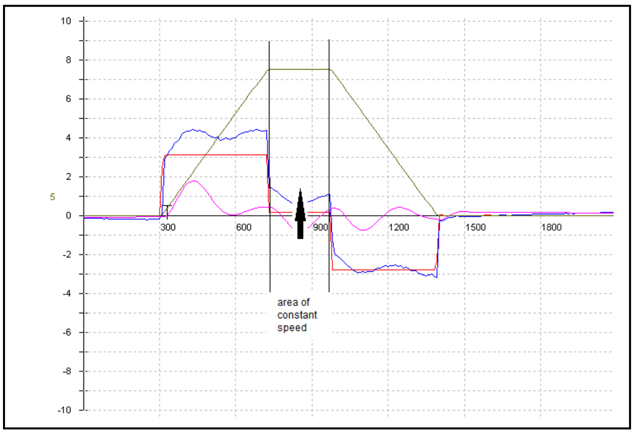
During the acceleration phase, the 'Sum of additive torques' lies within the curve of ID84 'Torque feedback value'. However, in the negative acceleration phase it is uncompensated, the 'Sum of additive torques' exceeds the curve of ID84 'Torque feedback value'. The 'Inertia' ID34224 must be reduced.



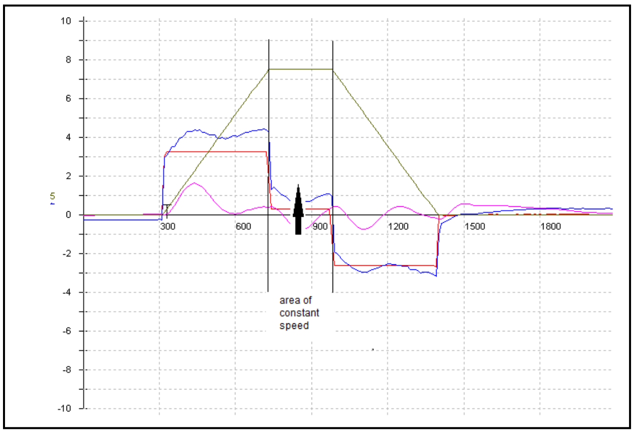
Optimizing the frictional torque

The 'Friction torque' ID34221 is subsequently determined. The 'static frictional torque' has its full effect when $n_{actual} \geq n_{friction\ threshold}$. (ID34224 'Inertia'remains constant.)
The frictional torque shifts the curve of the 'Sum of additive torques' parallel to the x-axis, until ID32915 'Sum of additive torques' and ID84 'Torque feedback value' are approximately covered in the area of constant speed.

ID34221 = 0.5 Nm

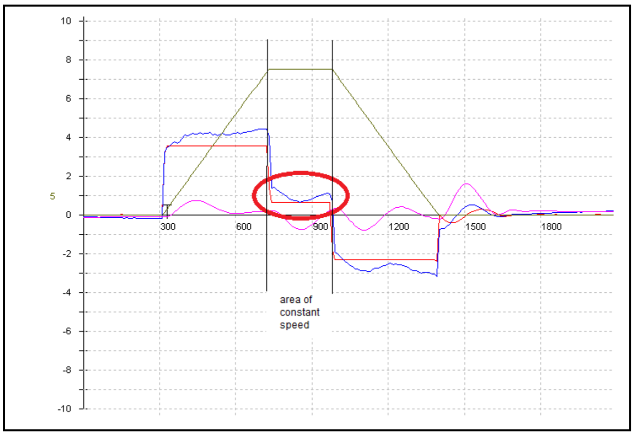


ID34221 = 1.0 Nm



ID34221 = 2.0 Nm

In the area of constant speed, the 'Sum of additive torques' is approximately congruent with ID84 'Torque feedback value'.

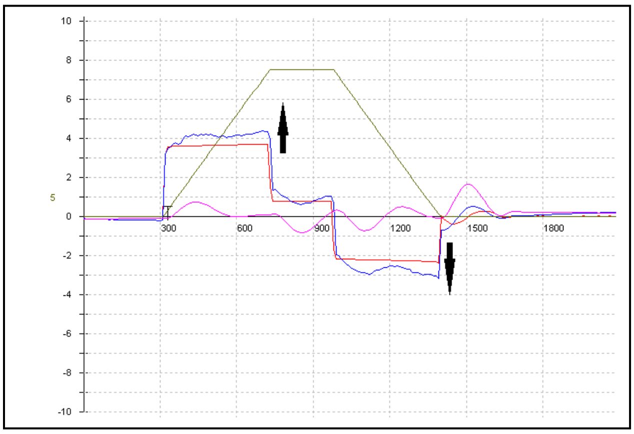


Optimizing the linear frictional torque

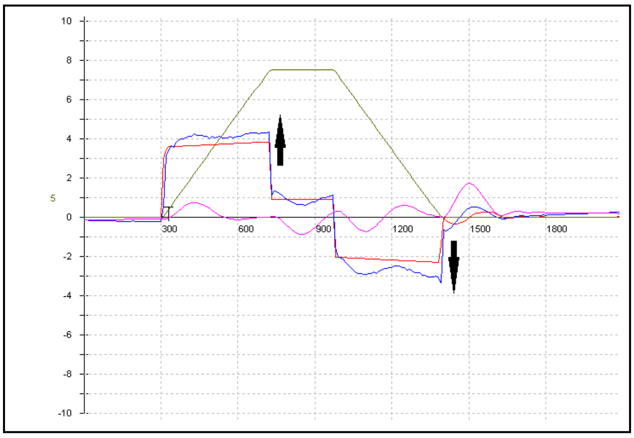
In the third step, ID34222 'Friction torque linear' is determined. The 'Friction torque linear' is proportional to the speed. (ID34224 'Inertia' and ID34221 'Friction torque' remain constant.)

The 'linear frictional torque' tilts the curve of the 'Sum of additive torques' in the areas of the increasing or falling speed values.

ID34222 = 1.0 Nm

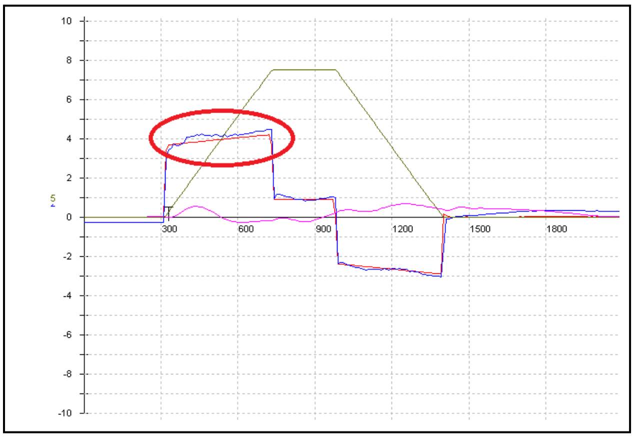


ID34222 = 2.0 Nm



ID34222 = 3.0 Nm

The 'Sum of additive torques' increases during the acceleration by means of the frictional torque proportional to the speed.



Optimizing the holding torque

The holding torque can be determined in the speed control operating mode. To do this, ID84 'Torque feedback value' must be read out during controlled stop of the motor (speed setpoint = 0).

The input value for the ID34223 'Holding torque' is calculated using the following formula. Refer to the motor data sheet for ID32771 'Nominal torque'.

$$\mathrm{ID34223} = \frac{\mathrm{ID84}}{100} \times \mathrm{ID32771}$$

Parameter ID	Parameter description	Colors in the following oscillogram
ID37	'Additive velocity command value'	Red
ID84	'Torque feedback value'	Green
ID32915	'Sum of additive torques'	Light blue

Example:

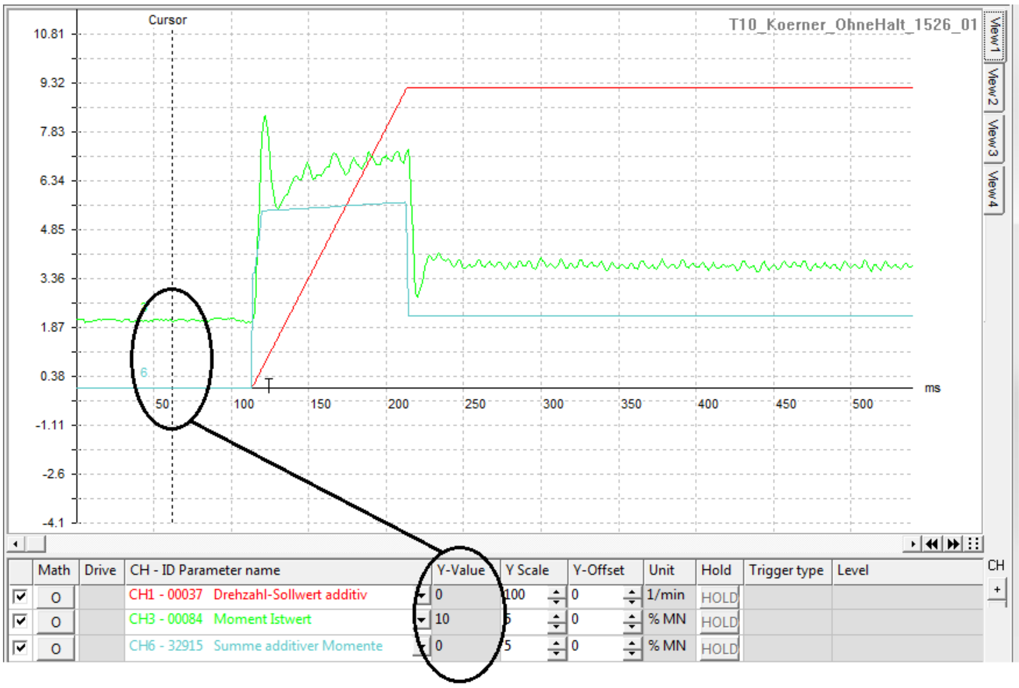
ID32771 'Nominal torque' amounts to 4.4 Nm according to the motor data sheet.

In controlled stop of the motor (speed setpoint = 0), ID84 'Torque feedback value' amounts to 10 %M_N according to the following measurement.

Calculation ID34223 'Holding torque'

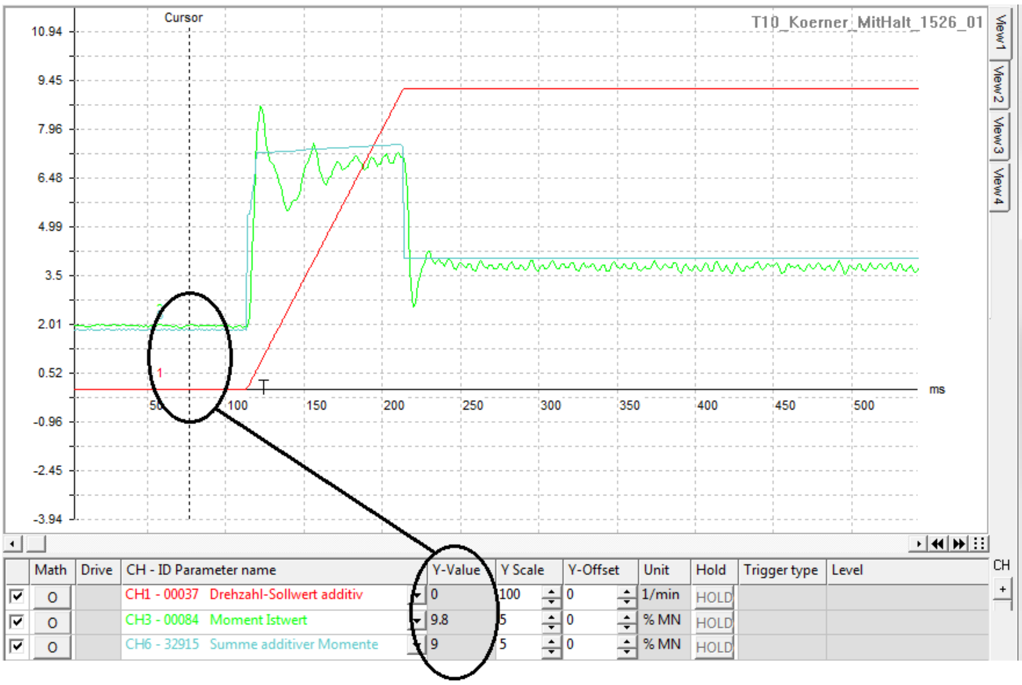
$$\mathrm{ID34223} = \frac{\mathrm{ID84}}{100} \times \mathrm{ID32771}$$

$$\mathrm{ID34223} = \frac{10\ \%\mathrm{M_N}}{100} \times 4.4\ \mathrm{Nm}\ =\ 0.4\ \mathrm{Nm}$$



ID34223 = 0.4 Nm

In controlled stop of the motor (speed setpoint = 0), ID32915 'Sum of additive torques' is nearly congruent with the 'Torque feedback value'. In the following course of the measurement (acceleration / constant speed), the holding torque is a part of the 'Sum of additive torques'.



5 Relevant parameters

Parameter	Parameter description	Meaning See document 'Parameter description' (AMK part no. 203704)
ID37 [3)]	'Additive velocity command value'	Additive speed setpoint
ID81 [3)]	'Additive torque command value'	Additive torque setpoint
ID194 [3)]	'Acceleration setpoint'	Acceleration setpoint of a movement
ID32800 [1)] ID32801 ... ID32805	'AMK main operating mode' 'AMK secondary operating modes'	Bit strip for configuration of the operating mode
ID34221 [1)]	'Friction torque'	Static frictional torque
ID34222 [1)]	'Friction torque linear'	Fluid friction, proportional to the speed, with the surfaces gliding on each other
ID34223 [1)]	'Holding torque'	Constant holding torque
ID34224 [1)]	'Inertia'	Moment of inertia, proportional to the acceleration
ID34225 [1)]	'Mode feed forward control'	Bit strip for configuring the load model

1) The parameter value must be set specific to the application

3) Parameter value is automatically generated by the controller card