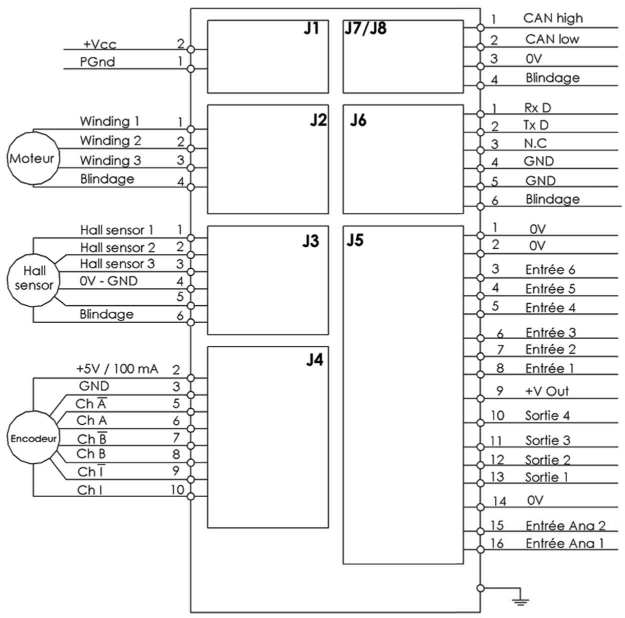
EPOS 24/5
Maxon

Les avantages :
Carte numérique de positionnement
pour moteur jusqu'à 120 W,
E/S digitales et analogiques,
Gestion des cycles de fonctionnement
(entrées-sorties logiques, liaison série ou CANopen),
Auto tuning des paramètres de régulation,
Interface graphique utilisateur.

4 quadrants / 120 W

Puissance max	120 W
Tension d'alimentation	11 à 24 VDC
Courant de sortie en pointe	10 A (<1s)
Courant de sortie permanent max	5A
Vitesse moteur maximum	25 000 tr/min (moteur 2 pôles)
Mode de régulation	Courant, Vitesse, Position
Mode de fonctionnement	Entrées/sorties digitales Liaison RS232 ou CAN
ENTREES :	
Description	6 entrées digitales 24 VDC
Analogiques	2 entrées analogiques résolution 10-bit 0.. +5 VDC
Codeur	A,A\,B,B\,I,I\ (max 1 MHz)
Liaison série	RS-232
Liaison CAN	CAN-ID configurable avec DIP Switch 1 ... 7
SORTIES :	
Description	4 sorties digitales 24 VDC
Alimentation sondes hall	+5 VDC , max. 30 mA
Alimentation codeur	+5 VDC , max. 100 mA
REGLAGES :	
Profil de déplacement	Accélération, décélération, vitesse, course
Paramètres de régulation	Recherche automatique (auto tuning)
Visualisation graphique	Courant, Vitesse, Position
PROTECTIONS :	
Suralimentation	Fusible
Surcharge de courant	Limitation par réglage
Court-circuit moteur	oui
Court-circuit sur entrées / sorties	oui
Court-circuit sur alim. Auxiliaire	oui
ENVIRONNEMENT :	
Exploitation	-10 à +45°C
Stockage	-40 à +85°C
Humidité relative	20 à 80% Non condensée
CONNEXIONS :	
Connecteur	Molex Mini-Fit Jr., Molex Micro-Fit 3.0
Connecteur codeur	Fiche DIN 41651
MECANIQUE :	
Poids	170 g
Boitier	105 x 83 x 24 mm
Fixation	Par vis M3



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9 Controller Architecture

9.1 In Brief

A wide variety of operating modes permit flexible configuration of drive and automation systems by using positioning, speed and current regulation. The built-in CANopen interface allows networking to multiple axes drives as well as online commanding by CAN bus master units.

In addition to the standard EPOS2 PID position control, also feedforward compensation is available. The feedforward compensation provides faster setpoint following in applications with higher load inertia and accelerations and/or in applications with considerable speed-dependent load (as with friction-afflicted drives). With some EPOS2 Positioning Controllers, dual loop regulation is available.

9.1.1 Objective

The present Application Note explains the EPOS2 controller architecture. Furthermore explained will be mapping of internal controller parameters to controller parameters in SI units, and vice versa.

In addition to PID position regulation, the functionalities of built-in acceleration and velocity feedforward are described. Their advantages, compared to simple PID control are shown using two “in practice examples”.

Contents

9.1.2 Scope

Hardware	Order #	Firmware Version	Reference
EPOS2		2121h	Firmware Specification
EPOS2 70/10	375711	2120h or higher	
EPOS2 50/5	347717	2110h or higher	
EPOS2 Module 36/2	360665	2110h or higher	
EPOS2 24/5	367676	2110h or higher	
EPOS2 24/2	380264 390003 390438	2121h or higher	

Table 9-121 Controller Architecture – covered Hardware and required Documents

9.1.3 Tools

Tools	Description
Software	«EPOS Studio» Version 1.43 or higher

Table 9-122 Controller Architecture – recommended Tools

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9.2 Overview

The EPOS2 controller architecture contains three built-in control loops.

- Current regulation is used in all modes.
- Position and velocity controllers are only used in position-based, respectively velocity-based modes.
- Current control loop receives as input the position, respectively velocity controller's output.

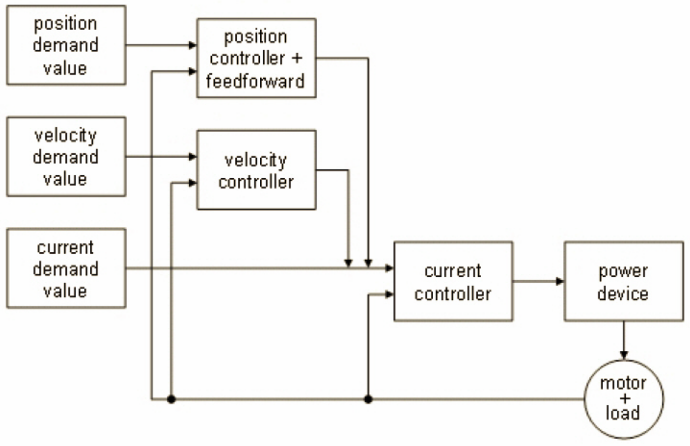

Figure 9-72 Controller Architecture

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9.3 Regulation Methods

9.3.1 Current Regulation

During a movement within a drive system, forces and/or torques must be controlled. Therefore, as a principal regulation structure, EPOS2 offers current-based control.

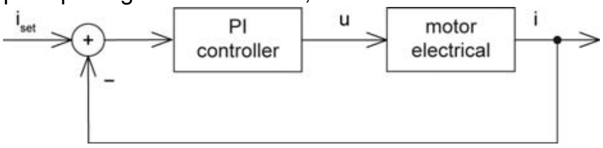

Figure 9-73 Controller Architecture – Current Regulator

Constants

Sampling period: T_s = 100 µs

Object Dictionary Entries

Symbol	Name	Index	Subindex
K_{P_EPOS2}	Current Regulator P-Gain	0x60F6	0x01
K_{I_EPOS2}	Current Regulator I-Gain	0x60F6	0x02

Table 9-123 Current Regulation – Object Dictionary

Conversion of PI Controller Parameters (EPOS2 to SI Units)

$$K_{P...SI} = \frac{1\Omega}{2^8} \cdot K_{P...EPOSs} = 3.91m\Omega \cdot K_{P...EPOS2}$$

$$K_{I...SI} = \frac{1\Omega}{2^8 T_s} \cdot K_{I...EPOSs} = 3.91\frac{\Omega}{s} \cdot K_{I...EPOS2}$$

Current controller parameters in SI units can be used in analytical calculations, respectively numerical simulations via transfer function:

$$C_{current}(s) = K_{P...SI} + \frac{K_{I...SI}}{s}$$

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9.3.2 Velocity Regulation (with Feedforward)

Based on the subordinated current control, EPOS2 also offers velocity regulation.

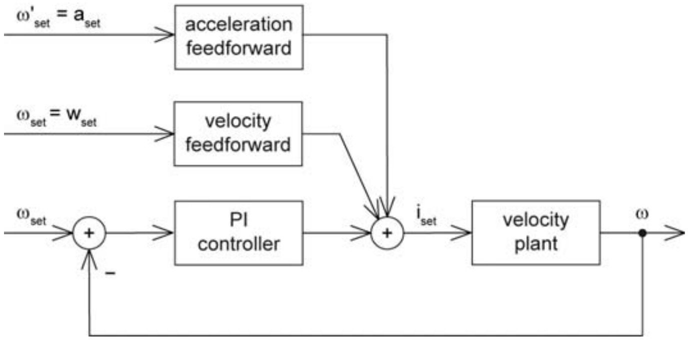

Figure 9-74 Controller Architecture – Velocity Regulator

Constants

Sampling period: T_s = 1 ms

Object Dictionary Entries

Symbol	Name	Index	Subindex
K_{P_EPOS2}	Speed Regulator P-Gain	0x60F9	0x01
K_{I_EPOS2}	Speed Regulator I-Gain	0x60F9	0x02
K_{ω_EPOS2}	Velocity Feedforward Factor in Speed Regulator	0x60F9	0x04
K_{α_EPOS2}	Acceleration Feedforward Factor in Speed Regulator	0x60F9	0x05

Table 9-124 Velocity Regulation – Object Dictionary

Conversion of PI Controller Parameters (EPOS2 to SI Units)

$$K_{P...SI} = 20\frac{\mu A}{(rad)/s} \cdot K_{P...EPOS2}$$

$$K_{I...SI} = 5\frac{(mA)/s}{(rad)/s} \cdot K_{I...EPOS2}$$

Velocity controller parameters in SI units can be used in analytical calculations, respectively numerical simulations via transfer function:

$$C_{velocity}(s) = K_{P...SI} + \frac{K_{I...SI}}{s}$$

Conversion of Feedforward Parameters (EPOS2 to SI Units)

Velocity feedforward: $K_{\omega...SI} = 1\frac{\mu A}{(rad)/s} \cdot K_{\omega...EPOS2}$

Acceleration feedforward: $K_{\alpha...SI} = 1\frac{\mu A}{(rad)/s^2} \cdot K_{\alpha...EPOS2}$

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9.3.3 Position Regulation (with Feedforward)

Based on the subordinated current control, EPOS2 is able to close a positioning control loop.

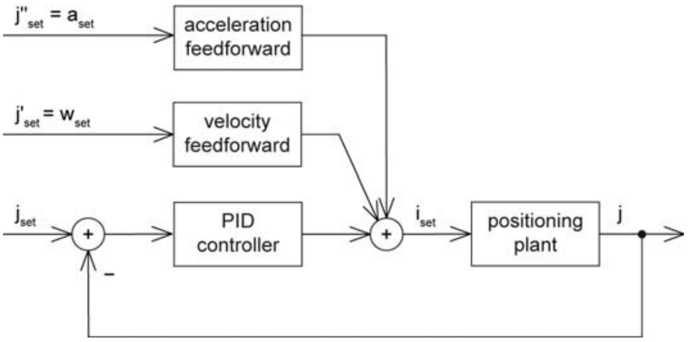

Figure 9-75 Controller Architecture – Position Regulator with Feedforward

Constants

Sampling period: T_s = 1 ms

Object Dictionary Entries

Symbol	Name	Index	Subindex
K_{P_EPOS2}	Position Regulator P-Gain	0x60FB	0x01
K_{I_EPOS2}	Position Regulator I-Gain	0x60FB	0x02
K_{D_EPOS2}	Position Regulator D-Gain	0x60FB	0x03
K_{ω_EPOS2}	Velocity Feedforward Factor in Position Regulator	0x60FB	0x04
K_{α_EPOS2}	Acceleration Feedforward Factor in Position Regulator	0x60FB	0x05

Table 9-125 Position Regulation with Feedforward – Object Dictionary

The position controller is implemented as PID controller. To improve the motion system's setpoint following, positioning regulation is supplemented by feedforward control. Thereby, velocity feedforward serves for compensation of speed-proportional friction, whereas acceleration feedforward considers known inertia.

Conversion of PI Controller Parameters (EPOS2 to SI Units)

$$K_{P...SI} = 10\frac{mA}{rad} \cdot K_{P...EPOS2}$$

$$K_{I...SI} = 78\frac{(mA)/s}{rad} \cdot K_{I...EPOS2}$$

$$K_{D...SI} = 80\frac{\mu As}{rad} \cdot K_{D...EPOS2}$$

Position controller parameters in SI units can be used in analytical calculations, respectively numerical simulations via transfer function:

$$C_{position}(s) = K_{P...SI} + \frac{K_{I...SI}}{s} + \frac{K_{D...SI}s}{1 + \frac{K_{D...SI}}{16K_{P...SI}}s}$$

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Conversion of Feedforward Parameters (EPOS2 to SI Units)

Velocity feedforward: $K_{\omega...SI} = 1\frac{\mu A}{(rad)/s} \cdot K_{\omega...EPOS2}$

Acceleration feedforward: $K_{\alpha...SI} = 1\frac{\mu A}{(rad)/s^2} \cdot K_{\alpha...EPOS2}$

9.3.4 Operation Modes with Feedforward

Acceleration and velocity feedforward have an effect in «Profile Position Mode», «Profile Velocity Mode» and «Homing Mode». All other operating modes are not influenced.

9.3.4.1 Purpose of Velocity Feedforward

Velocity feedforward provides additional current in cases, where the load increases with speed, such as speed-dependent friction. The load is assumed to increase proportional with speed. The optimal velocity feedforward parameter in SI units is…

$$K_{\omega...SI} = \frac{r}{k_M}$$

Meaning: With given total friction proportional factor “r” relative to the motor shaft, and the motor’s torque constant “k_M”, you ought to adjust the velocity feedforward parameter to…

$$K_{\omega...EPOS2} = \frac{r}{k_M} \cdot \frac{(rad)/s}{1\mu A} = \frac{r}{k_M} \cdot \frac{10^6 (rad)/s}{A}$$

9.3.4.2 Purpose of Acceleration Feedforward

Acceleration feedforward provides additional current in cases of high acceleration and/or high load inertias. The optimal acceleration feedforward parameter in SI units is…

$$K_{\alpha...SI} = \frac{J}{k_M}$$

Meaning: With given total inertia “J” relative to the motor shaft, and the motor’s torque constant “k_M”, you ought to adjust the acceleration feedforward parameter to…

$$K_{\alpha...EPOS2} = \frac{J}{k_M} \cdot \frac{(rad)/s^2}{1\mu A} = \frac{J}{k_M} \cdot \frac{10^6 (rad)/s^2}{A}$$

9.4 Regulation Tuning

maxon motor’s «EPOS Studio» features «Regulation Tuning» as powerful wizard allowing to automatically tune all controller and feedforward parameters described above for most drive systems within a few minutes. For details ➔chapter “7 Regulation Tuning” on page 7-91.

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9.5 Dual Loop Regulation

Available with EPOS2 70/10, EPOS2 50/5 and EPOS2 Module 36/2 only!

In many applications it is common to use gears to increase motor torque, or screw spindles to transform motor rotation into linear movement. The gear itself is made of a lot of different parts, such as, belts, pinions, pulleys, spindles, etc.

The associated elasticity and backlash of these parts create an effect of compliance and as well as a delay in the drive chain. Often, the mechanical transmission between motor and load has some backlash, too, resulting in a certain “delay” being introduced to the plant. This delay influences the regulation stability and may have such big impact that one may be forced to reduce the dynamic behavior or the precision of the drive.

To overcome these limitations and to combine a motor/gear system with a precise and high dynamic regulation, it will be necessary to control the motor movement as well as the load movement. This results in a new control structure called “dual loop”, featuring two individual encoders – one directly mounted to the motor, the another mounted at the gear or linear slide or directly on/near to the load.

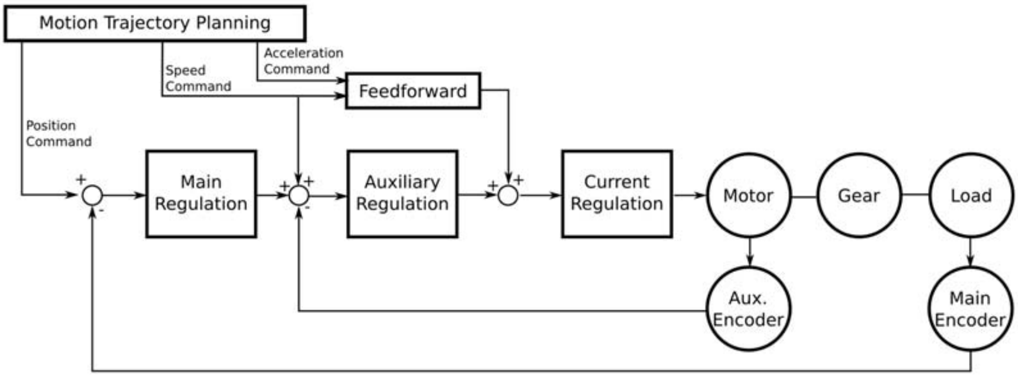

Figure 9-76 Dual Loop Architecture

The auxiliary regulation is designed to provide damping and dynamic system behavior while the main regulation generates the desired position precision.

9.5.1 Current Regulation

The dual loop current controller is implemented similar to the current controller in a single loop system. For details ➔chapter “9.3.1 Current Regulation” on page 9-117.

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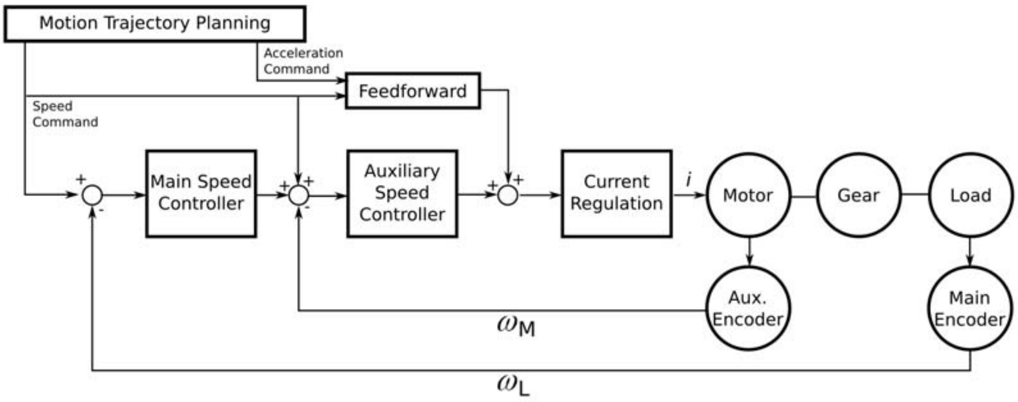
9.5.2 Velocity Regulation (with Feedforward)

The design is based on current regulation.



ω_M	motor speed
ω_L	load speed

Figure 9-77 Dual Loop Velocity Regulation

In velocity mode, the auxiliary controller appropriately stabilizes the loop; however, the main controller provides the correct speed feedback.

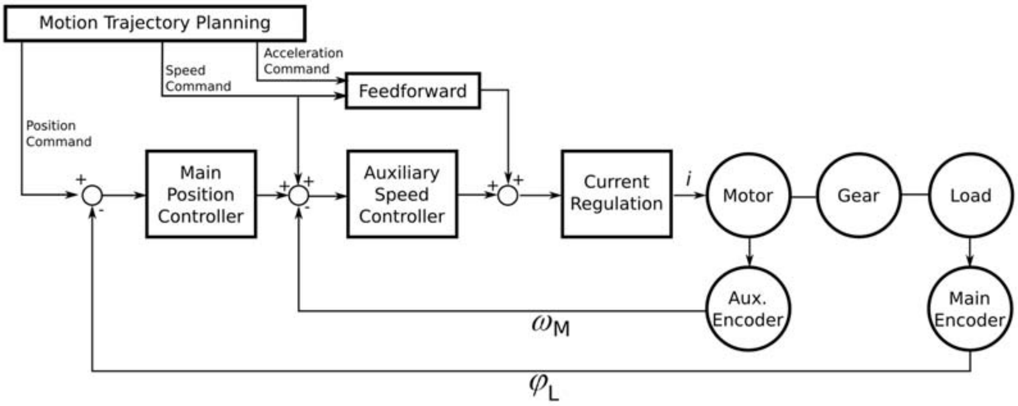
The dual loop velocity controller (that is main controller and auxiliary controller together) is implemented as PI controller.

Conversion parameters

Conversion of PI controller and feedforward parameters in dual loop (EPOS2 to SI units) are identical to that in single loop (➔chapter “9.3.2 Velocity Regulation (with Feedforward)” on page 9-118).

9.5.3 Position Regulation (with Feedforward)

The design is based on current regulation.



ω_M	motor speed
φ_L	load position

Figure 9-78 Dual Loop Position Regulation

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In position mode, the auxiliary controller is designed to stabilize the loop, whereas the main controller provides the correct position feedback.

The dual loop position controller (that is main controller and auxiliary controller together) is realized as PID controller and features the same sampling period as the dual loop velocity controller.

Conversion parameters

Conversion of PI controller and feedforward parameters in dual loop (EPOS2 to SI units) are identical to that in single loop (➔chapter “9.3.3 Position Regulation (with Feedforward)” on page 9-119).

9.5.4 Conclusion

The dual loop topology is adequate if the ratio of motor inertia and load inertia is not too large. The drive elements (motor, gear, encoders, load) must be dimensioned correctly.

General Selection Practice

To achieve reliability of the system, follow the scheme below to determine the individual components:

- **Motor**
  Chose a motor capable to fulfill the load’s requirements for maximum torque, continuous torque, and speed. For detailed information ➔chapter “1.6 Sources for additional Information” on page 1-11, item [7].
- **Gear**
  Chose a gear capable to fulfill the load’s torque and speed range. Boundary conditions are maximum motor load, maximum gear load, and the associated speed limits.
  Another influence that might need consideration is the minimum motor heat dissipation capability. Use the following formula to determine the optimum gear ratio:

  $$I = \sqrt{\frac{Jl}{Jm}}$$

  Jl load inertia
  Jm motor inertia
- **Motor Encoder**
  Chose a motor encoder capable to provide sufficient stiffness in the inner loop. A few hundred increments per revolution as the motor encoder’s minimum resolution are recommended.
- **Load Encoder**
  Chose a load encoder capable to at least deliver the required resolution and accuracy on the load side.

General Rule
With Dual Loop Regulation, the following general restriction applies:

$$AuxEncoderResolution \cdot GearRatio \leq MainEncoderResolution$$

9.5.5 Auto Tuning

The dual loop start up is similar to the start up of the single loop regulation and can be described with the following major steps:

1) Identification and modeling of the plant.
2) Calculation of all controller parameters (current, auxiliary, main, feedforward).
3) Mapping; the calculated controller parameters (main, auxiliary) are mathematically transformed to PI controller parameters (for velocity regulation) or to PID controller parameters (for position regulation).
4) Verification; the system’s dynamic response is measured and displayed using the scope function in «EPOS2 Studio». This allows verification, whether the system behavior is as expected.

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9.6 Application Examples

Please find below two “in practice examples” suitable for daily use.

For comparability and validity reasons, the measured simulation results are converted to the units “mA”, “rpm” and “qc”!

9.6.1 Example 1: System with high Inertia and low Friction

System Components

Item	Description	Setting
Controller EPOS2 50/5 (347717)		
Motor maxon EC 40 (118896)	No load speed (line 2)	n_0 = 10’400 rpm
	No load current (line 3)	I_0 = 258 mA
	Nominal current (line 6)	I_n = 3.4 A
	Resistance phase to phase (line 10)	R = 1.25 Ω
	Inductance phase to phase (line 11)	L = 0.319 mH
	Torque constant (line 12)	k_M = 38.2 mNm/A
	Rotor inertia (line 16	J_{motor} = 85 gcm^2
Encoder HEDL 5540 (110516)	Encoder pulse number	500
Mechanical load Fly wheel	Inertia	J_{load} = 5000 gcm^2

Table 9-126 Controller Architecture – Example 1: Components

Model of the Plant

The following parameters can be deduced:

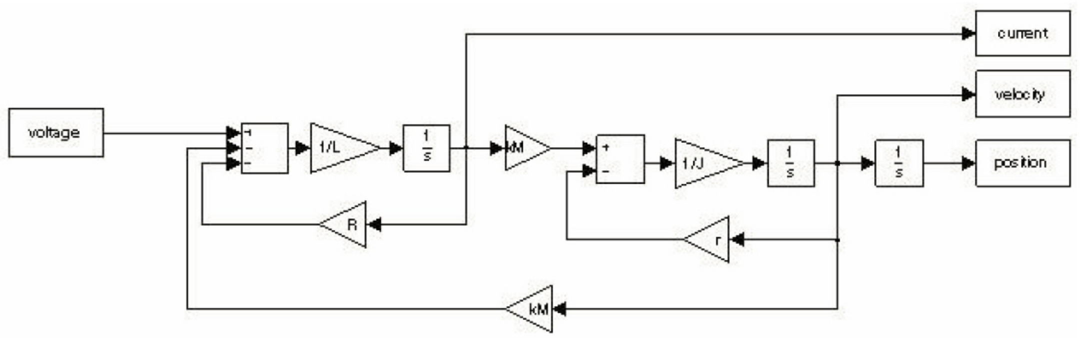

Figure 9-79 Example1 – Block Diagram

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Electrical Part

R = 1.25 Ω

L = 0.319 mH

Interface between electrical and mechanical Parts

$$k_M = 38.2\frac{mNm}{A}$$

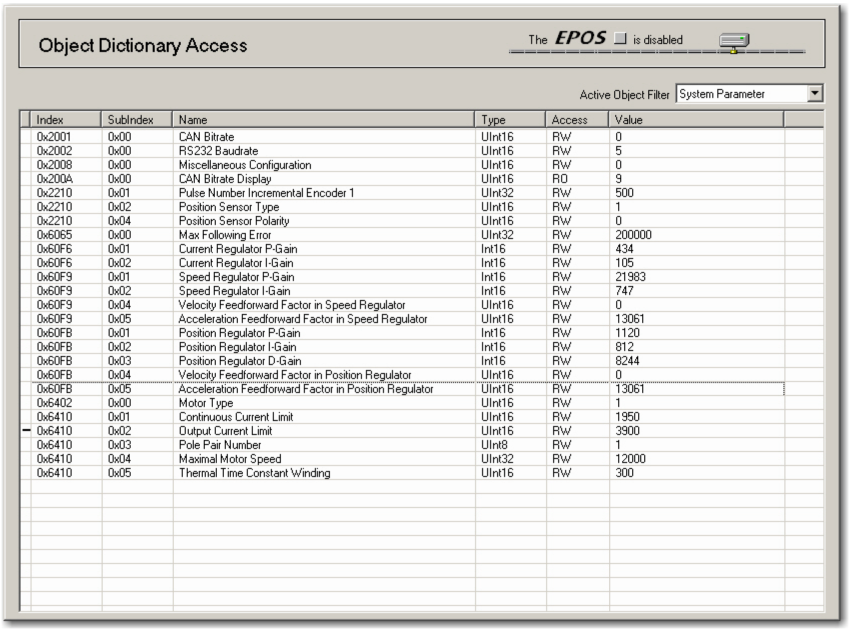
Mechanical Part

$$J = J_{motor} + J_{load} = 5085gcm^2$$

$$r = \frac{k_M I_0}{n_0 \frac{2\pi rad}{1} \cdot \frac{1min}{60s}} = \frac{9.86mNm}{1089rad^2} = 9.05\frac{\mu Nm}{(rad)/s}$$

- Input is the voltage at the motor winding.
- Outputs are current, velocity or position.

Regulation Tuning as to the described conditions results in the following controller and feedforward parameters:



Index	SubIndex	Name	Type	Access	Value
0x2001	0x00	CAN Bitrate	UInt16	RW	0
0x2002	0x00	RS232 Baudrate	UInt16	RW	5
0x2008	0x00	Miscellaneous Configuration	UInt16	RW	0
0x200A	0x00	CAN Bitrate Display	UInt16	RO	9
0x2210	0x01	Pulse Number Incremental Encoder 1	UInt32	RW	500
0x2210	0x02	Position Sensor Type	UInt16	RW	1
0x2210	0x04	Position Sensor Polarity	UInt16	RW	0
0x6065	0x00	Max Following Error	UInt32	RW	200000
0x60F6	0x01	Current Regulator P-Gain	Int16	RW	434
0x60F6	0x02	Current Regulator I-Gain	Int16	RW	105
0x60F9	0x01	Speed Regulator P-Gain	Int16	RW	21983
0x60F9	0x02	Speed Regulator I-Gain	Int16	RW	747
0x60F9	0x04	Velocity Feedforward Factor in Speed Regulator	UInt16	RW	0
0x60F9	0x05	Acceleration Feedforward Factor in Speed Regulator	UInt16	RW	13061
0x60FB	0x01	Position Regulator P-Gain	Int16	RW	1120
0x60FB	0x02	Position Regulator I-Gain	Int16	RW	812
0x60FB	0x03	Position Regulator D-Gain	Int16	RW	8244
0x60FB	0x04	Velocity Feedforward Factor in Position Regulator	UInt16	RW	0
0x60FB	0x05	Acceleration Feedforward Factor in Position Regulator	UInt16	RW	13061
0x6402	0x00	Motor Type	UInt16	RW	1
0x6410	0x01	Continuous Current Limit	UInt16	RW	1950
0x6410	0x02	Output Current Limit	UInt16	RW	3900
0x6410	0x03	Pole Pair Number	UInt8	RW	1
0x6410	0x04	Maximal Motor Speed	UInt32	RW	12000
0x6410	0x05	Thermal Time Constant Winding	UInt16	RW	300

Figure 9-80 Example1 – System Parameters, real

For numerical simulation, the conversion results from EPOS2 to SI units are as follows:

Current Controller

$$K_{P...EPOS2} = 434 \quad \rightrightarrows \quad K_{P...SI} = 1.70\Omega$$

$$K_{I...EPOS2} = 105 \quad \rightrightarrows \quad K_{I...SI} = 4.11\frac{k\Omega}{s}$$

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Velocity Controller

$$K_{P\ldots EPOS2} = 21983 \quad \rightrightarrows \quad K_{P\ldots SI} = 0.440\frac{A}{(rad)/s}$$

$$K_{I\ldots EPOS2} = 747 \quad \rightrightarrows \quad K_{I\ldots SI} = 3.74\frac{A/s}{(rad)/s}$$

Position Controller

$$K_{P\ldots EPOS2} = 1120 \quad \rightrightarrows \quad K_{P\ldots SI} = 11.2\frac{A}{rad}$$

$$K_{I\ldots EPOS2} = 812 \quad \rightrightarrows \quad K_{I\ldots SI} = 63.2\frac{A/s}{rad}$$

$$K_{D\ldots EPOS2} = 8244 \quad \rightrightarrows \quad K_{D\ldots SI} = 0.660\frac{As}{rad}$$

Positioning and Velocity Feedforward

$$K_{\omega\ldots EPOS2} = 0 \quad \rightrightarrows \quad K_{\varpi\ldots SI} = 0\frac{A}{(rad)/s}$$

$$K_{\alpha\ldots EPOS2} = 13061 \quad \rightrightarrows \quad K_{\alpha\ldots SI} = 13.06\frac{mA}{(rad)/s^2}$$

Plausibility Check

$$K_{\omega\ldots SI} = \frac{r}{k_M} = 237\frac{\mu A}{(rad)/s} \quad (\rightrightarrows) \quad K_{\varpi\ldots SI} = 237\frac{\mu A}{(rad)/s} \sim 0\frac{A}{(rad)/s}$$

$$K_{\omega\ldots SI} = \frac{J}{k_M} = \frac{5085 \cdot 10^{-7}\frac{Nm}{(rad)/s}}{38.2 \cdot 10^{-3}\frac{Nm}{A}} = 13.3\frac{mA}{(rad)/s^2}$$

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Verification of Current Control

The plant is connected to the PI current controller. The controller is parameterized as described above.

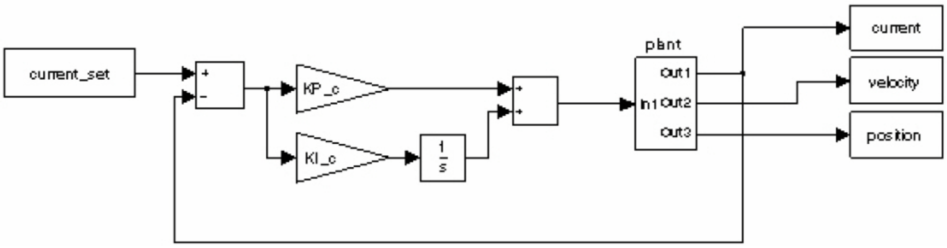

Figure 9-81   Example1 – Current Regulation, Block Model

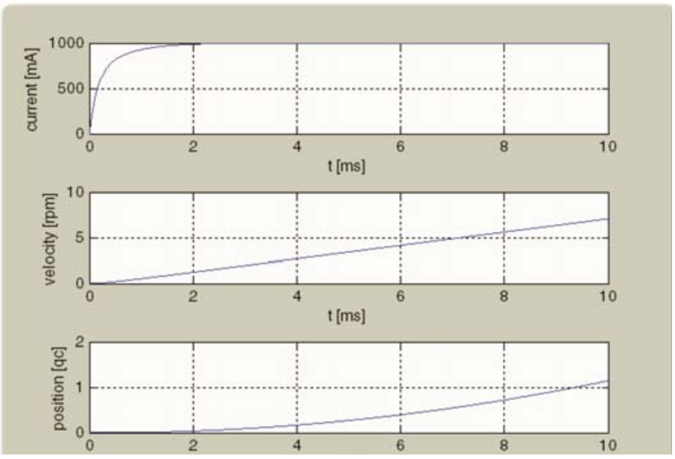

Figure 9-82   Example1 – Current Regulation, simulated

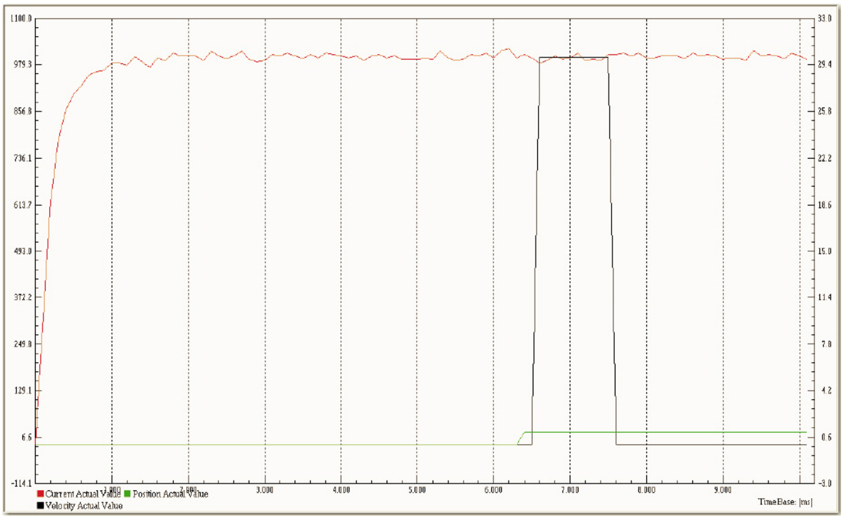

Figure 9-83   Example1 – Current Regulation, measured

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Verification of Velocity Control

The PI velocity controller is connected to current regulation.

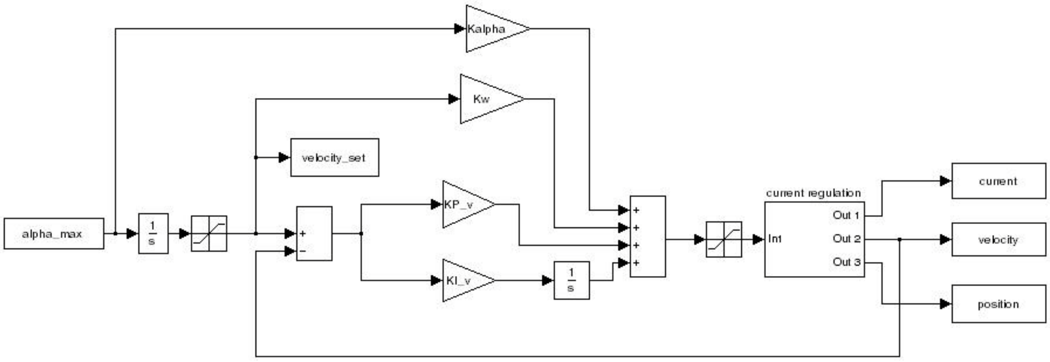

Figure 9-84 Example1 – Velocity Regulation, Block Model

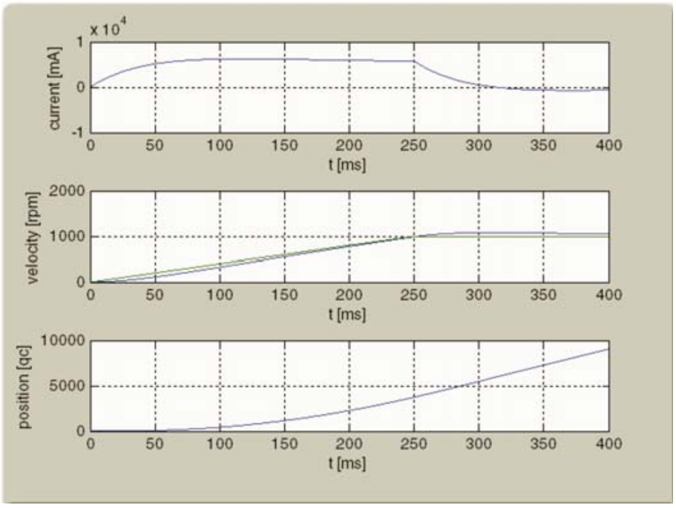

Figure 9-85 Example1 – Velocity Regulation, simulated

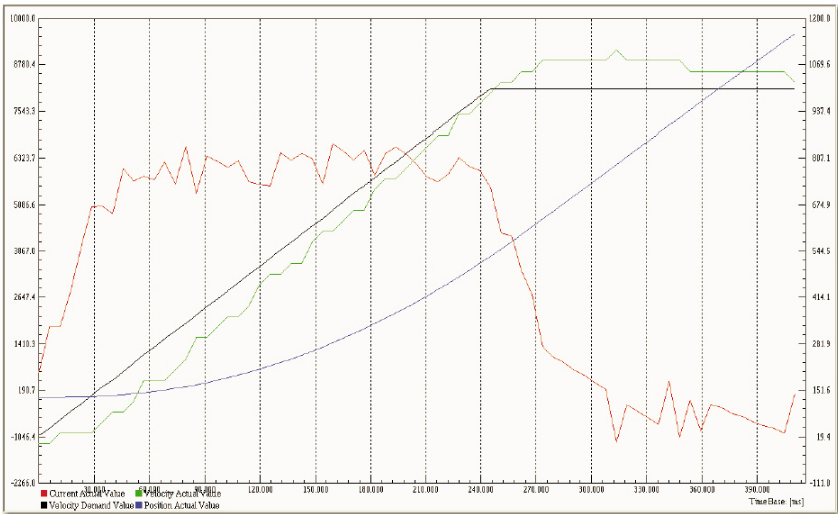

Figure 9-86 Example1 – Velocity Regulation, measured

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Verification of Position Control with Feedforward

The PID position controller is connected to current regulation.

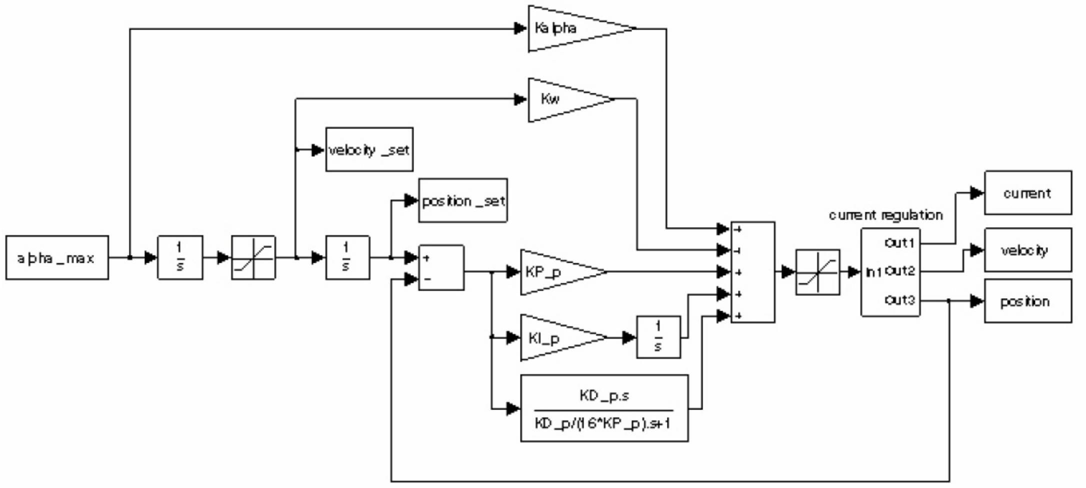

Figure 9-87 Example1 – Position Control with Feedforward, Block Model

With correct Feedforward

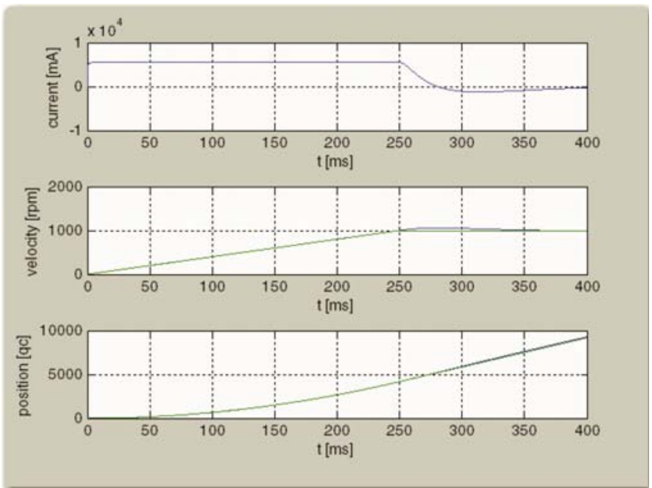

Figure 9-88 Example1 – Position Control with Feedforward, simulated

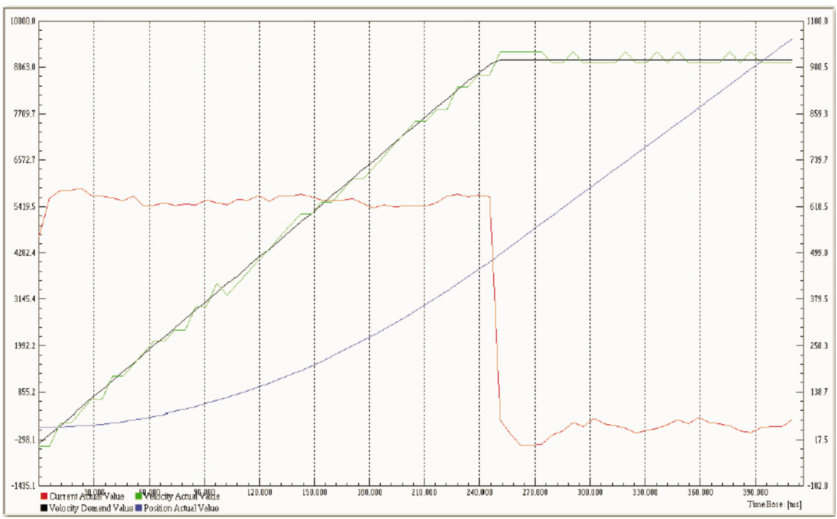

Figure 9-89 Example1 – Position Control with Feedforward, measured

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Without Feedforward

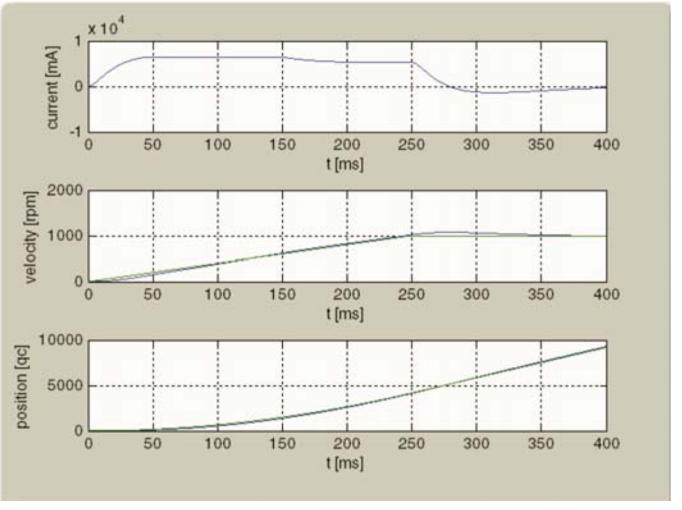

Figure 9-90 Example1 – Position Control without Feedforward, simulated

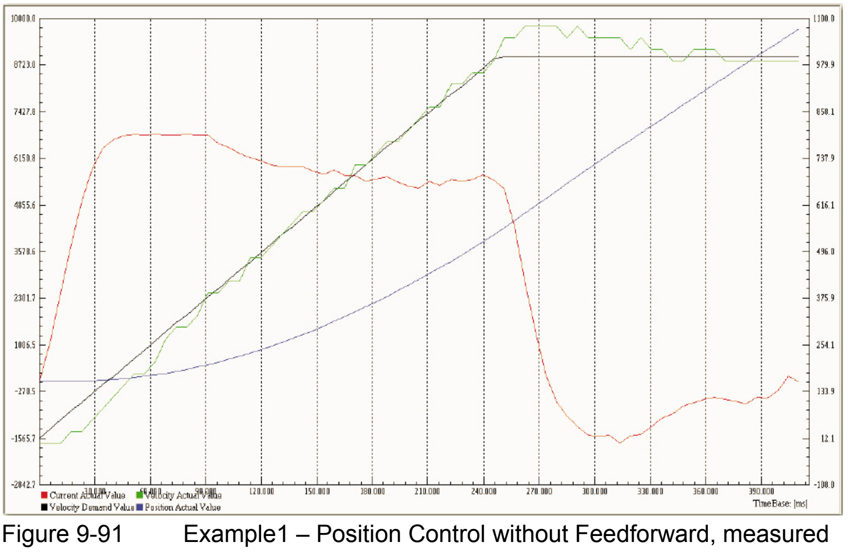

Figure 9-91 Example1 – Position Control without Feedforward, measured

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With incorrect Feedforward (acceleration Feedforward parameter doubled)

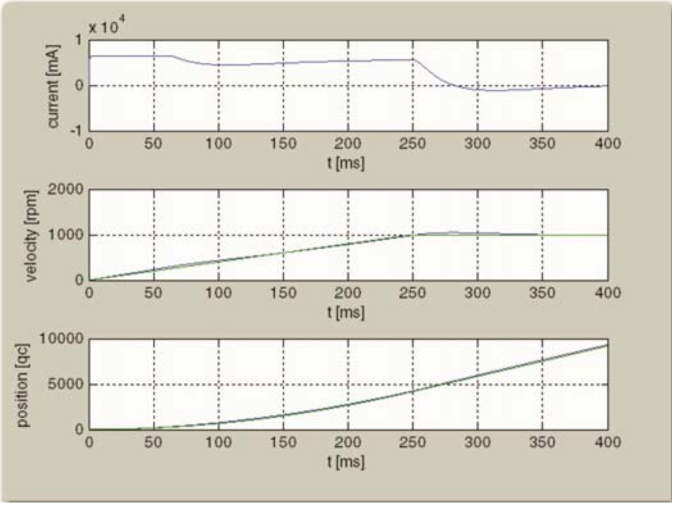

Figure 9-92 Example1 – Position Control with incorrect Feedforward, simulated

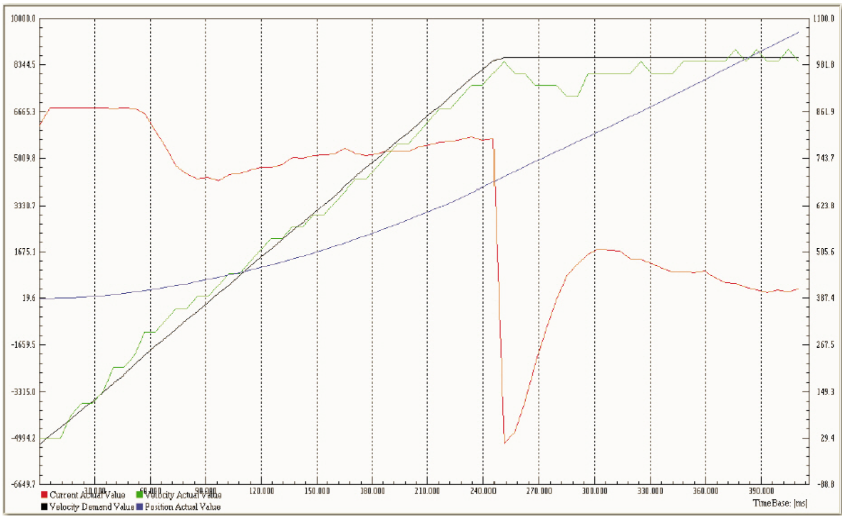

Figure 9-93 Example1 – Position Control with incorrect Feedforward, measured

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