EPOS

Positioning Controller

Application Note
"Position Regulation with Feed Forward"

Edition May 2008

EPOS 24/1, EPOS 24/5, EPOS 70/10, MCD EPOS
Firmware version 2020h or higher

Introduction

EPOS is a modular-designed digital positioning system suitable for DC and EC motors with incremental encoder. The performance range of these compact positioning controllers starts at a few Watt and goes up to 700 Watt (1750 Watt peak).

A variety of operating modes allows all kinds of drive and automation systems to be flexibly assembled using positioning, speed and current regulation. The built-in CANopen interface allows networking to multiple axis drives and online commanding by CAN bus master units.

In addition to the standard EPOS PID position control feed forward compensation is available.
This feed forward compensation provides good results in application with higher load inertia and accelerations and/or in applications with considerable speed dependent load (example: friction).

Objectives

This application note explains the functionality of the built-in acceleration and velocity feed forward. Advantages compared to simple PID control are shown.

References and Required Tool

The latest editions of maxon motor documents and tools are freely available at http://www.maxonmotor.com category «Service & Downloads».

Document	Suitable order number for EPOS Positioning Controller
EPOS Firmware Specification	280937, 302267, 302287, 317270, 275512, 300583

Tool	
EPOS Studio Version 1.30 or higher	280937, 302267, 302287, 317270, 275512, 347717, 300583

Controller architecture

For the position control a discrete PID controller with anti windup, acceleration feed forward and velocity feed forward was implemented using a digital signal processor (DSP) where the sample time (T_S) was taken at 1ms, much smaller than the mechanical time constant of a typical drive system. The structure is shown in the following figure.

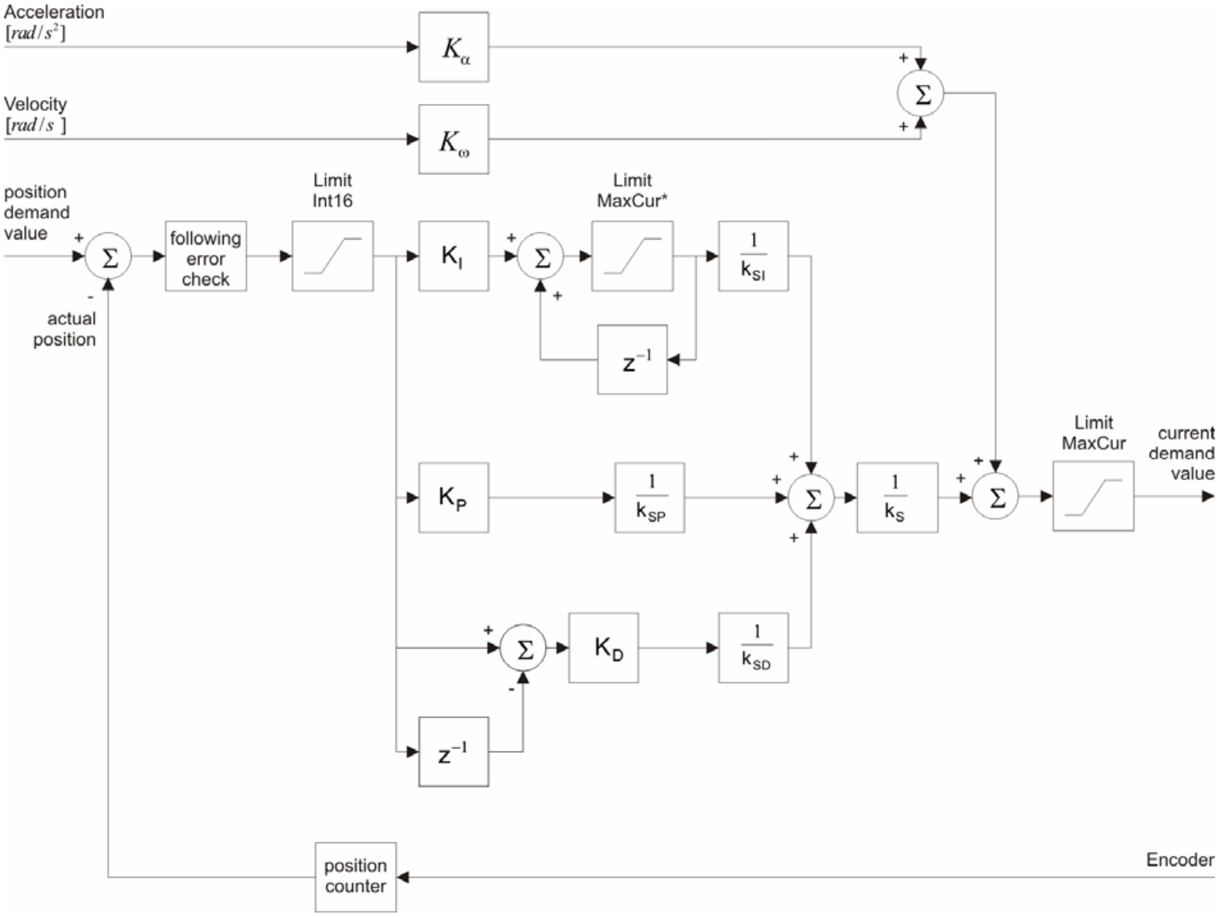

Figure 1: Controller architecture

Constants

Constant	EPOS 24/1	EPOS 24/5	EPOS 70/10
k_{SP}	$2^5 = 32$	$2^3 = 8$	$2^2 = 4$
k_{SI}	$2^8 = 256$	$2^6 = 64$	$2^5 = 32$
k_{SD}	$2^2 = 4$	$2^0 = 1$	$2^0 = 1$

Encoder pulse number	k_s
0 - 200	$2^0 = 1$
201 - 1000	$2^1 = 2$
1001 - 5000	$2^2 = 4$
5001 - 7500	$2^3 = 8$

Object dictionary entries

Symbol	Name	Index	Sub-Index
K_P	Position Regulator P-Gain	0x60FB	0x01
K_I	Position Regulator I-Gain	0x60FB	0x02
K_D	Position Regulator D-Gain	0x60FB	0x03
K_ω	Velocity Feedforward Factor	0x60FB	0x04
K_α	Acceleration Feedforward Factor	0x60FB	0x05

Units

Acceleration: $\left[\frac{rad}{s^2}\right]$

Velocity: $\left[\frac{rad}{s}\right]$

Position: $[qc]=\left[\frac{1\cdot(turn)}{Encoder\_pulse\_number\cdot 4}\right]$ (quadrature counts)

Current: $[mA]$

K_P: $\left[\frac{mA}{k_{SP}\cdot k_S\cdot qc}\right]$

K_I: $\left[\frac{mA}{k_{SI}\cdot k_S\cdot qc\cdot T_S}\right]$

K_D: $\left[\frac{mA\cdot T_S}{k_{SD}\cdot k_S\cdot qc}\right]$

K_α: $\left[\frac{A}{rad/s^2}\cdot 10^{-6}\right]$ (EPOS 24/5, EPOS 70/10 and MCD EPOS 60W)

K_α: $\left[\frac{A}{rad/s^2}\cdot 10^{-7}\right]$ (EPOS 24/1)

K_ω: $\left[\frac{\mu A}{rad/s}\right]$ (EPOS 24/1, EPOS 24/5, EPOS 70/10 and MCD EPOS 60W)

Operation Modes

The acceleration and velocity feed forward take effect in Profile Position Mode and Homing Mode. There is no influence to all the other operation modes like Position Mode, Profile Velocity Mode, Velocity Mode and Current Mode.

Purpose of K_α (Acceleration Feedforward Factor)

K_α provides additional current in cases of high acceleration and/or high load inertias.

Purpose of K_ω (Velocity Feedforward Factor)

K_ω provides additional current in cases, where the load increases with speed, e.g. speed dependent friction. The load is assumed to increase linear with speed.

Regulation Tuning

Regulation tuning is a sophisticated process for most drive systems. maxon motor EPOS Studio includes a powerful wizard called Regulation Tuning. By means of this Regulation Tuning wizard most systems can be well tuned within a few minutes. To tune an EPOS drive system follow these steps:

Step 1: Motor and system specific settings
Execute the Startup Wizard. It can be found via the navigation window Wizards of the EPOS Studio.

Figure 2: Startup-Wizard

Step 2: Current regulator tuning
Execute the regulation tuning by executing the regulation tuning wizard and follow the instructions to tune the current regulator. Do not tune the position regulator nor the velocity regulator at this moment.

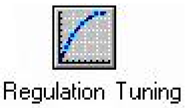

Figure 3: Regulation Tuning

Step 3a: Calculation of acceleration feed forward factor
Calculate the acceleration feed forward factor K_α as follows:

$K_\alpha = \frac{J_{tot}}{k_m} \cdot 100$	[EPOS 24/5, EPOS 70/10 and MCD EPOS 60W]
$K_\alpha = \frac{J_{tot}}{k_m} \cdot 1000$	[EPOS 24/1]

- $k_m\ [mNm/A]$ is the motor torque constant (maxon motor catalogue line 12)
- $J_{tot}\ [gcm^2]$ is the total inertia of the drive system. If the total inertia is not known take twice the rotor inertia (maxon catalogue line 16) and check position regulation. Increase J_{tot} in the upper formula if necessary.

$J_{tot} = J_{motor} + J_{load}$	$[gcm^2]$

Step 3b: Write the new acceleration feed forward factor
Write the calculated value of K_α to the object Acceleration Feedforward Factor (go to Object Dictionary):

K_α	Acceleration Feedforward Factor	0x60FB	0x05

Step 4a: Calculation of VelocityFeedforward Factor
Calculate the Velocity Feedforward Factor K_{ω} as follows

$K_{\omega} = \frac{30}{\pi} \cdot \frac{\Delta I}{\Delta \omega}$	[µA /rad /s]

- K_{ω} [µA /rad /s] considers a linear load current increase ΔI [µA] if the angular velocity is enhanced by $\Delta \omega$ [rpm]
- $\frac{\Delta I}{\Delta \omega}$ can easily be determined by measuring the current at two different speeds. (You can also assume I=0 at ω=0).

Step 4b: Write the new velocity feed forward factor
Write the calculated value of K_{ω} to the object Velocity Feedforward Factor (go to Object Dictionary):

K_{ω}	Velocity Feedforward Factor	0x60FB	0x04

Step 5: Regulation tuning
Now the system is prepared for the position regulation tuning with the Regulation Tuning Wizard. See Getting Started document for a step by step instruction.

Example

As an example a maxon motor EC40 was used:

Motor (#118899)

No load velocity (line 3)	3100 rpm
No load current (line 6)	41 mA
Torque constant (line 12)	145 mNm/A
Rotor inertia (line 15)	85 gcm^2

The mechanical load was given with four brass discs, each with 740 gcm^2 inertia:

Mechanical load

Load inertia	2960 gcm^2

With the given load conditions the motor inertia to load inertia rate is 1 : 35. Therefore the system is not easy to control.
The following measurements have been made with the built-in data recorder of the tool EPOS Studio. To start the data recorder select the recorder tab:

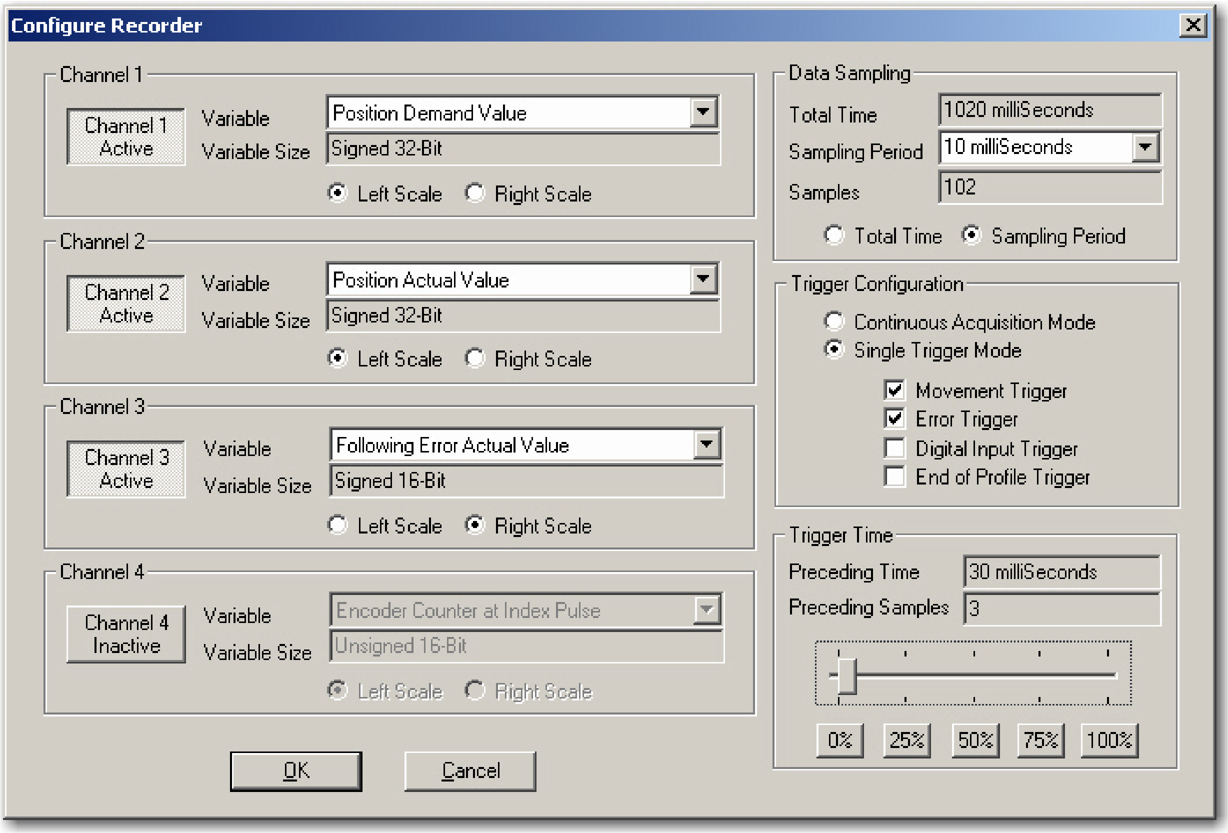

Figure 4: Data recorder configuration

The following graph results without feed forward after auto tuning:

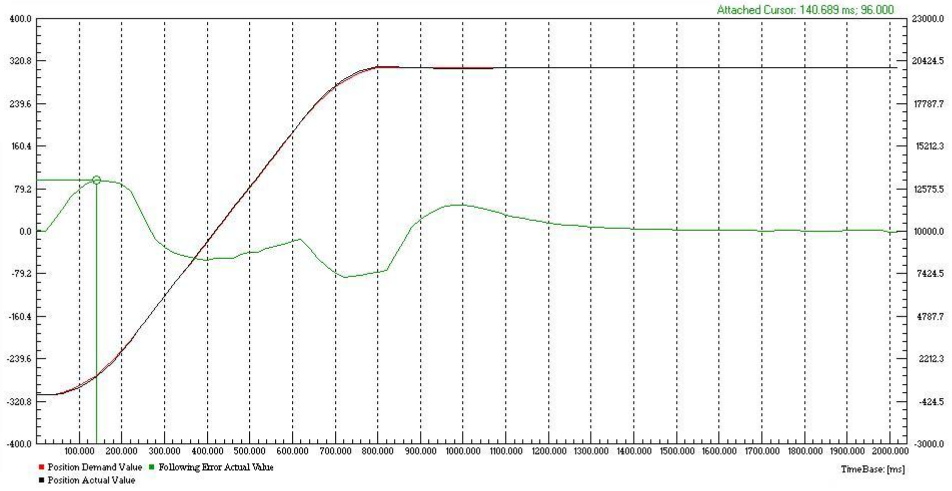

Figure 5: Recorded profile with stiff PID control

Position Regulator P-Gain	1895
Position Regulator I-Gain	76
Position Regulator D-Gain	16500
Velocity Feedforward Factor	0
Acceleration Feedforward Factor	0
Maximal Position Error	96qc

The following graph results with calculated feed forward parameters after auto tuning:

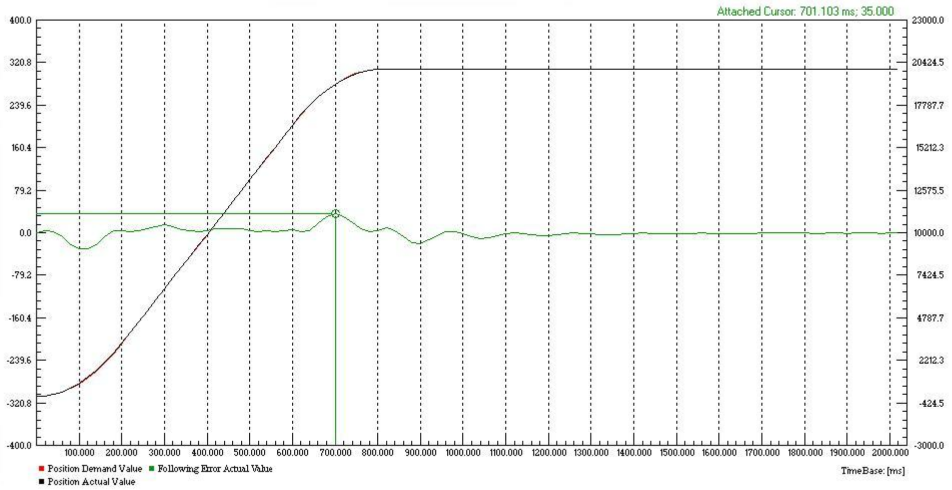

Figure 6: Recorded profile with feed forward and smooth PID control

Position Regulator P-Gain	1500
Position Regulator I-Gain	40
Position Regulator D-Gain	1505
Velocity Feedforward Factor	132
Acceleration Feedforward Factor	2100
Maximal Position Error	35 qc

Conclusion

In practice direct drive systems often are used as a result of lower system costs and requirements for a backlash free system. Therefore ratio between motor inertia and load inertia often are 1:10 or higher.
The EPOS motion controller uses traditional PID control and with firmware version 2020h or higher there is a acceleration feed forward and velocity feed forward implemented. With this controller architecture it is possible to smoothly control systems with high ratio between motor and load inertia.