# 4 Interpolated Position Mode

## 4.1 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 EtherCAT interface allows networking to multiple axes drives as well as online commanding by EtherCAT master units.

For fast communication with several EPOS3 70/10 EtherCAT devices, use the EtherCAT protocol. The individual devices of a network are commanded by a EtherCAT master.

### 4.1.1 Objective

«Interpolated Position Mode» is used to control multiply coordinated axes or a single axis with the need for time interpolation of setpoint data. The trajectory is calculated by the EtherCAT master and passed on to the controller's interpolated position buffer as a set of points. The controller then reads the points from the buffer and performs linear or cubic interpolation between them.

The present Application Note explains structure, functionality and use of the operation mode «Interpolated Position Mode» and features “in practice examples” suitable for daily use.

**Contents**



### 4.1.2 Scope

| Hardware | Order # | Firmware Version | Reference (➔page 1-9) |
|---|---|---|---|
| EPOS3 EtherCAT | | 2200h | Firmware Specification<br>Communication Guide (➔[ 6 ] |
| EPOS3 70/10 EtherCAT | 411146 | 2200h or higher | |

Table 4-22 Interpolated Position Mode – covered Hardware and required Documents

### 4.1.3 Tools

| Tools | Description |
|---|---|
| Software | «EPOS Studio» Version 2.00 or higher |

Table 4-23 Interpolated Position Mode – recommended Tools

## 4.2 In Detail

### 4.2.1 Introductory Analogy

Let us assume: In a company, a department manager must convert the department goals into clear tasks for his coworkers. It must be considered that the individual tasks oftentimes stand to each other in close interdependency. Thus, the department manager will gladly count on capable coworkers, being able to solve their tasks even on basis on just substantial data. For the solution's quality, it is in particular important that it…

a) is factually correct; i.e. it will not require further checks,

b) will be finished in time and

c) was reached efficiently.

The functionality «Interpolated Position Mode» values up the positioning controller EPOS3 EtherCAT to such a "capable coworker" in a superordinate drive system. Following, the thesis' description:

In a drive system, normally several axes must be moved according to the guidelines of a central controller. This can take place in the way that each local axis controller receives the next target position in real time – in time and at the same time to each sampling instance. This strategy has the advantage that the local controllers need only little intelligence. However, the central controller must compute target positions for every sampling interval and must communicate the data to every local controller in real time.

As to above analogy…

- it would be favorable if only few, but substantial points of the driving profiles would be considered,
- it would be desirable if the corresponding data could be transmitted to the local controller not necessarily at the same time, but rather in time.

Both goals can be reached by interpolation and data buffering.

First, the central controller decides which points of the local trajectories are substantial for a synchronized total movement. Then, each relevant point of the local trajectories is supplemented with the corresponding velocity and time – i.e. triplicates of the kind (position, velocity, time = PVT) are formed. These triplicates are then transferred to the associated axis controllers, in time. Each local controller possesses a buffer to receive these data. EPOS3 EtherCAT's buffer covers 64 locations for triplicates. The data transfer to the EPOS3 EtherCAT is in time as long as the buffer contains 1 to 64 new triplicates.

In EPOS3 EtherCAT, local position regulation is sampled with a rate of 1 kHz. Thus, requiring 1000 target positions per second in real time. These target positions are computed in EPOS3 EtherCAT by means of interpolation. Each triplicate forms a base point with the abscissa time and the two ordinates position and velocity. Therefore, two triplicates deliver two abscissas and four corresponding ordinates, permitting an interpolation polynomial of third order unambiguously computed between the two base points. The computation, as well as the evaluation of the polynomial in the local sampling clock, take place on basis of simple arithmetic and are efficiently executed by the EPOS3 EtherCAT.

The endpoint of the polynomial [n] forms the starting point of the polynomial [n+1]. Therefore, it is sufficient to indicate only the relative time in a data triplicate (i.e. the length of the time interval). In fact, with the EPOS3 EtherCAT, the time distance of two base points can be selected between 1 ms and 255 ms. This interval length can be adapted by the central controller to realize the desired total movement.

Finally, Interpolated Position Mode can be qualified as follows: The resulting smooth driving profiles, as well as the close temporal synchronization allow to superpose several high-dynamic single movements to a precise total movement in a drive system.

### 4.2.2 General Description

The Interpolated Position Mode described in the CANopen specification CiA 402 V3.0 is a general case. The objects are well-specified or a linear interpolation (PT). The interpolation type can also be extended by manufacturer-specific algorithms (selectable by «Interpolation Submode Selection», Object 0x60C0).

### 4.2.3 Spline Interpolation

For the Interpolated Position Mode, the interpolation type is a cubic spline interpolation. The higher-level trajectory planner sends a set of interpolation points by PVT reference point. Each PVT reference point contains information on position, velocity and time of a profile segment end point. The trajectory generator of the drive performs a third order interpolation between the actual and the next reference point.

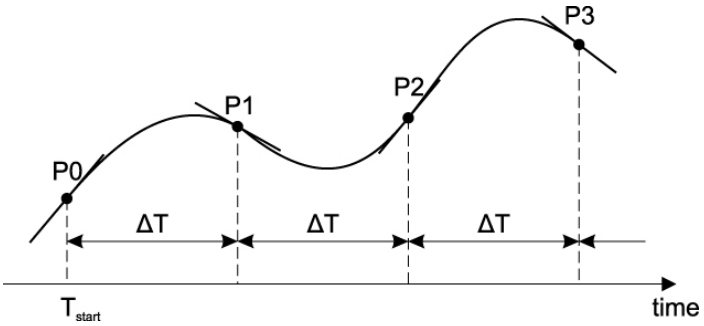



Figure 4-26 Interpolated Position Mode – PVT Principle

From two successive PVT reference points, the interpolation parameters a, b, c and d can be calculated:

$d = P[t_0] = P[n]$

$c = V[t_0] = V[n]$

$b = T^{-2}[n] * (3 * (P[n] - P[n-1]) + T[n] * (V[n] + 2 * V[n-1]))$

$a = T^{-3}[n] * (2 * (P[n] - P[n-1]) + T[n] * (V[n] + V[n-1]))$

The interpolated values for position, velocity and (possibly also) acceleration will be calculated as follows:

$P(t) = a * (t - t_0)^3 + b * (t - t_0)^2 + c * (t - t_0) + d$

$V(t) = 3a * (t - t_0)^2 + 2b * (t - t_0) + c$

$A(t) = 6a * (t - t_0) + 2b$

$t_0$: time of interpolation segment end (→ in this calculation $t_0$ is greater then t!)

It is not mandatory that the time intervals are identical.

## 4.3 IPM Implementation by maxon

The Interpolated Position Mode is implemented in the EPOS3 EtherCAT as an additional operational mode (operating mode 7 as specified in CiA 402 V3.0).

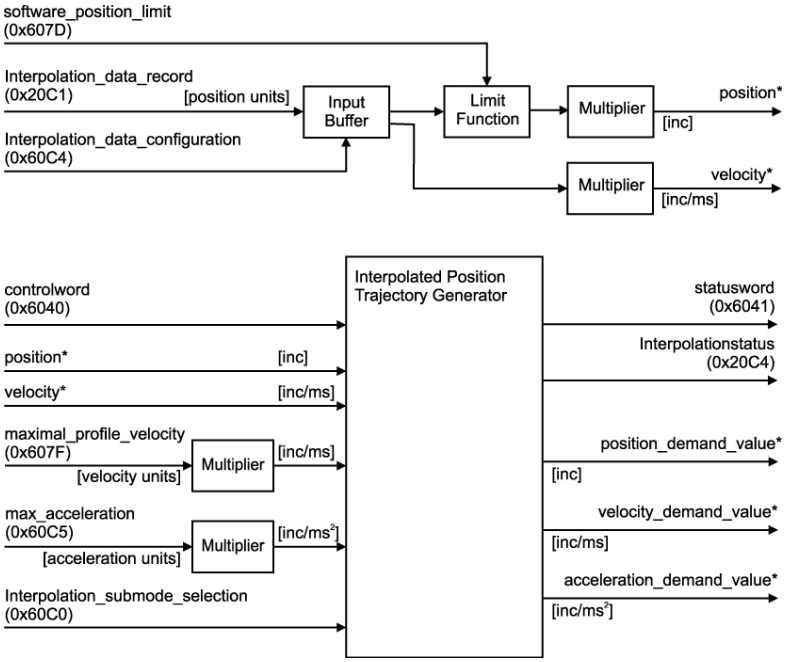



Figure 4-27 Interpolated Position Mode – Interpolation Controller

### 4.3.1 Interpolated Position Data Buffer

PVT reference points will be sent in a manufacturer-specific 64 bit data record of a complex data structure to a FIFO object.

#### 4.3.1.1 Definition of complex Data Structure 0x0040

| MSB | | LSB |
|---|---|---|
| Time (unsigned8) | Velocity (signed24) | Position (signed32) |

Table 4-24 Interpolated Position Mode – IPM Data Buffer Structure

#### 4.3.1.2 Structure of the FIFO

The FIFO will be implemented by a circular buffer with the length of 64 entries

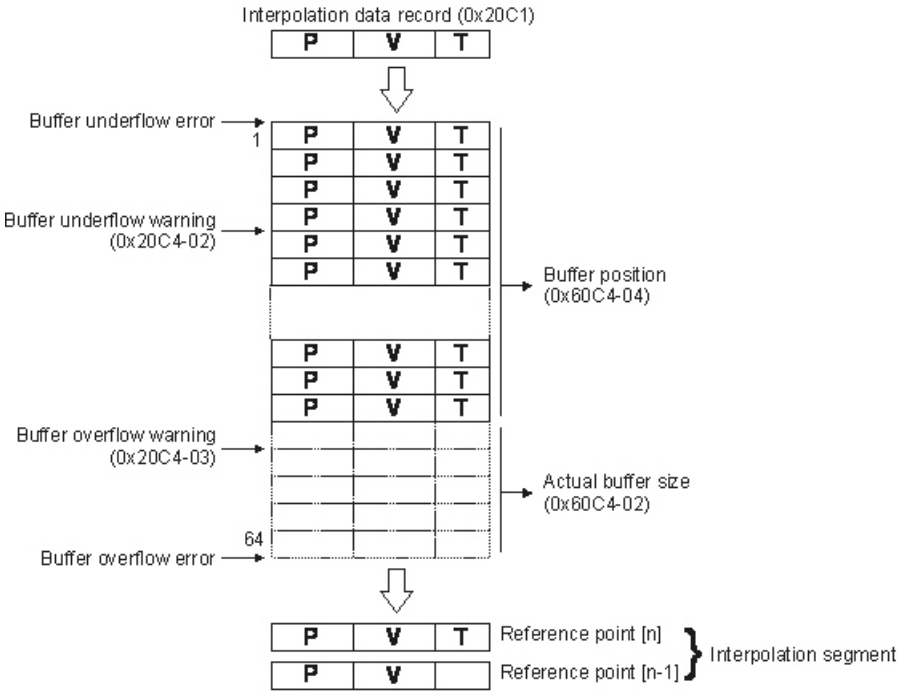



Figure 4-28 Interpolated Position Mode – FIFO Organization

#### 4.3.2 Interpolated Position Mode FSA

The interpolated position finite state automaton is a sub FSA of the Operation enable state.

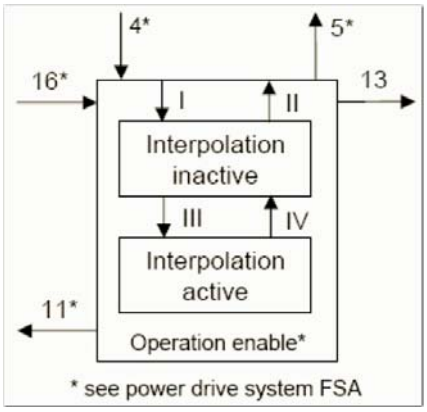



Figure 4-29 Interpolated Position Mode – FSA

| FSA State | Function |
|---|---|
| Interpolation inactive | The drive device accepts input data and buffers it for interpolation calculations, but does not move the axis. |
| Interpolation active | The drive device accepts input data and moves the axis. |

Table 4-25 Interpolated Position Mode – FSA States and supported Functions

| Transition | Event | | Action |
|---|---|---|---|
| I | ip mode selected (➔object 6060h, page 4-44) | | clear data buffer |
| II | ip mode not selected (➔object 6060h, page 4-44) | | none |
| III | enable ip mode: | set Controlword bit 4 to 1 | none |
| IV | disable ip mode: | set Controlword bit 4 to 0<br>or ip data record with time = 0 | none |

Table 4-26 Interpolated Position Mode – Transition Events and Actions

### 4.3.3 Configuration Parameters

| Parameter | Index | Description |
|---|---|---|
| Interpolation Sub Mode Selection | 0x60C0 | Indicates the actually chosen interpolation mode. |
| Interpolation Time Period | 0x60C2 | Indicates the configured interpolation cycle time. |
| Interpolation Data Configuration | 0x60C4 | Provides information on configuration and state of the buffer. It can also be used to clear the buffer. |
| Software Position Limit | 0x607D | Contains the sub-parameters «Minimal Position Limit» and «Maximal Position Limit» that define the absolute position limits or the position demand value. A new target position will be checked against these limits |
| Position Window | 0x6067 | Permits definition of a position range around a target position to be regarded as valid. If the drive is within this area for a specified time, the related Statusword control bit 10 «Target reached» is set. |
| Position Window Time | 0x6068 | Defines the time or the position window. |
| Profile Velocity | 0x6081 | If calculated velocity of the interpolation exceeds this value, a warning bit in Interpolation Buffer Status Word will be set. |
| Profile Acceleration | 0x6083 | If calculated acceleration of the interpolation exceeds this value, a warning bit in Interpolation Buffer Status Word will be set. |
| Maximal Profile Velocity | 0x607F | If calculated velocity of the interpolation exceeds this value, an error bit in Interpolation Buffer Status Word will be set and the device will switch to Fault reaction state. |
| Maximal Acceleration | 0x60C5 | If calculated acceleration of the interpolation exceeds this value, an error bit in Interpolation Buffer Status Word will be set and the device will switch to Fault reaction state. |
| Interpolation Status | 0x20C4 | The Interpolation buffer underflow/overflow warning level is configured in subindex 2 and 3. |

Table 4-27 Interpolated Position Mode – Configuration Parameters

### 4.3.4 Commanding Parameters

| Parameter | Index | Description |
|---|---|---|
| Controlword | 0x6040 | The mode will be controlled by a write access to the Controlword's mode-dependent bits. |
| Interpolation Data Record | 0x20C1 | Contains a FIFO to feed PVT reference points to the data buffer. |

Table 4-28 Interpolated Position Mode – Commanding Parameters

**Controlword (Interpolated Position Mode-specific Bits)**

| Bit 15…9 | Bit 8 | Bit 7 | Bit 6, 5 | Bit 4 | Bit 3…0 |
|---|---|---|---|---|---|
| ➔FwSpec | Halt | ➔FwSpec | reserved (0) | Enable ip mode | ➔FwSpec |

Table 4-29 Interpolated Position Mode – Controlword

| Name | Value | Description |
|---|---|---|
| Enable ip mode | 0 | Interpolated Position Mode inactive |
| | 1 | Interpolated Position Mode active |
| Halt | 0 | Execute instruction of bit 4 |
| | 1 | Stop axis with profile deceleration |

Table 4-30 Interpolated Position Mode – Controlword Bits

### 4.3.5 Output Parameters

| Parameter | Index | Description |
|---|---|---|
| Interpolation status | 0x20C4 | The mode's statusword is placed in subindex 1 of this object. |
| Statusword | 0x6041 | Mode state can be observed by Statusword bits. |
| Position Demand Value | 0x6062 | The output of the trajectory generator – it is used as input for the position control function. |

Table 4-31 Interpolated Position Mode – Output Parameters

**Statusword (Interpolated Position Mode-specific Bits)**

| Bit 15, 14 | Bit 13 | Bit 12 | Bit 11 | Bit 10 | Bit 9…0 |
|---|---|---|---|---|---|
| ➔FwSpec | reserved | ip mode active | ➔FwSpec | Target reached | ➔FwSpec |

Table 4-32 Interpolated Position Mode – Statusword

| Name | Value | Description |
|---|---|---|
| Target reached | 0 | Halt = 0: Target Position not (yet) reached<br>Halt = 1: Axle decelerates |
| | 1 | Halt = 0: Target Position reached<br>Halt = 1: Velocity of axle is 0 |
| ip mode active | 0 | ip mode inactive |
| | 1 | ip mode active |

Table 4-33 Interpolated Position Mode – Statusword Bits

### 4.3.6 Object Description in Detail

#### 4.3.6.1 Interpolation Data Record

**Description**

Sets PVT reference points in the Interpolated Position Mode in the cubic spline interpolation sub-mode. The position is given absolute in [Position units], typically [qc]), the velocity is given in [Velocity units], typically [rpm]), and the time is given in [ms]. The object structure is defined in ➔"Interpolated Position Data Buffer" on page 4-34.

**Remarks**

Normally used to feed PVT reference points to the drive while a PVT motion is executing. Therefore the object may be mapped to a RxPDO with transmission type of 255 (asynchronous).

In the Interpolation active state at least two data records have to be in the FIFO. Otherwise a Queue underflow Emergency will be launched and the drive changes to Fault reaction state.

A data record with time = 0 changes the state to Interpolation inactive without any error.

| | | |
|---|---|---|
| Name | Interpolation Data Record | |
| Index | 0x20C1 | |
| Subindex | 0x00 | |
| Type | complex data structure 0x0040 | |
| Access | WO | |
| Default Value | – | |
| Value Range | – | – |
| PDO Mapping | yes | |

#### 4.3.6.2 Interpolation Status

**Description**

Provides access to status information on the IP input data buffer.

| | |
|---|---|
| Name | Interpolation Status |
| Index | 0x20C4 |
| Number of entries | 0x03 |

| | | |
|---|---|---|
| Name | Interpolation Buffer Status | |
| Index | 0x20C4 | |
| Subindex | 0x01 | |
| Type | UNSIGNED16 | |
| Access | RO | |
| Default Value | – | |
| Value Range | – | – |
| PDO Mapping | yes | |

| Bit 15 | Bit 14 | Bit 13…12 | Bit 11…8 | Bit 7…4 | Bit 3…0 |
|---|---|---|---|---|---|
| IP Mode active | Buffer enabled | reserved (0) | IPM buffer errors | reserved (0) | IPM buffer warnings |

Table 4-34 Interpolation Buffer Status Word

| Name | Bit | Value | Description |
|---|---|---|---|
| Underflow Warning | 0 | 0 | No buffer underflow warning |
| | | 1 | Buffer underflow warning level (0x20C4-2) is reached |
| Overflow Warning | 1 | 0 | No buffer overflow warning |
| | | 1 | Buffer overflow warning level (0x20C4-3) is reached |
| Velocity Warning | 2 | 0 | No profile velocity violation detected |
| | | 1 | IPM velocity greater than profile velocity (0x6081) detected |
| Acceleration Warning | 3 | 0 | No profile acceleration violation detected |
| | | 1 | IPM acceleration greater than profile acceleration (0x6083) detected |
| Underflow Error | 8 | 0 | No buffer underflow error |
| | | 1 | Buffer underflow error (trajectory abort) |
| Overflow Error | 9 | 0 | No buffer overflow error |
| | | 1 | Buffer overflow error (trajectory abort) |
| Velocity Error | 10 | 0 | No maximal profile velocity error |
| | | 1 | IPM velocity greater than maximal profile velocity (0x607F) detected |
| Acceleration Error | 11 | 0 | No maximal profile acceleration error |
| | | 1 | IPM acceleration greater than maximal profile acceleration (0x60C5) detected |
| Buffer enabled | 14 | 0 | Disabled access to the input buffer |
| | | 1 | Access to the input buffer enabled |
| IP Mode active | 15 | 0 | IP mode inactive (same as bit 12 in statusword) |
| | | 1 | IP mode active |

Table 4-35 Interpolation Buffer Status Bits

**Description**

Gives the lower signalization level of the data input FIFO. If the filling level is below this border the warning flag (bit 0) in the Interpolation buffer status will be set.

| | | |
|---|---|---|
| Name | Interpolation Buffer Underflow Warning | |
| Index | 0x20C4 | |
| Subindex | 0x02 | |
| Type | UNSIGNED16 | |
| Access | RW | |
| Default Value | 4 | |
| Value Range | 0 | 63 |
| PDO Mapping | no | |

**Description**

Gives the higher signalization level of the data input FIFO. If the filling level is above this border the warning flag (bit 1) in the Interpolation buffer status will be set.

| | | |
|---|---|---|
| Name | Interpolation Buffer Overflow Warning | |
| Index | 0x20C4 | |
| Subindex | 0x03 | |
| Type | UNSIGNED16 | |
| Access | RW | |
| Default Value | 60 | |
| Value Range | 1 | 64 |
| PDO Mapping | no | |

#### 4.3.6.3 Interpolation Sub Mode Selection

**Description**

Indicates the actually chosen interpolation mode.

| | | |
|---|---|---|
| Name | Interpolation Sub Mode Selection | |
| Index | 0x60C0 | |
| Subindex | 0x00 | |
| Type | INTEGER16 | |
| Access | RW | |
| Default Value | -1 | |
| Value Range | -1 | -1 |
| PDO Mapping | no | |

| Value | Description |
|---|---|
| -32 768…-2 | Manufacturer-specific (reserved) |
| -1 | cubic spline interpolation (PVT) |
| 0 | Linear interpolation (not yet implemented) |
| 1…32 767 | reserved |

Table 4-36 Interpolation Sub Mode Selection – Definition

#### 4.3.6.4 Interpolation Time Period

**Description**

Indicates the configured interpolation cycle time. The interpolation time period (subindex 0x01) value is given in $10^{\text{interpolation time index}}$ per second. The interpolation time index (subindex 0x02) is dimensionless.

| | | |
|---|---|---|
| Name | Interpolation Time Period | |
| Index | 0x60C2 | |
| Number of entries | 0x02 | |

| | | |
|---|---|---|
| Name | Interpolation Time Period Value | |
| Index | 0x60C2 | |
| Subindex | 0x01 | |
| Type | UNSIGNED8 | |
| Access | RW | |
| Default Value | 1 | |
| Value Range | 1 | 1 |
| PDO Mapping | no | |

| | | |
|---|---|---|
| Name | Interpolation Time Index | |
| Index | 0x60C2 | |
| Subindex | 0x01 | |
| Type | INTEGER8 | |
| Access | RW | |
| Default Value | -3 | |
| Value Range | -3 | -3 |
| PDO Mapping | no | |

#### 4.3.6.5 Interpolation Data Configuration

**Description**

Provides the maximal buffer size and is given in interpolation data records.

| | | |
|---|---|---|
| Name | Interpolation Data Configuration | |
| Index | 0x60C4 | |
| Number of entries | 0x06 | |

| | | |
|---|---|---|
| Name | Maximum Buffer Size | |
| Index | 0x60C4 | |
| Subindex | 0x01 | |
| Type | UNSIGNED32 | |
| Access | RO | |
| Default Value | – | |
| Value Range | 64 | 64 |
| PDO Mapping | no | |

**Description**

Provides the actual free buffer size and is given in interpolation data records.

| | | |
|---|---|---|
| Name | Actual Buffer Size | |
| Index | 0x60C4 | |
| Subindex | 0x02 | |
| Type | UNSIGNED32 | |
| Access | RO | |
| Default Value | – | |
| Value Range | 0 | 64 |
| PDO Mapping | yes | |

**Description**

The value 0 indicates a FIFO buffer organization.

| | | |
|---|---|---|
| Name | Buffer Organization | |
| Index | 0x60C4 | |
| Subindex | 0x03 | |
| Type | UNSIGNED8 | |
| Access | RW | |
| Default Value | – | |
| Value Range | – | – |
| PDO Mapping | no | |

| Value | Description |
|---|---|
| 0 | FIFO buffer |
| 1 | Ring buffer (not supported) |
| 2…255 | reserved |

Table 4-37 Buffer Organization – Definition

**Description**

Provides used buffer space and is given in interpolation data records. Writing to this object has no effect.

| | | |
|---|---|---|
| Name | Buffer Position | |
| Index | 0x60C4 | |
| Subindex | 0x04 | |
| Type | UNSIGNED16 | |
| Access | RW | |
| Default Value | 0 | |
| Value Range | 0 | 64 |
| PDO Mapping | no | |

**Description**

Interpolation data record size is 8 bytes.

| | | |
|---|---|---|
| Name | Size of Data Record | |
| Index | 0x60C4 | |
| Subindex | 0x05 | |
| Type | UNSIGNED8 | |
| Access | WO | |
| Default Value | – | |
| Value Range | 8 | 8 |
| PDO Mapping | no | |

**Description**

If 0 is written, the data buffer is cleared and the access to it is denied. If 1 is written, the access to the data buffer is enabled.

**Related Objects**

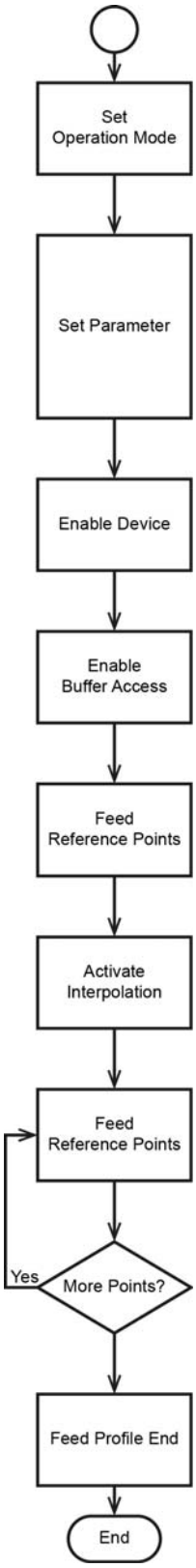
➔“Interpolation Status” on page 4-38

| | | |
|---|---|---|
| Name | Buffer Clear | |
| Index | 0x60C4 | |
| Subindex | 0x06 | |
| Type | UNSIGNED8 | |
| Access | WO | |
| Default Value | 0 | |
| Value Range | 0 | 1 |
| PDO Mapping | no | |

| Value | Description |
|---|---|
| 0 | Clear input buffer (and all data records) access disabled |
| 1 | Enable access to the input buffer for the drive functions |
| 2…255 | reserved |

Table 4-38 Buffer Clear – Definition

### 4.3.7 Typical IPM Commanding Sequence




| Object Name | Object | User Value [Default Value] |
|---|---|---|
| | | |
| Modes of Operation | 0x6060-00 | 0x07 (Interpolated Position Mode) |
| | | |
| Max. Following Error<br>Min. Position Limit<br>Max. Position Limit<br>Max. Profile Velocity<br>Max. Acceleration<br>Profile Velocity<br>Profile Acceleration<br>Quick Stop Deceleration | 0x6065-00<br>0x607D-01<br>0x607D-02<br>0x607F-00<br>0x60C5-00<br>0x6081-00<br>0x6083-00<br>0x6084-00 | Application specific [2000 qc]<br>Application specific [-2147483648 qc]<br>Application specific [2147483647 qc]<br>Motor specific [25000 rpm]<br>Application specific [4294967295 rpm/s]<br>Application specific [1000 rpm]<br>Application specific [10000 rpm/s]<br>Application specific [10000 rpm/s |
| | | |
| Controlword (Shutdown)<br>Controlword (SwitchOn) | 0x6040-00<br>0x6040-00 | 0x0006<br>0x000F |
| | | |
| Buffer Clear | 0x60C4-06 | 0x01 |
| | | |
| Interpolation Data Record | 0x20C1-00 | Reference points (PVT), minimum 2 points! |
| | | |
| Controlword (enable ip mode) | 0x6040-00 | 0x001F |
| | | |
| **if** (Interpolation Buffer Status)<br>**do** Interpolation Data Record<br>**until** (Interpolation Buffer Status) | 0x20C4-01<br>0x20C1-00<br>0x20C4-01 | Bit 0 == 1 (Underflow Warning)<br>Reference point (PVT)<br>Bit 1 == 1 (Overflow Warning) |
| | | |
| Interpolation Data Record | 0x20C1-00 | Reference point (PVT) with time = 0 |
| | | |

Table 4-39 Interpolated Position Mode – typical Command Sequence

As long as the interpolation is active, feeding of new reference points is the main task. To minimize the communication overhead, it might make sense to map the “Interpolation Data Record” in a (asynchronous) receive PDO. If the “Interpolation Buffer Status” is mapped to an event trigger transmit PDO (possibly along with the Statusword), processing of reference point feeding can easier be implemented.

## 4.4 Configuration

### 4.4.1 Interruption in Case of Error

If a currently running interpolation (index 0x20C4, subindex 0x03 “Interpolation Status” bit 15 “ip mode active” set) will be interrupted by an occurring error, the EPOS3 EtherCAT will react accordingly (i.e. disabling the controller and changing to state switch on disabled).

The interpolation can only be restarted by re-synchronization due to the fact that state “Operation enable” must be entered again, whereby the bit “ip mode active” will be cleared.