CiA 402 - Drives and Motion Control Device Profile

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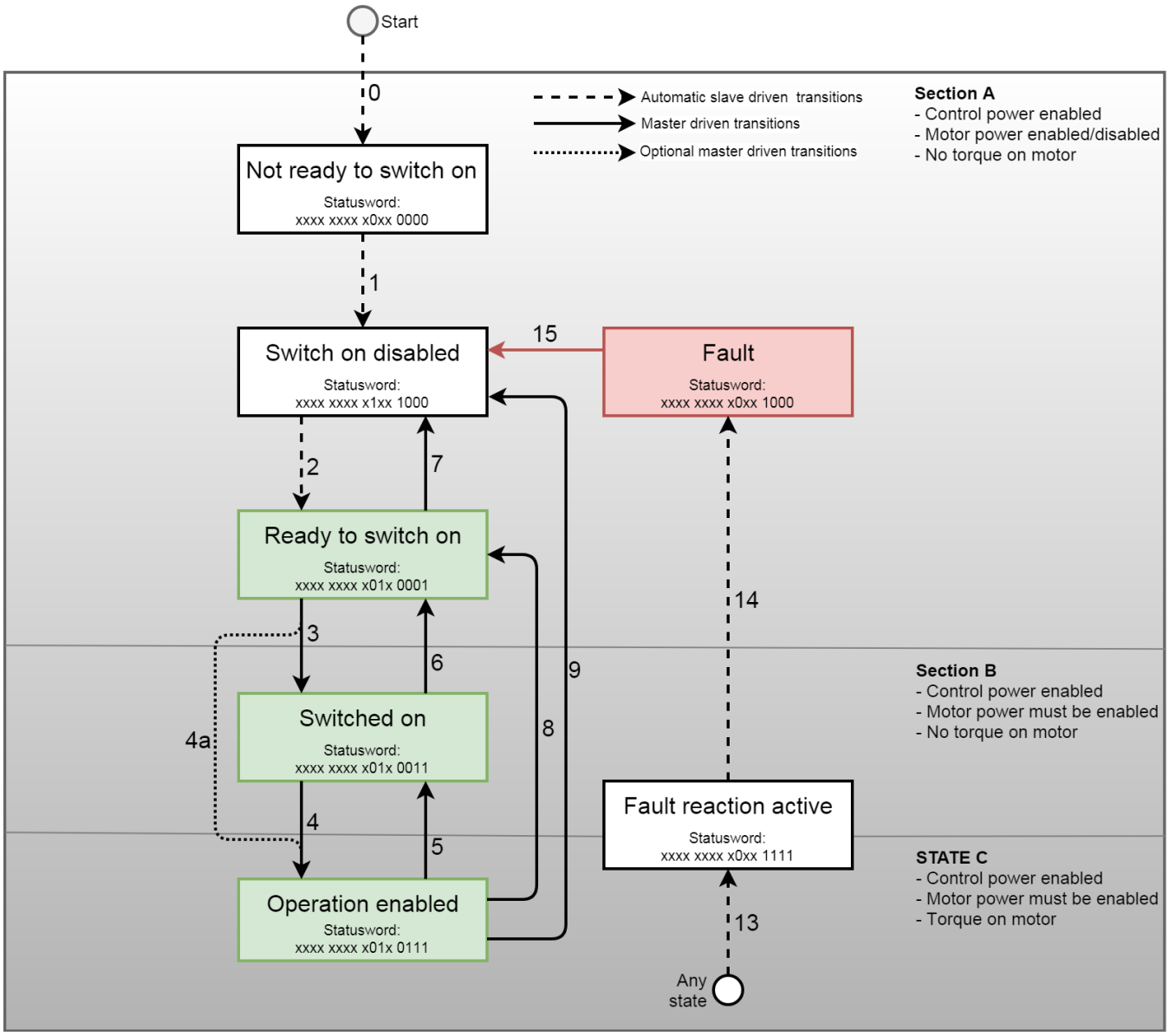
Controlling the Power Drive System

State Machine

The drive state machine is controlled by the Controlword (0x6040) and the status is viewed by the Statusword (0x6041). The state machine can be operated as shown below



There are a few things to note when using the state machine

- When the mode of operation is set to any CiA402 mode the state machine automatically transitions to "Ready to switch on".
- When the transitioning out of "Fault" the state machine automatically transitions to "Ready to switch on".
- Section A
  - no torque is present on the motor in Section A regardless of if motor power is present
- Section B
  - motor power must be present to transition to "Switched on".
  - If motor power is switched off or not present a fault will occur.
  - no torque is present on the motor in Section B.
- Section C
  - If motor power is switched off or not present a fault will occur.
  - Torque is present on the motor in Section C.
  - It is possible for the master to transition straight to "Operation enabled".
- See the Controlword description for additional information on state transitions 1-15.

Controlword (0x6040)

The Controlword is used to transition between and set the required states in the state machine.

The Controlword bits are defined as follows:

Bit	Name	Abbreviation

0	Switch on	SO
1	Enable voltage	EV
2	Quick stop	QS
3	Enable operation	EO
4-6	Operation mode specific	OMS
7	Fault reset	F
8	Halt	H
9	Operation mode specific	OMS
10	Reserved	R
11-15	Manufacturer specific	MS

- The drive does not support the Quick stop bit and shall be ignored if set to 0.

The following bits are required when transitioning between states:

Transition		Value (h)	BITS						
			0 (SO)	1 (EV)	2 (QS)	3 (EO)	4-6 (OMS)	7 (F)	8-15
15	**Fault Ready to switch on**	**0x86**	0	1	1	0	xxx	1	xxxxxxxx
8/9/0	**Non fault Ready to switch on**	**0x06**	0	1	1	0	xxx	0	xxxxxxxx
3/5	**Switched on[1]**	**0x07**	1	1	1	0	xxx	0	xxxxxxxx
4/4a	**Operation enabled**	**0x0F/0x1F**	1	1	1	1	xxx	0	xxxxxxxx

[1] The switched on state is often bypassed by the master.

Statusword (0x6041)

The statusword has the following defined bits

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ms		oms		ila	tr	rm	ms	w	sod	qs	ve	f	oe	so	rtso

Definitions

- ms = manufacture specific
- oms = operation mode specific
- ila = internal limit active
- tr = target reached
- rm = remote
- w = warning
- sod = switch on disabled
- qs = quick stop
- ve = voltage enabled
- f = fault
- oe = operation enabled
- so = switched on
- rtso = ready to switch on

FSA States

The Statusword indicates the current state of the drive state machine. The following table outlines the Statusword bits and the represented state

State	Statusword Bits	Functional Meaning
Not ready to switch on	xxxx xxxx x0xx 0000	No CiA mode of operation selected
Switch on disabled[1]	xxxx xxxx x100 0000	No motor torque - drive disabled

Ready to switch on	xxxx xxxx x01x 0001	No motor torque - drive disabled
Switched on	xxxx xxxx x01x 0011	No motor toque - drive disabled
Operation Enabled	xxxx xxxx x01x 0111	Motor has torque - drive enabled
Fault reaction active[1]	xxxx xxxx x0xx 1111	Motor is losing torque - drive disabling
Fault	xxxx xxxx x0xx 1000	No motor torque - drive disabled
Quick stop active[2]	xxxx xxxx x00x 0111	Not implemented

[1] these states are automatically transitioned through
[2] quick stop active is not currently implemented

Voltage Enabled - Bit4

The CM1-E has separate control and motor power. The 24V motor power status can be read through bit 4 on the statusword.

- bit4=1 - 24V motor drive power is detected.
- bit4=0 - motor drive power is not detected.

The voltage DC value is also available on object 0x6079 (DC link voltage).

Modes of Operation

CiA402 defines modes of operation. This allows the user to use the drive in a mode that is most suited to the application.

Modes of operation object list

Index	Name	Function
0x6060	Modes of operation	Write the required mode of operation
0x6061	Modes of operation display	Read the current mode of operation set on the drive

The following modes of operation are available on the drive

Mode of operation	Abbreviation	0x6060 value
Profile Position mode	PP mode	1
Profile Velocity mode	PV mode	3
Homing Mode	HM mode	6
Cyclic Synchronous Position mode	CSP mode	8
Cyclic Synchronous Velocity mode	CSV mode	9

Switching between modes

The drive is designed for dynamic switching between modes of operation. The "Modes of operation" and "Modes of operation display" are available in the RxPDO and TxPDO respectively. This allows the user to switch modes of operation without changing the ESM out of Operational. It is recommended the motor is put into a safe known state before switching modes. The master should send PDO data to the current mode of operation and the desired mode while switching modes. This should be continued until the "Modes of operation display" indicates the new mode has been set.

Profile Position Mode

Profile position mode provides an effective way to run the motor in position mode with very little overhead on the Ethercat master. The EtherCAT master sets the required acceleration, velocity and position before issuing the run command/bit. Single set-point is implemented which means the master can change the target position, speed and acceleration at any point by updating the values and issuing a new run bit. If the drive is required to continuously update position it is recommended that CSP mode is used instead. The Profile mode PDO mapping or the Dynamic Switching of Modes PDO mapping should be selected to effectively run Profile Position mode. See PDO Mappings for more information.

The following objects are used in Profile Position mode

Object	Name	Value	Unit	Description	PDO Mapped
0x6040	Controlword	-	-	See Controlword for general usage.	Yes
0x6041	Statusword	-	-	See Statusword for general usage.	Yes
0x6060	Modes of operation	1	-	Sets the mode to Profile Position mode	Yes
0x607A	Target Position	-2^{32} to $+2^{31}$	pulses	Sets the target position.	Yes
0x6081	Profile velocity	See CiA 402 - Drives and Motion Control Device Profile#Peak Speeds	pulses /s	Sets the target velocity of the profile.	Yes
0x6083	Profile acceleration(1)	0 - 32767	pulses /s^2	Sets the profile acceleration. The deceleration uses the same value.	Yes

(1) The acceleration used internally in the drive has a unit of 1000 pulses/s2. As such the value is 0x6083 is rounded to the nearest 1000. If the value is less than 1000 the value of 1000 used.

Use of Controlword and Statusword

The Controlword and Statusword use some additional mode specific bits in Profile Position mode.

Controlword

The following tables show the controlword usage.'

15-10	9	8	7	6	5	4	3-0
See Controlword	Change on set-point	Halt	See Controlword	abs/rel	Change set immediately	New set-point	See Controlword

Bit	Name	Value	Definition
4	New set-point	0 1	Next positioning shall be started immediately.
5	Change set immediately	1 - N/A	Bit 5 will always be considered a 1 and will be ignored. Change set immediately is always executed
6	abs/rel	N/A	Absolute positioning is always executed. This bit shall be ignored
8	Halt	0	Positioning shall be executed or continued
		1	The axis shall be stopped using the deceleration value in 0x6083
9	Change on set-point	N/A	Single set point mode is always executed. Bit9 is ignored.

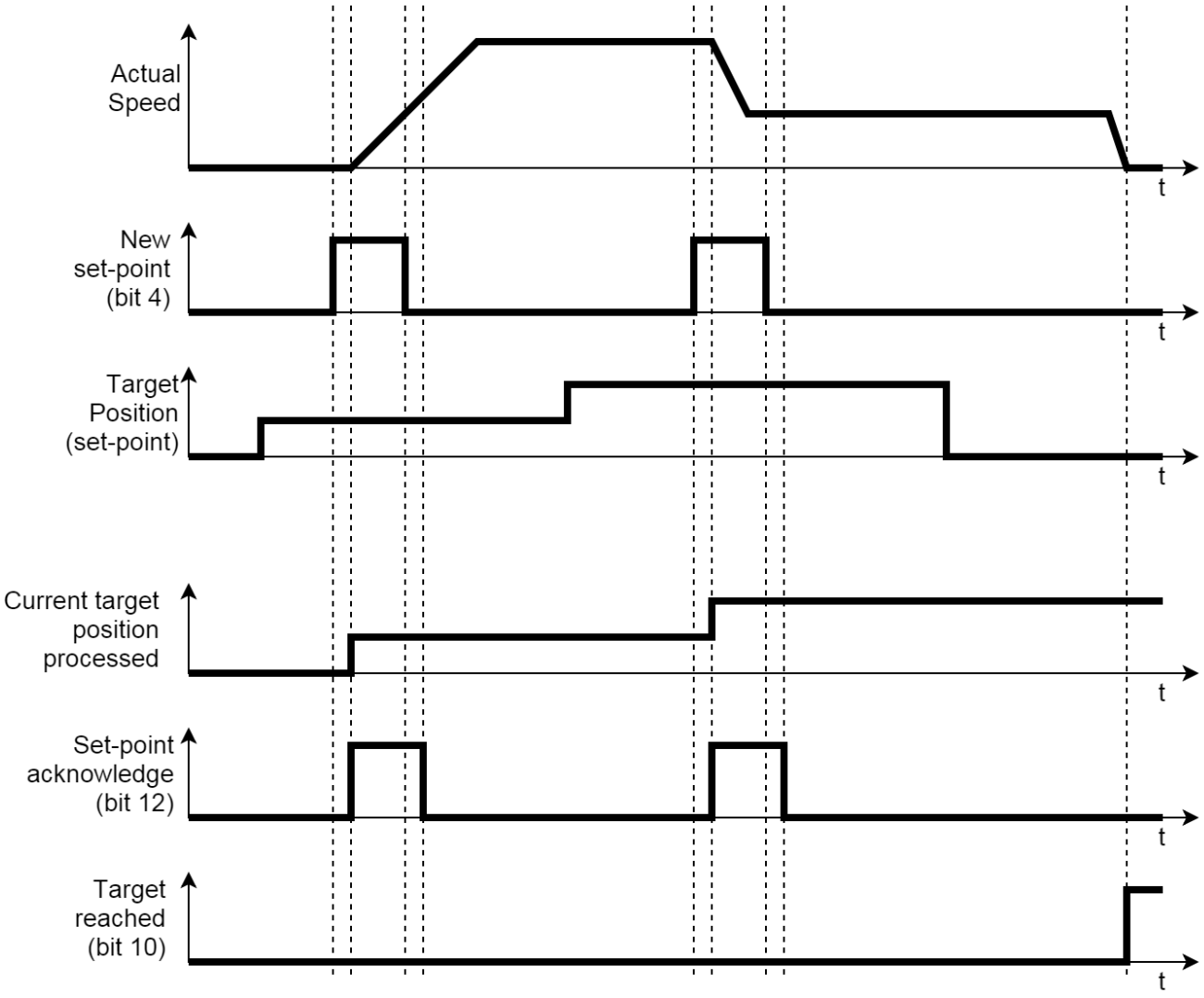
Statusword

The following tables show the statusword usage.

15	14	13	12	11	10	9-0
See Statusword		Following Error	Set-point acknowledge	See Statusword	Target reached	See Statusword

Bit	Value	Definition
10	0	Halt (Bit 8 in controlword) = 0: Target position not reached Halt (Bit 8 in controlword) = 1: Axis decelerating
	1	Halt (Bit 8 in controlword) = 0: Target position reached Halt (Bit 8 in controlword) = 1: Velocity of axis is 0
12	0	Waiting for new setpoint
	1	Set point has been processed.
13	0	No following error. The drive is able to follow the commanded trajectory
	1	Following error. The drive cannot follow the commanded trajectory.

Single set-point handshaking procedure



Use of acceleration and deceleration value

The deceleration value is always set to the acceleration value.

The acceleration used internally in the drive has a unit of 1000 pulses/s2. As such the value is 0x6083 is rounded to the nearest 1000. If the value is less than 1000 the value of 1000 used.

Profile Velocity Mode

Profile Velocity mode provides an effective way to run the motor in velocity mode with very little overhead on the Ethercat master. The EtherCAT master sets the required acceleration, deceleration and then issues the target velocity. The drive will ramp up to the target velocity.

The following objects are used in Velocity Profile mode

Object	Name	Value	Unit	Description	PDO Mapped
0x6040	Controlword	-	-	See Controlword for general usage.	Yes
0x6041	Statusword	-	-	See Statusword for general usage.	Yes
0x6060	Modes of operation	3	-	Sets the mode to Profile Velocity mode	Yes
0x60FF	Target speed	See Peak Speeds	pulses/s	Sets the target speed	Yes
0x6083	Profile Acceleration	0-32767	Kpulses/s^2	Profile Acceleration	No
0x6084	Profile Deceleration	0-32767	Kpulses/s^2	Profile Deceleration	No

Use of Controlword and Statusword

The Controlword and Statusword use some additional mode specific bits in Profile velocity mode.

The Controlword Bit8 is used a s a Halt bit.

Bit	Value	Definition
8	0	The motion shall be executed or continued
	1	The axis shall be stopped using the deceleration value in 0x6084

The Statusword implements 2 additional bits to indicate if the target velocity is reached and/or is the current velocity is 0.

Bit	Value	Definition
10	0	Halt (Bit 8 in controlword) = 0: Target not reached Halt (Bit 8 in controlword) = 1: Axis decelerating
	1	Halt (Bit 8 in controlword) = 0: Target reached Halt (Bit 8 in controlword) = 1: Velocity of axis is 0
12	0	Speed is not equal to 0
	1	Speed is equal to 0

Use of acceleration and deceleration value

The deceleration value is only used when the target velocity is set to 0 or the halt bit is set. For all other changes in velocity the acceleration value is used.

Homing Mode

Homing mode can be used to utilize the drives embedded homing routines. These routines allow accurate homing to be achieved without the delays communicating to the controller. The standard Cool Muscle home routines are accessible through the homing modes object. Homing mode does not require any specialized PDO mappings and can be used with any of the standard mappings. See PDO Mappings for more information.

The following objects are used in Homing mode

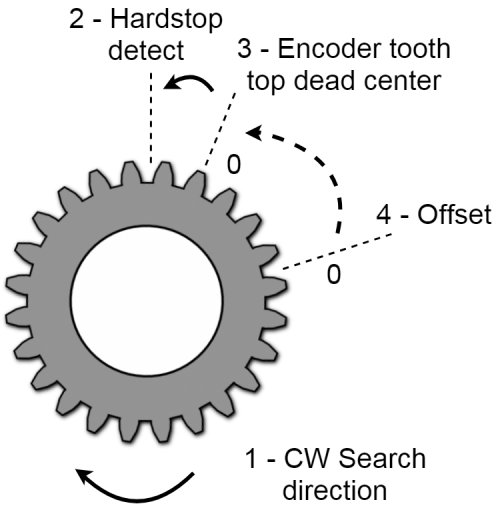
Object	Name	Value	Unit	Description	PDO Mapped
0x6040	Controlword	-	-	See CiA 402 - Drives and Motion Control Device Profile#Controlword for general usage.	Yes
0x6041	Statusword	-	-	See Statusword for general usage.	Yes
0x6060	Modes of operation	6	-	Sets the mode to Homing mode	Yes
0x607C	Home Offset	-3276700 to +3276700	encoder pulses (50 000 per motor revolution)	Once a home sensor or hardstop has been achieved the motor will move the distance of the offset. The final position will be set to 0. This value is written to an internal motor register which has a resolution of 100 pulses. As such the value written into 0x607C will be rounded to the nearest 100 internally.	No
0x6098	Homing Method	0 to -6	-	• 0: No home routine selected • -1: Hardstop CW • -2: Hardstop CCW • -3: Input 2 sensor CW • -4: Input 2 sensor CCW • -5: Input 3 sensor CW • -6: Input 3 sensor CCW See Homing Methods for additional information	No
0x6099: 01	Homing Speed	1000 - 500000	pulses/s	The homing speed is written to an internal register which has a unit of 100 pulses/s. The value written into 0x6099 will be rounded to the closest 100.	No
0x609A	Homing Acceleration	1000-5000000	pulse/s^2	The homing acceleration is written to an internal register which has a unit of 1000 pulses /s. The value written into 0x609A will be rounded to the closest 1000.	No
0x60F6: 1B	Homing Torque	10-100	% rated torque	Set the torque during the home routine. 1. When homing to a hardstop this value will indicate the limit at which the hardstop is reached 2. When homing to a switch this value will limit the torque during the home routine.	No

Homing Methods

Two distinct methods are available when executing a home routine.

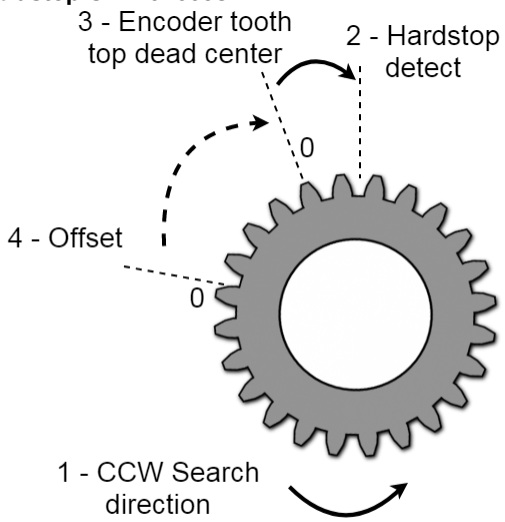
1. Hardstop detect - the motor moves towards a hardstop. When the hardstop is reached the driver reads the position of the magnetic encoder. It then moves back 2 teeth of the encoder gear to set the absolute position. Moving back the two teeth allows for high repeatability as fatigue and variance in the hardstop detect can be accounted for automatically.
2. Sensor detect - the motor moves towards a home sensor. When the sensor is triggered the driver interrupt captures the motor position. The motor decelerates and moves back to the captured position.
    a. If the sensor is detect when the home routine is first initiated the motor will move off the sensor first in the opposite direction to the defined origin search direction.

Hardstop CW - 0x6098=-1



1. Motor runs CW towards a hardstop.
2. The driver monitors the motor current and detects when a hardstop has been reached.
3. Motor backs up CCW to the 2nd previous encoder tooth (improved repeatability) and sets the position to 0.
4. If an offset is set the motor moves the offset distance
    a. Care should be taken not to set a +ve offset as this will move the load into the hardstop
5. Sets the final position to 0.

Hardstop CW - 0x6098=-1

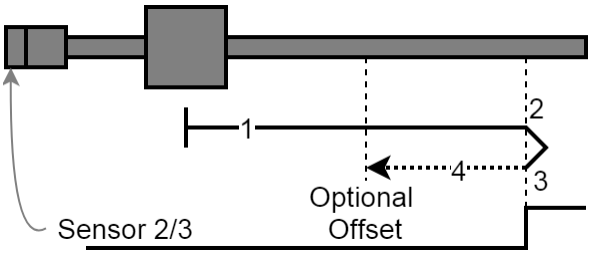


1. Motor runs CCW towards a hardstop.
2. The driver monitors the motor current and detects when a hardstop has been reached.
3. Motor backs CW up to the 2nd previous encoder tooth (improved repeatability) and sets the position to 0.
4. If an offset is set the motor moves the offset distance.
    a. Care should be taken not to set a -ve offset as this will drive the load into the hardstop
5. Sets the final position to 0.

Sensor CW - 0x6098=-3 or -5

INPUT2 - 0x6098=-3

INPUT3 - 0x6098=-5



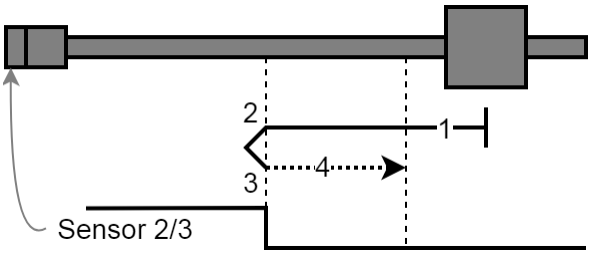
- Diagram shown with motor connected to linear actuator.
    - CW rotation moves the load left to right
- Sensor is connected directly on IN2 or IN3

1. Motor runs CW waiting for sensor input
2. Sensor rising edge triggers the input, motor captures encoder position, decelerates and reverses direction
3. Motor stops on captured position and sets position to 0
4. If an offset is defined the motor continues to the defined offset and sets the final target position to 0.
    a. Offset could be +ve or -ve. The above diagram shows a -ve offset

Sensor CCW - 0x6098=-4 or -6

INPUT2 - 0x6098=-4

INPUT3 - 0x6098=-6



- Diagram shown with motor connected to linear actuator.
    - CCW rotation moves the load right to left
- Sensor is connected directly on IN2 or IN3

1. Motor runs CCW waiting for sensor input
2. Sensor rising edge triggers the input, motor captures encoder position, decelerates and reverses direction
3. Motor stops on captured position and sets position to 0
4. If an offset is defined the motor continues to the defined offset and sets the final target position to 0.
    a. Offset could be +ve or -ve. The above diagram shows a +ve offset.

Use of Controlword and Statusword

The Controlword and Statusword use some additional mode specific bits in Homing mode.

Controlword

The following tables show the controlword usage.

15-9	8	7	6-5	4	3-0
See Controlword	Halt	See Controlword	reserved (0)	Homing operation Start	See Controlword

Bit	Name	Value	Definition
4	Homing operation start	0 1	Start or continue homing procedure
8	Halt	0	Enable bit 4
		1	The axis shall be stopped using the deceleration value in 0x609A

Statusword

The following tables show the statusword usage.

15-14	13	12	11	10	9-0
See Statusword	Homing Error	Homing attained	See Statusword	Target reached	See Statusword

General Definitions

Bit	Value	Definition
10	0	Homing procedure is in progress
	1	The motor has reached its target position or is currently disabled via the controlword
12	0	Homing not attained. • This value will by default start at 0. • This value will be reset to 0 when a new home routine is started.
	1	Homing attained • This value will be set to 1 when a home has been achieved. I.e. a hardstop has been hit or a sensor has been triggered • This value will be reset to 0 when a new home routine is started • This value will be reset to 0 if there is a home routine error or the home routine is aborted before the motor reaches target position
13	0	No home routine error
	1	Home routine error

Bit Sequence

Bit 13	Bit 12	Bit 10	Description
0	0	0	Homing procedure in progress
0	0	1	Homing procedure is interrupted or not started • motor could be enabled or disabled depending on controlword
0	1	0	Homing is attained, but target is not reached • Hardstop - hardstop has been detected. Offset not completed • Sensor - sensor has been detected. Offset not completed
0	1	1	Homing procedure is completed successfully. Current position is set to 0. • Hardstop - hardstop has been detected. Offset completed • Sensor - sensor has been detected. Offset completed
1	0	0	Homing error occurred, velocity is not 0

1	0	1	Homing error occurred, velocity is 0 Occurs if any motor error occurs.
1	1	1	An error exists but a home routine has been completed.

Cyclic Synchronous Position Mode

Cyclic synchronous position mode is set by setting the Modes of operation to 8. CSP mode is designed to allow the master controller full control of the position target. The 0x6064 position target shall be updated every PDO cycle. Failure to update the position target at the defined PDO interval will result in noisy and poor motion.

The following objects are used in CSP mode

Object	Value	Unit	Description	PDO Mapped
0x6040	-	-	See Controlword	Yes
0x6041	-	-	See Statusword	Yes
0x607A	-2^{32} to $+2^{31}$	pulses	Target position	Yes
0x6064	-2^{32} to $+2^{31}$	pulses	Position actual value	Yes
0x6060	8	-	CSP mode set	Yes

- Additional PDO objects are available. See PDO Mappings.

Use of Controlword and Statusword

No additional Controlword and Statusword bits are implemented.

Cyclic Synchronous Velocity Mode

Cyclic synchronous velocity mode is set by setting the Modes of operation to 9. CSV mode is designed to allow the master controller full control of the instantaneous velocity target. The 0x60FF velocity target shall be updated every PDO cycle. Failure to update the position velocity at the defined PDO time interval will result in noisy and poor motion.

The following objects are used in CSP mode

Object	Value	Unit	Description	PDO Mapped
0x6040	-	-	See Controlword	Yes
0x6041	-	-	See Statusword	Yes
0x60FF	See Peak Speeds	pulses/ms	Target velocity	Yes
0x606C	See Peak Speeds	pulses/ms	Velocity actual value	Yes
0x6060	9	-	CSV mode set	Yes

- Additional PDO objects are available. See PDO Mappings.

Motor maximum speeds

Part number	Max Speed RPM	Max 0x606C (Target velocity)
CM1-E-17S30D	3000 rpm	-2,500,000 to +2,500,000
CM1-E-17L30D	3000 rpm	-2,500,000 to +2,500,000
CM1-E-23S30D	3000 rpm	-2,500,000 to +2,500,000
CM1-E-23L20D	2000 rpm	-1,666,667 to +1,666,667

Use of Controlword and Statusword

No additional Controlword and Statusword bits are implemented.

Motor Peak Speeds

The four supported motors have differing peak speeds. See the table below for each motors maximum speed

Model Number	RPM	Pulses/s	Pulses/ms
CM1-E-17S30D	3000rpm	2500000	2500
CM1-E-17L30D	3000rpm	2500000	2500
CM1-E-23S30D	3000rpm	2500000	2500
CM1-E-23L20D	2000rpm	1666666	1666