HENSCHEL ROBOTICS

DOC-HD17-ETC-MAN



HDrive-ETC

Integrated servo drive · EtherCAT

Operating instructions

Revision 1.5 · November 2026

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Document information

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Purpose

This technical manual provides comprehensive guidance for commissioning and operating the HDrive-ETC servo drive. It is intended for qualified technicians and engineers responsible for system integration and maintenance.

Scope

- Installation and commissioning procedures
- Technical specifications and parameters
- Safety guidelines and warnings
- Troubleshooting and maintenance information

Document control

Rev.	Date	Author	Summary of changes
1.0	September 2024	Technical Team	Initial release
1.1	November 2025	Technical Team	EMC certification, specification updates
1.2	March 2026	Technical Team	Manual layout and editorial revision (Typst)
1.3	August 2026	Technical Team	Limit-switch homing modes 15–18 (sequence, DI mapping, speeds)
1.4	October 2026	Technical Team	Object 0x60FF / 0x606C and PDO velocity units: deg/s (not RPM)
1.5	November 2026	Technical Team	Error codes (0x603F) corrected; Error Codes TOC under Troubleshooting

Important Notice
This document contains critical safety information. Please read all sections carefully before proceeding with installation or operation.

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1 Legal & Safety

1.1 Liability Disclaimer

Henschel-Robotics GmbH assumes no liability for any damages resulting from improper use of the product. Familiarity with this handbook is considered an essential part of proper usage. Therefore, it is imperative to follow all instructions provided in this handbook and in the technical documentation for the encoder system.

Henschel-Robotics GmbH is not responsible for any malfunctions or failures arising from non-compliance with these operating instructions.

1.1.1 Intended Use

The **HDrive System** is an electronic servo motor device designed for use in industrial environments. It is intended for indoor operation within a protected setting. The servo motors are not water-resistant and must be installed accordingly to ensure safe and reliable operation.

Usage Restriction Notice
The HDrive Servo Motor may only be used for the purposes specified above. Any use outside the defined technical parameters, integration with incompatible components, or modifications that alter the product's intended function can lead to operational malfunctions. **Henschel-Robotics GmbH assumes no liability** for any issues or damages resulting from such misuse.

1.2 Safety Guidelines

1.2.1 General Safety Requirements

CRITICAL SAFETY REQUIREMENTS

Installation & Maintenance

- Installation and maintenance must be performed exclusively by **qualified personnel**
- Ensure **power supply is disconnected** and all mechanical components are stationary
- Always comply with **professional safety regulations** in force within your country

Electrical Hazards

- **High voltage, current, and moving mechanical parts** present risks of serious or fatal injury
- Do not operate the device in **explosive or flammable environments**
- The device must be operated **only for its intended purpose**

Compliance Notice

- Failure to observe these precautions constitutes a **breach of safety standards**
- Any misuse may cause **severe personal injury and/or environmental damage**

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1.2.2 Electrical Safety Guidelines

ELECTRICAL SAFETY PROTOCOLS

Power Supply Requirements

- Ensure the **power supply is switched OFF** before connecting the device
- Connect according to instructions provided in this manual
- **Power supply must be stable and noise-free**
- Install **EMC filters** on the power line if necessary

Cable Management

- Any **unused output signal wires** must be **individually insulated**
- Always use **shielded cables**, preferably **twisted-pair** types
- Keep all cables **as short as possible**
- **Do not route signal cables** near high-voltage power lines

EMC Compliance (2014/30/EU Directive)

- **Discharge static electricity** from body and tools before handling
- **Apply shielding** if required
- **Avoid using strong magnets** on or near the device
- Connect cable shield to **clean ground** free from interference

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2 Product Overview

2.1 System Overview

The **Henschel-Robotics GmbH "HDrive"** is an integrated servo motor solution based on advanced multi-pole stepper motor technology. This comprehensive system integrates:

- **Power Unit** — High-efficiency motor drive electronics
- **Communication Module** — EtherCAT real-time communication interface
- **Position Sensor** — 14-bit magnetic encoder system
- **Control System** — ARM™ micro-controller with comprehensive axis planner

The integrated electronics provide **position**, **speed**, and **torque control** capabilities with factory-calibrated precision.

2.1.1 Key Features

Feature	Description
Communication	EtherCAT real-time communication
Control	Closed-loop position, velocity, and torque control
Performance	High dynamics and efficiency, low torque ripple
Accuracy	±0.1° (1σ) positioning accuracy
Encoder	14-bit magnetic encoder system

2.2 Product Variants

2.2.1 Product Naming Convention

The HDrive is available with or without gearbox options. The product naming follows this structure:

`HDrive-ETC-[i]`

Symbol	Options	Description
ETC	ETC	Communication protocol (EtherCAT)
i	i	Industrial version with V_{pwr} = 48 VDC

> **NOTE**
> **Example:** `HDrive-ETC-i` = Nema 17 flange (this manual), EtherCAT, industrial version

Mechanical flange size (e.g. Nema 17 or 23) is defined by the mechanical ordering code and datasheet for each catalog variant.

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2.3 Compliance & Certifications

The HDrive has successfully passed comprehensive EMC testing according to European standards.

2.3.1 Emission

Standard	Description	Status
EN 55011:2016/A1:2017 CISPR 11-2015+AMD1:2016	Radiated Emission	**PASS**

2.3.2 Immunity

Standard	Description	Status
EN 61000-4-3:2006 +A1 +A2 IEC 61000-4-3:2006 +A1 +A2	Electromagnetic fields	**PASS**
EN 61000-4-4:2012 IEC 61000-4-4:2012	Fast electric transients (Burst)	**PASS**
EN 61000-4-5:2014 +A1:2017 IEC 61000-4-5:2014 +AMD1:2017	Surges	**PASS**

> **NOTE**
> **Certification Date:** Nov 21, 2025 — Full compliance with EU EMC Directive 2014/30/EU

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3 Installation & Commissioning

This section provides comprehensive guidance for mechanical and electrical installation, as well as system commissioning procedures for the HDrive-ETC servo drive.

3.1 Mechanical Installation

3.1.1 Mounting Requirements

The motor should be attached using the **four M3 threads** located on the front face (near the motor shaft):

Parameter	Value	Notes
Thread Size	M3	Metric thread
Thread Depth	4.5 mm	Maximum engagement depth
Mounting Pattern	4 holes	Square pattern on front face

3.1.2 Centering Ring Specification

Use the **2 mm deep centering ring** with precise dimensions to ensure proper alignment:

Centering Ring:

Parameter	Value
Ring Depth	2.0 mm
Ring Diameter	$22^{+0}_{-0.05}$ mm (with tolerance)

Motor Shaft:

- **Material:** Aluminium
- **Maximum Axial Load (Dynamic):** 10 N
- **Maximum Radial Load (Dynamic)** @ 20 mm shaft length: 21 N

> **WARNING**
> Proper centering is essential for optimal performance and longevity of the system.

3.2 Electrical Installation

3.2.1 Connectors Overview

Field wiring uses **M8** circular connectors per IEC 61076-2-104. **All** field ports — **power supply**, **digital inputs**, and **EtherCAT** — use **A-coded** 4-pin shells (three separate sockets; same mechanical keying and pin layout family, different electrical functions per port).

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Use only **A-coded** M8 cables and cordsets rated for the intended signal (power, I/O, or Ethernet) and IP class. For EtherCAT, use **shielded** twisted-pair industrial cordsets with **A-coded** M8 plugs to the master or the next slave.

3.2.2 Power Supply Requirements

The HDrive-ETC requires a **24 V DC power supply** with the following specifications:

Parameter	Value	Unit
Supply Voltage V_s	24	V DC
Supply Voltage V_p	24–48	V DC
Voltage Tolerance	±10%	V DC
Current Rating V_s	0.5	A
Current Rating V_p	2	A
Max. Power Consumption	36	W

3.2.3 M8 A-coded — pin numbering (all M8 ports)

All M8 sockets on the drive use the **same A-coded** 4-pin geometry. Pin **numbers** refer to the same mechanical positions on every connector; **electrical functions** differ per port (see tables below).

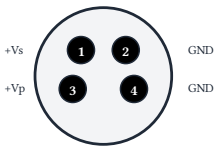
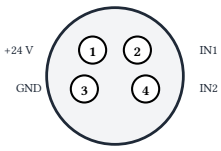
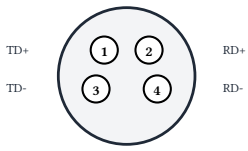
Power supply	Digital I/O	EtherCAT
		

*Table 1: M8 A-coded connectors on the drive — front view (mating face). **Power supply:** male plug (black pins, white numbers). **Digital I/O** and **EtherCAT:** female sockets (white contacts, black numbers).*

3.2.4 Power Connector Pinout (M8 A-coded)

The power input is a **4-pin M8 A-coded male** plug with redundant supply and ground pins (left column in Table 1):

Pin	Function	Description	Wire color
1	+24 V	Positive power supply V_s	Brown
2	GND	Ground reference	Blue
3	+24 V	Positive power supply V_p	White
4	GND	Ground reference (redundant)	Black

> **NOTE**
> GND-P and GND-S are connected inside the device.

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3.2.5 EtherCAT Connector Pinout (M8 A-coded)

EtherCAT uses a **100 Mbit/s** Fast Ethernet PHY on an **M8 A-coded** interface — the same shell and pin numbering as the supply and digital I/O ports. Pin assignment follows the usual **TD/RD** pair naming for twisted-pair Ethernet (see right column in Table 1).

Pin	Signal	Direction	Description
1	TD+	Transmit	Transmit data, positive
2	RD+	Receive	Receive data, positive
3	TD–	Transmit	Transmit data, negative
4	RD–	Receive	Receive data, negative

NOTE
Cable: shielded twisted pair suitable for 100BASE-TX; maintain cable shield connection to the plant earth concept per your EMC plan.

3.2.6 Digital I/O Connector Pinout (M8 A-coded)

The digital input port is a **4-pin M8 A-coded** connector (center column in Table 1).

Pin	Function	Description
1	+24 VDC	Sensor supply V_s, 100 mA fused
2	Input 1	Digital input 1
3	GND	Ground reference
4	Input 2	Digital input 2

NOTE
Input logic turns HIGH when input exceeds 12 VDC. Input turns LOW when below 9 VDC.

3.3 System Startup Sequence

The HDrive follows a standardized startup sequence:

1. **Power On**
   - Apply 24 V DC power supply
   - Motor LED turns white
   - Bootloader loads firmware (2 seconds)
   - Motor LED turns solid red, then yellow
2. **EtherCAT Initialization**
   - Establish communication with EtherCAT master
   - Motor LED blinks green
3. **Ready for Operation**
   - System ready for control commands

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- Motor LED turns solid green

> **NOTE**
> **Typical startup time:** 2–5 seconds depending on network configuration.

3.4 TwinCAT Configuration

For TwinCAT integration, follow these configuration steps:

1. **Network Setup** — Add HDrive to EtherCAT network topology; configure network parameters
2. **Motor Parameters** — Set motor-specific parameters; configure encoder settings
3. **Control Modes** — Configure position, velocity, and torque modes; set control loop parameters
4. **Communication Test** — Verify EtherCAT communication; test control commands

3.4.1 NC following error (Time Compensation)

In CSP, TwinCAT NC computes the axis following error from its own setpoint versus the drive actual position (`0x6064`). A large lag at constant speed is often mostly bus/task/drive dead time ($\omega \cdot T$), not load torque. Compensate that in TwinCAT — not via CoE `0x60F4` (raw CiA following error: actual − demand in 0.1°).

Path: **MOTION → NC-Task → Axes → HDrive → Drive → Time Compensation**.

Verified starting values for unloaded CSP (NC following error ≈ 0 at constant speed):

Parameter	Value
Time Compensation Mode Drive (position mode only)	`ON (with velocity and acceleration)`
IO Time is absolute	`FALSE`
Task Delay in Cycles	`1`
Drive Delay in Cycles	`1`
Additional Drive Delay	`15000` µs (15 ms)

Table 2: TwinCAT NC Drive Time Compensation — HDrive CSP reference

1. **Encoder → Time Compensation** — Enable input-side compensation (`DcInputShift`; optional **Encoder Delay in Cycles**) so actual position is likewise time-aligned.
2. **Position Lag Monitoring** — Thresholds only (max lag / filter time); it does not remove dead-time lag.

Do not use the legacy **Delay Velo / Position** parameters on new projects. Re-check at standstill (following error ≈ 0) and under load (residual lag remains visible). If cycle time or filters change, re-tune **Additional Drive Delay**.

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4 Technical Documentation

4.1 Control Architecture

The HDrive-ETC employs sophisticated **time-discrete control algorithms** that provide independent adjustment of torque, position, and speed controllers. This modular control architecture enables precise tuning for specific application requirements.

> **Critical Warning**
> The open and freely parameterizable control architecture must be carefully adjusted to the respective application. **Improper parameter tuning can damage the drive and attached load.**

4.1.1 Field-Oriented Control (FOC)

The stepper motor is controlled using **field-oriented control (FOC)** methodology, which provides:

- **Separate regulation** of torque-generating and reactive currents
- **Enhanced efficiency** compared to traditional stepper control
- **Cogging torque suppression** with reduced vibration and noise
- **Precise torque control** for demanding applications

4.1.1.1 Coordinate Transformation

- **Park Transform** — Rotates αβ coordinates to synchronous DQ frame
- **Inverse Transforms** — Converts DQ back to ABC for PWM generation

4.1.1.2 Control Architecture

- **D-Axis Control** — Flux-producing current regulation
- **Q-Axis Control** — Torque-producing current regulation
- **Speed Control** — Controls the current of the motor to maintain a speed
- **Position Control** — Controls the position of the motor

4.1.1.3 Advanced Features

- **Current Filtering** — Low-pass filtering of DQ currents
- **Voltage Feedforward** — Back-EMF compensation
- **Phase Current Monitoring** — Real-time A/B phase current measurement
- **Torque Ripple Compensation** — Advanced ripple reduction algorithms

4.2 Control Structure Overview

The HDrive-ETC uses a **cascaded control structure** that provides smooth, precise motion control through three interconnected control loops:

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4.2.1 Control Loop Hierarchy

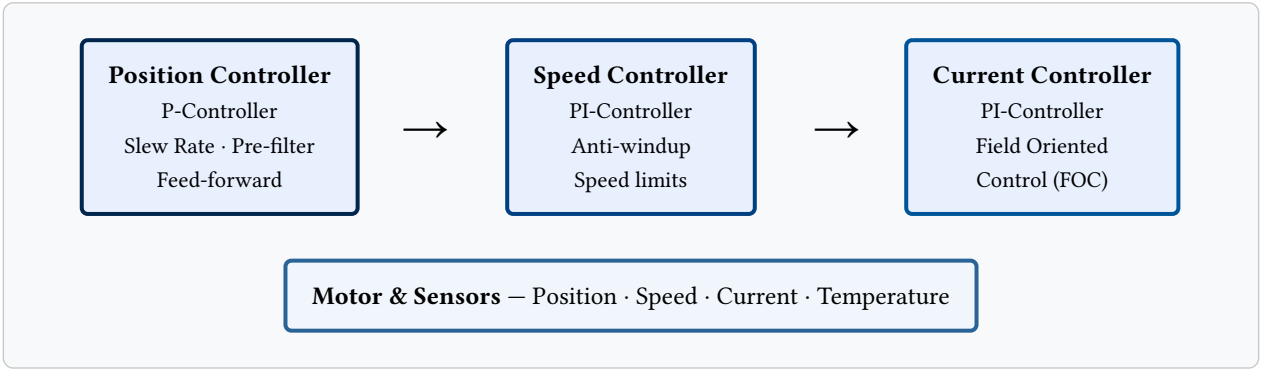


Figure 1: Cascaded control structure of the HDrive-ETC

4.2.2 Control Loops and Modes

Loop / mode	Purpose	Input → output	Controller	Rate
Position loop (outermost)	Precise positioning	Target position → target speed command	P	2 kHz
Speed loop (middle)	Motor velocity	Target speed (from position loop) → target current command	PI	2 kHz
Current loop (innermost)	Torque / current	Target current (from speed loop) → PWM to motor phases	PI	20 kHz
Position mode	Full cascade	Position → Speed → Current	—	—
Speed mode	Direct speed	Speed → Current	—	—
Torque mode	Direct current / torque	Current command → PWM (no outer loops)	—	—

4.3 System Architecture

4.3.1 Real-time Control System

Parameter	Rate	Description
ADC Interrupt	20 kHz	Current measurement sampling
Current Control	20 kHz	FOC update rate
Position Control	2 kHz	Position loop update
State Machine	2 kHz	System state machine

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4.3.2 State Machine Implementation

Main States:

- **Not Ready to Switch On** — System initialization
- **Switch On Disabled** — Power applied, not ready
- **Ready to Switch On** — System ready for operation
- **Switched On** — Motor enabled, not operational
- **Operation Enabled** — Full operational mode
- **Quick Stop Active** — Emergency stop condition
- **Fault Reaction Active** — Error handling mode
- **Fault** — System error state

Safety Monitoring:

- **Voltage Monitoring** — Over/under voltage detection
- **Temperature Monitoring** — Thermal protection
- **Speed Monitoring** — Over-speed protection

4.4 Firmware Management

4.4.1 Firmware Upgrade Procedure

The firmware can be upgraded using the **EtherCAT interface**. The EEPROM configuration will be maintained.

1. **Connection Setup** — Connect to HDrive via EtherCAT to Beckhoff TwinCAT; verify communication status
2. **Firmware Access** — Put EtherCAT state machine to Bootstrap State
3. **Upload Process** — Upload new firmware file with “File Access over EtherCAT (FoE)”; monitor progress
4. **Completion** — Wait for upgrade to complete; switch EtherCAT state machine to Init state; drive restarts, checks and loads the new firmware (1 minute)

4.5 Performance Tuning

4.5.1 Control Bandwidth Optimization

The **current control bandwidth** determines how quickly the drive can react to external disturbances — such as sudden load changes, friction, or mechanical impacts. A higher bandwidth results in faster disturbance rejection and stiffer torque regulation. It does **not** increase top speed; speed is governed by the speed and position loops above it.

Environment / Load	Current BW	Disturbance Characteristics
Low-disturbance positioning	300 Hz	Stable load, minimal external forces, smooth motion priority
Standard automation	500 Hz	Moderate load variation, typical pick-and-place or conveyor applications

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High-disturbance applications	800 Hz	Variable or impulsive loads, fast rejection of external forces required

The position control bandwidth should be set to approximately **1/20 of the current control bandwidth**. For example, with a current bandwidth of 500 Hz, the position bandwidth should be around 25 Hz. The velocity bandwidth is derived from the position bandwidth and does not need to be entered manually.

RECOMMENDATION
Start with conservative settings and gradually increase bandwidth while monitoring system stability. Unnecessarily high current bandwidth can amplify electrical noise.

4.6 Digital I/O Configuration

4.6.1 Digital Input/Output Capabilities

Pin	Function	Type	Description	Voltage
DI1	Digital Input 1	Input	General purpose; negative limit switch (modes 15 / 17)	24 V / 0 V
DI2	Digital Input 2	Input	General purpose; positive limit switch (modes 16 / 18)	24 V / 0 V

Digital Input Features:

- **Pull-up resistors** configured for reliable signal detection
- **Debounced inputs** with 5-cycle stability requirement
- **Polarity inversion** support via EtherCAT configuration
- **Position latch functionality** for precise position capture

4.6.2 Position Latch Function

The HDrive includes an advanced **position latch system** that captures the exact motor position when triggered by digital input signals. This feature is essential for precise positioning applications and reference point detection.

4.6.2.1 Latch Trigger Modes

Trigger Mode	Description	EtherCAT Value
Rising Edge	Triggers when input transitions from LOW to HIGH	1
Falling Edge	Triggers when input transitions from HIGH to LOW	2
Both Edges	Triggers on both rising and falling transitions	Both modes

4.6.2.2 Latch Implementation Details

- **Debouncing:** 5-cycle stability requirement prevents false triggers from electrical noise
- **Position Capture:** Captures position with high precision (1/10 degree resolution)

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- **Trigger Source:** Records which input and edge type caused the latch
- **Latch Reset:** Manual reset capability via EtherCAT object dictionary

4.6.2.3 EtherCAT Object Dictionary Entries

Object	Name	Data Type	Description
0x6667	Latch Position 1	DINT (32-bit)	Captured position from DI1
0x6668	Latch Trigger Source 1	SINT (8-bit)	Trigger source (1=rising, 2=falling)
0x6669	Latch Reset 1	SINT (8-bit)	Reset latch 1 (write 1 to reset)
0x6670	Latch Position 2	DINT (32-bit)	Captured position from DI2
0x6671	Latch Trigger Source 2	SINT (8-bit)	Trigger source (1=rising, 2=falling)
0x6672	Latch Reset 2	SINT (8-bit)	Reset latch 2 (write 1 to reset)

4.6.2.4 Usage Example

1. **Configure trigger mode** via EtherCAT master
2. **Connect sensor** to DI1 or DI2 (e.g., proximity switch, encoder index)
3. **Monitor latch status** through EtherCAT objects
4. **Read captured position** when latch is triggered
5. **Reset latch** to enable next capture cycle

> **NOTE**
> Only one latch event is captured per reset cycle. The latch must be manually reset before it can capture a new position.

4.7 EtherCAT Object Mappings

4.7.1 Target Value Objects (Write from EtherCAT Master)

Object	Name	Data Type	Description	Control Mode
0x607A	Target Position	DINT (32-bit)	Target position in 1/10 degrees	Position
0x60FF	Target Velocity	DINT (32-bit)	Target speed in deg/s	Speed
0x6071	Target Torque	INT (16-bit)	Target torque in mNm	Torque
0x6060	Mode of Operation	SINT (8-bit)	Control mode selection	All Modes

4.7.2 Control Parameter Objects (Configuration)

Object	Name	Description	Units
0x6660	Cascade Control	P/I gains for all controllers	Various
0x6660.1	Current P-Gain	Current controller proportional gain	A/A

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0x6660.2	Current I-Gain	Current controller integral gain	A/(A·s)
0x6660.4	Speed P-Gain	Speed controller proportional gain	A/RPM
0x6660.5	Speed I-Gain	Speed controller integral gain	A/(RPM·s)
0x6660.6	Position P-Gain	Position controller proportional gain	RPM/°

4.7.3 Actual Value Objects (Read by EtherCAT Master)

Object	Name	Data Type	Description
0x6064	Position Actual	DINT (32-bit)	Current position in 1/10 degrees
0x606C	Velocity Actual	DINT (32-bit)	Current speed in deg/s
0x6077	Torque Actual	INT (16-bit)	Current torque in mNm
0x6041	Status Word	UINT (16-bit)	Motor status and error flags

4.7.4 Control Mode Selection (Object 0x6060)

Numeric values follow CiA 402 for modes **1**, **3**, **4**, **6**, and **8** (see firmware `IOperationMode.h`).

Value	CiA 402 / name	Behaviour on HDrive-ETC
1	Profile position (PP)	Internal **path planner** (`Motion`): target position 0x607A (and profile velocity / acceleration / deceleration) are latched on the rising edge of Control Word **bit 4** (new set-point). A new set-point always replaces a running move immediately (bit 5 ignored for now). Status Word bit 12 = set-point acknowledge, bit 10 = target reached (window 0x6067). Absolute positioning only.
3	Profile velocity (PV)	Profile / limited speed control.
4	Profile torque (PT)	Torque / current mode.
6	Homing (CiA 402)	Runs the method in **0x6098** (supported: **15–18**, same procedures as modes 15–18). Control Word bit 4 rising edge starts homing; Status Word bit 12 = attained, bit 13 = error.
8	Cyclic sync. position (CSP)	No internal profile generator: **0x607A** is treated as the position setpoint **each EtherCAT cycle** (firmware `AXIS_STATE_MOTORMODE_POSITION_NOPP`). Use with TwinCAT **NC / CSP** (or any master that streams position cyclically). Also referred to as **cyclic position** / NC cyclic setpoint in fieldbus tooling.
15	Neg. limit switch, advanced	Search **DI1** in the negative direction; user zero at encoder 0° after leaving the switch.
16	Pos. limit switch, advanced	Search **DI2** in the positive direction; user zero at encoder 0° after leaving the switch.
17	Neg. limit switch, simple	Search **DI1** in the negative direction; user zero at the switch **opening** edge.

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18	Pos. limit switch, simple	Search **DI2** in the positive direction; user zero at the switch **opening** edge.
–99	Calibration	Encoder / ripple calibration (motor must be able to move as required by the routine).

4.7.4.1 Position: mode 1 (PP) vs mode 8 (CSP)

Aspect	Mode 1 — profile position (PP)	Mode 8 — cyclic sync. position (CSP)
Object 0x6060	`1`	`8`
Path planner	Yes — on-drive profile (`Motion + OperationModeProfilePosition`)	No — master setpoint each cycle
Typical master	PLC / simple master; target + limits; no cyclic NC	TwinCAT NC / CSP or equivalent cyclic position
Demanded position (0x607A)	Target for internal planner	Direct command every cycle

> **NOTE**
> Beckhoff **NC** cyclic position uses CiA 402 **CSP** ⟶ **8**. Point-to-point moves with on-drive ramps ⟶ **1**.

4.8 Limit-switch homing (modes 15–18)

These four modes are the drive's limit-switch referencing sequence. They can be selected directly, or through CiA 402 homing mode **6** with the method (**15–18**) in object **0x6098**. The shaft encoder is absolute over one mechanical revolution (360°); the switch is used to find a mechanical edge and, in simple mode, to define user zero.

4.8.1 Input assignment and polarity

Mode	Direction	Digital input	Zero after homing
15	Negative	DI1 — object **0x6691** (bit 0 of **0x60FD**)	Encoder magnet 0° (advanced)
16	Positive	DI2 — object **0x6692** (bit 1 of **0x60FD**)	Encoder magnet 0° (advanced)
17	Negative	DI1 — object **0x6691** (bit 0 of **0x60FD**)	Switch opening edge (simple)
18	Positive	DI2 — object **0x6692** (bit 1 of **0x60FD**)	Switch opening edge (simple)

The homing logic reads the same processed inputs as the CoE objects: hardware-revision pin swap (rev ≥ 2), 500 Hz filter, and polarity **0x60FE**.

Object	Value	Switch active when

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0x60FE	`0` (default)	Low-active: physical low / pull-up to GND is active (`1` in **0x6691** / **0x6692**).
0x60FE	`1`	High-active: physical high is active.

An input is treated as **pressed** when the corresponding object is `1`.

4.8.2 Sequence (identical for 15–18 until the switch is open again)

The first contact with the switch is **not** the stop point. The motor always reverses and stops (or continues, in advanced mode) only after the switch has **opened** again.

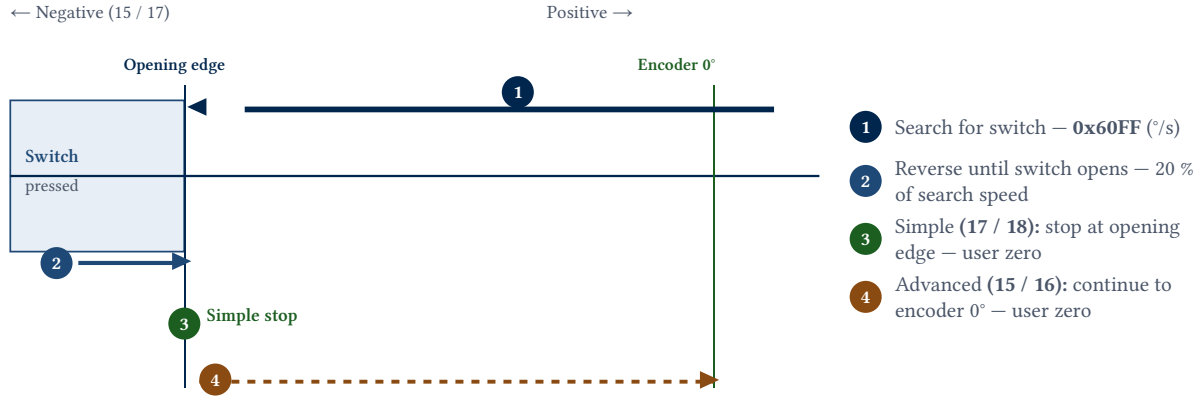


*Figure 2: Limit-switch homing, negative direction (modes **15** / **17**). Positive modes **16** / **18** are the same sequence mirrored. Step **3** ends simple homing; step **4** is advanced only.*

1. Enable the drive (CiA 402 **Operation enabled**).
2. Set search speed with **0x60FF** (in °/s, see below), then write **0x6060** to **15**, **16**, **17**, or **18**.
3. **Search:** drive toward the switch at search speed until the input is active (debounced, 1 ms).
4. **Reverse** to low (return) speed.
5. If the switch is already open again (overshoot): approach it again at return speed until it is active.
6. **Leave the switch:** keep driving at return speed **away** from the switch until the input is inactive (debounced). This is the **opening edge**.
7. **Simple (17 / 18):** disable the motor, wait 100 ms, store the current angle as position offset. User position (**0x6064**) is then 0 at this opening edge.
8. **Advanced (15 / 16):** do **not** stop at the opening edge. Continue at return speed in the same direction until the absolute encoder is within 1° of magnet 0°, then reset the position filter. User zero is encoder 0°, not the switch. If the opening edge is already that close to encoder 0°, the sequence aborts with error **50**.
9. On success the motor stays disabled, **0x6060** remains **15–18**, and the internal homing-completed flag is set. To run homing again, change **0x6060** to another mode and back.

Timeout is **5 minutes**. If the switch is never found, the motor is disabled and error **25** (limit-switch timeout) is set.

4.8.3 Search and return speed

There is **one** setpoint object for homing speed. Return speed is derived from it; it cannot be set separately.

Object	Role	Behaviour

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0x60FF	Target velocity	Sets **search** speed towards the switch, unit **°/s** (same object and scaling as profile velocity, mode **3**). The **sign is ignored**; direction comes from the mode (15/17 vs 16/18). Gear ratio is applied.
—	Return / creep speed	Always **20 %** of the search speed. Used after the switch is found: reverse, re-approach if overshot, leave until open, and (advanced only) crawl to encoder 0°.

If **0x60FF** is `0`, or the converted search speed is below 1 RPM, the firmware uses a default search speed of **50 RPM** (return speed 10 RPM).

> **NOTE**
> Object **0x6099** (Homing speed, sub-indices "search for switch" / "search for zero") exists in the object dictionary but is **not** used by modes 15–18. Do not expect those sub-indices to change homing speed.

4.8.4 Simple vs advanced — which zero?

Both modes share the same switch search. They do **not** differ in how accurately the switch edge is detected.

- **Simple (17 / 18):** user zero = mechanical **opening** edge of the limit switch. Use this when the switch is the machine reference (end of travel, fixture). Repeatability is that of the switch (hysteresis, mounting, approach speed).
- **Advanced (15 / 16):** user zero = absolute encoder magnet 0° (one count in 360°). The switch only finds the side / turn; the drive then abandons the switch as the zero. This is **not** a more accurate measurement of the same edge. On a geared or linear axis the motor may travel almost one motor revolution past the switch before encoder 0° occurs.

The encoder is already absolute over 360°. Advanced mode does not improve encoder resolution; it selects a different reference.

4.8.5 Master sequence (typical)

1. Set polarity **0x60FE** to match the switch wiring; confirm **0x6691** / **0x6692** while actuating the switch.
2. Write search speed to **0x60FF** in °/s (or leave 0 for the 50 RPM default).
3. **Switch on** / **enable operation**, then write **0x6060** = **17** (example: negative, simple).
4. Wait until the motor stops. User position **0x6064** should be 0 (simple) or encoder-aligned (advanced).
5. Switch **0x6060** to the required running mode (**1** or **8**).

> **Motion during homing**
> The axis moves autonomously until the sequence finishes or times out. Ensure the travel path to the switch is clear. A missing or inverted switch will run until the 5-minute timeout.

4.9 Bandwidth-Based Parameter Calculation

The HDrive-ETC features an **automatic parameter calculation system** that derives optimal control parameters from user-defined bandwidth settings.

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4.9.1 Bandwidth Configuration Objects

Object	Name	Description	Units
0x6640	Control Bandwidth	Bandwidth settings for all controllers	—
0x6640.1	Current BW	Current controller bandwidth (300–1000)	Hz
0x6640.2	Speed BW	Speed controller bandwidth (10–30)	Hz
0x6640.3	Position BW	Position controller bandwidth (10–30)	Hz

4.9.2 Damping Factor Configuration Objects

Object	Name	Description	Units
0x6620	Motor Dynamic	Damping factors for all controllers	—
0x6620.1	Current Damping	Current controller damping	%
0x6620.2	Speed Damping	Speed controller damping	%
0x6620.3	Position Damping	Position controller damping	%

4.9.3 Automatic Parameter Update

Trigger Object: 0x6637 — Trigger New Parameter Calculation

- **Write 1:** Triggers automatic parameter calculation. Reads current bandwidth and damping settings, calculates optimal gains, and updates all controllers.
- **Write 2:** Saves current parameters to EEPROM (persistent storage) for use after power cycles.
- **Write 3:** Restores factory default parameters and stores them to EEPROM.

These actions take effect immediately after writing the trigger value.

4.9.4 Parameter Integrity (CRC)

Object **0x66F1** — **Parameter integrity** (read-only) provides a CRC-16 fingerprint of all persisted user parameters (motor, control, commissioning data in the EEPROM motor-config block). Encoder and torque-ripple LUTs have their own CRC and are **not** included.

SubIndex	Name	Type	Description
0x66F1:0	Number of entries	USINT	Always 3
0x66F1:1	Live CRC	UINT	CRC of the current (RAM / OD) parameter set
0x66F1:2	NVM CRC	UINT	CRC of the last EEPROM image
0x66F1:3	Match	USINT	`1` = live equals NVM; `0` = unsaved changes

- After commissioning, record **Live CRC** (e.g. in the serial protocol) so later changes are detectable (CRA / configuration integrity).
- Changing any user parameter updates **Live CRC**. **Match** stays `0` until you save with **0x6637 = 2**.
- The web GUI shows the same values under **Maintenance → Configuration integrity**.

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Commit configuration (web GUI). Under **Maintenance → Configuration integrity**, the button **Commit configuration** writes `0x6637 = 2` (save current user parameters to EEPROM and reboot). That marks the current Live CRC as the intentional NVM baseline. After reboot, **Match = yes**. Use **Refresh CRC** to re-read `0x66F1` without saving.

Parameter field colours (web GUI).

Appearance	Meaning
Orange text + orange left bar	Edited locally — not yet written to drive RAM
Green text + amber left bar + badge `not in EEPROM`	Accepted in drive RAM — not yet saved to EEPROM
Default styling	Matches the last committed EEPROM baseline

Press **Enter** in a settings field (or use **Save → save to session**) to write the value to RAM; the field turns green. Persist with **Commit configuration** (or **Save → save to EEPROM and restart**).

4.9.5 Bandwidth Selection Guidelines

Controller	Typical Range	Recommended	Application
Current	100–1000 Hz	500 Hz	High precision, fast response
Speed	10–50 Hz	50 Hz	Smooth operation, good tracking
Position	1–30 Hz	20 Hz	Stable positioning, minimal overshoot

4.9.6 Damping Factor Guidelines

Controller	Typical Range	Recommended	Effect
Current	50–100%	70%	Fast settling, minimal overshoot
Speed	50–100%	70%	Smooth speed transitions
Position	100–150%	70%	Stable positioning, no oscillations

4.9.7 Motor Parameter Requirements

Parameter	Description	Units
Resistance	DC coil resistance	mΩ
Inductance	Coil inductance	µH
Torque Constant	Torque per ampere	mNm/A
Resonance Frequency	Mechanical resonance	Hz
Inertia	Rotor inertia	g·cm²
Damping	Mechanical damping	µN·m·s/rad

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NOTE
The parameter calculation system automatically limits bandwidth values based on hardware constraints and control loop stability requirements to ensure safe operation.

4.9.8 Control Tuning Parameters

Parameter	Object	Description	Units
Inertia	0x6633:01	Rotor inertia	g·cm²
Damping	0x6634:01	Mechanical damping	µN·m·s/rad
Current BW	0x6640:01	Current control bandwidth	Hz
Speed BW	0x6640:02	Speed control bandwidth	Hz
Position BW	0x6640:03	Position control bandwidth	Hz

4.9.9 Controller Tuning Best Practices

1. **Start with Low Bandwidths** — Begin with conservative settings:
   - Current Bandwidth: 400 Hz
   - Position Bandwidth: 15 Hz
2. **Initial Testing** — Set the motor to run back and forth between two positions in reverse sequencing mode.
3. **Inertia Adjustment** — Carefully adjust the **inertia parameter** so that the position control loop does **not overshoot**. The goal is smooth motion with no oscillation or ringing.
4. **Increase Bandwidth for Dynamics** — Once the inertia is well tuned, gradually increase bandwidth settings to achieve higher responsiveness.

RECOMMENDATION
Make small, incremental changes and retest each time for stable, reliable motion.

4.10 EtherCAT Object Dictionary

The **EtherCAT object dictionary** contains all configurable parameters and status information for the HDrive-ETC system.

4.10.1 Object Dictionary Structure

Category	Description	Access
Actual Motor Data	Real-time motor status and measurements	Read-only
Demanded Values	Target values from EtherCAT master	Write-only
Control Values	Control loop parameters and tuning	Read/Write
Stored Values	System configuration and persistent data	Read/Write
Motor System Values	Motor-specific parameters and limits	Read/Write

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4.10.2 Position Control Parameters

Parameter	Object ID	Description	Units	Range
Position P-Gain	posPCas	Proportional gain	—	0–1000
Max Position Speed	posMaxSpeedCas	Maximum control speed	RPM	0–2000
Max Slew Rate	posMaxSlewRate-Cas	Maximum position change rate	deg/s	0–360
Position Pre-filter	posPreFilter	Position input filter frequency	Hz	1–1000
Feed-forward Filter	posFFFilter	Feed-forward filter frequency	Hz	1–1000

4.10.3 Speed Control Parameters

Parameter	Object ID	Description	Units	Range
Speed P-Gain	speedPCas	Proportional gain	—	0–1000
Speed I-Gain	speedICas	Integral gain	—	0–1000
Speed Feed-forward	speedFgCas	Feed-forward gain	—	0–100
Speed Back-EMF	speedKbCas	Back-EMF compensation gain	—	0–100
Speed I-Max	speedImaxCas	Maximum integral windup	A	0–5

4.10.4 Current Control Parameters

Parameter	Object ID	Description	Units	Range
Current P-Gain	currPCas	Proportional gain	—	0–1000
Current I-Gain	currICas	Integral gain	—	0–1000
Current Back-EMF	currKbCas	Back-EMF compensation gain	—	0–100
Control Bandwidth	currentCtrlBW	Current control bandwidth	Hz	100–2000
Damping Factor	currentCtrlDF	Current control damping	—	0.1–2.0

4.10.5 Error Codes (0x603F)

See Section 5.1 for the full manufacturer error list (object **0x603F**).

4.11 Process Data Objects (PDOs)

4.11.1 RxPDO (Master → Slave) — Control Commands

Object	Description	Data Type	Units
Control Word (0x6040)	Operation mode commands	UINT16	—

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Target Position (0x607A)	Position setpoint	INT32	0.1°
Target Velocity (0x60FF)	Velocity setpoint	INT32	deg/s
Target Torque (0x6071)	Torque setpoint	INT16	mNm

4.11.2 TxPDO (Slave → Master) — Status Information

Object	Description	Data Type	Units
Status Word (0x6041)	System status and errors	UINT16	—
Actual Position (0x6064)	Current position	INT32	0.1°
Actual Velocity (0x606C)	Current velocity	INT32	deg/s
Actual Torque (0x6077)	Current torque	INT16	mNm
Actual Current (0x6078)	Motor current	INT16	mA
Actual Temperature (0x6079)	System temperature	INT16	0.1 °C

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5 Troubleshooting & Maintenance

5.1 Error Codes

Object **0x603F** holds the HDrive manufacturer error number (same value as decimal and as hex, e.g. 50 = `0x32`).

Code	Description	Action Required	Severity
0 / `0x00`	No error	Normal operation	Info
1 / `0x01`	Program error (null pointer)	Contact support / update firmware	Critical
15 / `0x0F`	Position overflow / underflow	Reset position reference	Warning
16 / `0x10`	Over temperature	Check cooling, reduce load	Critical
17 / `0x11`	Under voltage	Check DC supply (≥ 9 V)	Critical
18 / `0x12`	Over voltage	Check DC supply / braking	Critical
19 / `0x13`	Over speed	Reduce speed demand / check load	Critical
20 / `0x14`	Positive software position limit	Adjust limits or target	Warning
21 / `0x15`	Negative software position limit	Adjust limits or target	Warning
22 / `0x16`	Negative limit switch triggered	Clear travel / check DI1 polarity	Warning
23 / `0x17`	Positive limit switch triggered	Clear travel / check DI2 polarity	Warning
25 / `0x19`	Limit switch timeout	Switch not found within 5 min; check DI, polarity, travel	Error
26 / `0x1A`	Position sensor error	Check encoder connection	Critical
27 / `0x1B`	Power stage fault	Check power electronics / DRV	Critical
28 / `0x1C`	Watchdog timeout	System reset required	Critical
30 / `0x1E`	SPI position sensor error	Check SPI communication	Error

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31 / `0x1F`	Calibration error	Recalibrate system	Error
33 / `0x21`	Configuration error	Check parameter settings	Error
37 / `0x25`	Hardware not compatible	Check hardware revision	Critical
38 / `0x26`	EtherCAT connection interrupted	Check cable / master OP	Error
50 / `0x32`	Limit switch min. distance to encoder 0°	Advanced homing 15/16 only: opening edge was within 1° of magnet 0°. Use simple mode 17/18, or relocate the switch	Error
51 / `0x33`	Motor mode not existing	Select a supported 0x6060 value	Error
54 / `0x36`	Wrong path planner settings	Set 0x6083 / 0x6084 > 0	Error
55 / `0x37`	Homing method not supported	Set 0x6098 to 15–18 before starting mode 6	Error

Homing notes: methods **15/16** are advanced (zero at encoder 0°); **17/18** are simple (zero at switch opening). Status Word bits 12/13 (attained / error) apply in CiA Homing mode **6** only — not when 15–18 are selected directly as `0x6060`.

5.2 Diagnostic Procedures

5.2.1 Communication Problems

Symptom	Possible Cause	Solution
EtherCAT communication lost	Network cable issue	Check cable connections and integrity
Intermittent communication	EMC interference	Install EMC filters, check grounding
Slow response	Network congestion	Optimize EtherCAT cycle time
Node not found	Incorrect addressing	Verify node address configuration

5.2.2 Control Performance Issues

Symptom	Possible Cause	Solution
Position overshoot	Wrong inertia settings	Adapt inertia settings
Oscillations	Wrong bandwidth	Change system bandwidth
Slow response	Low bandwidth	Increase control bandwidth

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5.2.3 Motor Issues

Symptom	Possible Cause	Solution
Excessive heating	High current	Check load, reduce current limits

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6 Specifications

6.1 Electrical Specifications

6.1.1 Power Requirements

Parameter	Value	Unit	Notes
Supply Voltage V_s	24	V DC	Nominal operating voltage
Supply Voltage V_p	24–48	V DC	Nominal operating voltage
Voltage Tolerance	±10%	V DC	Operating range
Current Consumption V_s	0.5	A	Maximum continuous current
Current Consumption V_p	1.0	A	Maximum continuous current
Power Consumption	36	W	Maximum power draw
Power Factor	>0.9	—	Power efficiency

6.1.2 Communication Specifications

Parameter	Value	Unit	Notes
Protocol	EtherCAT	—	Real-time communication
Data Rate	100	Mbps	Ethernet speed
Cycle Time	1	ms	Typical update rate
Node Address	0–65535	—	Configurable

6.1.3 Encoder Specifications

Parameter	Value	Unit	Notes
Resolution	16 384	counts/rev	14-bit resolution
Accuracy	±0.1	°	Positioning accuracy
Type	Magnetic	—	Non-contact sensing
Calibration	Factory	—	Pre-calibrated

6.1.4 Control Performance Specifications

Parameter	Value	Unit	Notes
Position Accuracy	±0.1	°	Static positioning accuracy

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Repeatability	±0.05	°	Position repeatability
Current Control BW	100–1000	Hz	Configurable bandwidth
Pos/Speed Control BW	10–30	Hz	Configurable bandwidth

6.1.5 Real-time Performance

Parameter	Value	Unit	Notes
ADC Sampling Rate	20	kHz	Current measurement
Control Update Rate	20	kHz	Current control
Position Update Rate	2	kHz	Position control
State Machine Rate	2	kHz	System state machine
Min. EtherCAT Cycle	50	µs	Communication cycle

6.2 Environmental Specifications

6.2.1 Operating Conditions

Parameter	Value	Unit	Notes
Operating Temperature	–10 to +60	°C	Ambient temperature
Storage Temperature	–20 to +80	°C	Non-operating
Humidity	5 to 95	% RH	Non-condensing
Altitude	0 to 2000	m	Above sea level

6.2.2 Protection Ratings

Parameter	Value	Unit	Notes
IP Rating	IP40	—	Indoor use only
EMC	Class A	—	Industrial environment
Safety	CE Marked	—	EU compliance

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6.3 Performance Characteristics

6.3.1 Torque and Speed Performance

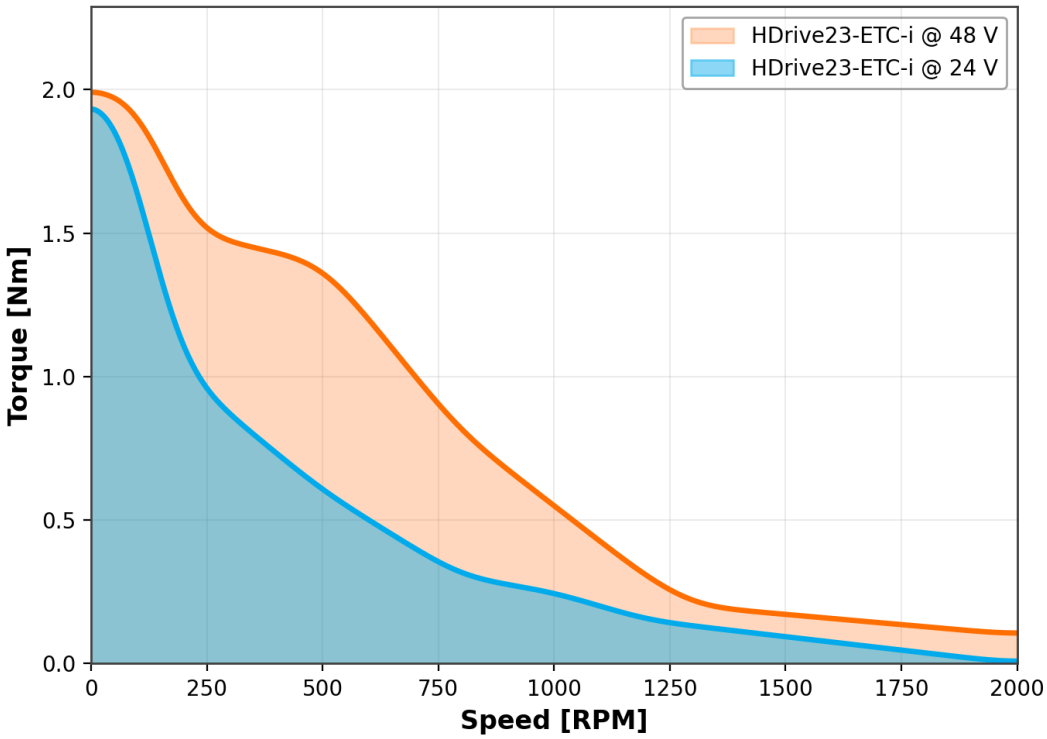


Figure 3: HDrive-ETC-i speed / torque characteristics

6.3.2 Physical Specifications

Parameter	Value	Unit	Notes
Weight	470	g	Total system weight
Dimensions	See diagram	mm	Overall dimensions
Mounting	M3 × 4	—	Mounting holes
Connectors	M8 A-coded ×3	—	Supply, digital I/O, EtherCAT; see Table 1

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