Operating Guide

B&P Elektromotoren

iC7-Aqua and iC7-HVACR Functional Safety

Frequency Converters, 1.3–1260 A



DESIGN AWARD 2023

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1 Introduction

1.1 Purpose of this Operating Guide

This operating guide provides information on the functional safety features of the iC7 drives and is targeted at users already familiar with the Danfoss iC7 series. It is intended as a supplement to the drive-specific guides.

The guide includes instructions on how to verify that the built-in functional safety features are active, and about configuring the safety features.

1.2 Additional Resources

Additional resources are available to help understand the features, and safely install and operate the iC7 series products:

- Safety guides, which provide important safety information related to installing iC7 series drives and power converters.
- Installation guides, which cover the mechanical and electrical installation of drives, power converters, or functional extension options.
- Design guides, which provide technical information to understand the capabilities of the iC7 series drives or power converters for integration into motor control and monitoring systems.
- Operating guides, which include instructions for control options, and other components for the drive.
- Application guides, which provide instructions on setting up the drive or power converter for a specific end use. Application guides for application software packages also provide an overview of the parameters and value ranges for operating the drives or power converters, configuration examples with recommended parameter settings, and troubleshooting steps.
- *Facts Worth Knowing about AC Drives*, available for download on www.danfoss.com.
- Other supplemental publications, drawings, and guides are available at www.danfoss.com.

Latest versions of Danfoss product guides are available for download at https://www.danfoss.com/en/service-and-support/documentation/.

1.3 Abbreviations

Table 1: Abbreviations Related to Functional Safety

Abbreviation	Reference	Description
FIT	–	Failure in time. 1 FIT corresponds to a failure per 1E9 hours of operation.
HFT	EN IEC 61508-4	Hardware fault tolerance: HFT = n means that n+1 faults could cause a loss of the safety function.
PFH	EN IEC 61508-4	Probability of dangerous failures per hour. Consider this value if the safety device is operated in high demand or continuous mode of operation, where the frequency of demands for operation made on a safety-related system is greater than 1 per year.
PFD	EN IEC 61508-4	Average probability of failure on demand, value used for low demand operation.
PL	EN ISO 13849-1	Discrete level used to specify the ability of safety-related parts of control systems to perform a safety function under foreseeable conditions. Levels divided into a to e.
PLr	EN ISO 13849-1	Required performance level (the required performance level for a particular safety function).

Table 1: Abbreviations Related to Functional Safety - (continued)

Abbreviation	Reference	Description
SIL	EN IEC 61508-4	Safety Integrity Level
STO	EN IEC 61800-5-2	Safe Torque Off
SS1	EN IEC 61800-5-2	Safe Stop 1

1.4 Version History

This guide is regularly reviewed and updated. All suggestions for improvement are welcome.

The original language of this guide is English.

Table 2: Version History

Version	Remarks
AQ540338948377, version 0101	First release.

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2 Safety

2.1 Qualified Personnel for Working with Functional Safety

Only qualified personnel can install, configure, commission, maintain, and decommission functional safety features and functions. Qualified personnel for working with functional safety features are qualified electrical engineers, or persons who have received training from qualified electrical engineers, and are suitably experienced to operate devices, systems, plants, and machinery in accordance with the general standards and guidelines for safety technology.

Furthermore, they must:

- Be familiar with the basic regulations concerning health and safety/accident prevention.
- Have read and understood the safety guidelines given in this guide.
- Have a good knowledge of the generic and specialist standards applicable to the specific application.

Installers and system integrators of systems incorporating power drive systems (safety-related) are responsible for:

- Hazard and risk analysis of the application.
- The overall safety of the application.
- Identifying safety functions required and allocating SIL or PL to each of the functions, other subsystems, and the validity of signals and commands from them.
- Designing appropriate safety-related control systems, such as hardware, software, and parameterization.

2.2 General Safety Considerations

When installing or operating the drive, pay attention to the safety information given in the instructions. For more information about safety guidelines for installation, see the product-specific safety guide that is included in the drive shipment. For more information about safety guidelines for operating the drive, see the product-specific guides.

⚠ WARNING



RISK OF ELECTRIC SHOCK

The STO safety function does not provide electrical safety. The STO function itself is not sufficient to implement the Emergency-Off function as defined by IEC 60204-1:2018. Using the STO function to implement Emergency-Off may lead to death or personal injury.

- Emergency-Off requires measures of electrical isolation, for example, by switching off mains via an extra contactor.

NOTICE

COMMISSIONING TEST

After installing the safety functions, perform a commissioning test.

A successful commissioning test is required after the initial installation, and after each change to the installation or application involving functional safety.

If the commissioning test fails, safe operation cannot be guaranteed.

3 Functional Safety with STO, Not Upgradable (+BEG1)

3.1 iC7 Functional Safety

3.1.1 Overview

Frequency converters with the functional safety option **STO, not upgradable (+BEG1)** provide the Safe Torque Off (STO) safety function with a dual-channel, galvanically isolated input, and an STO feedback signal for diagnostic purposes.

The drive integrates the STO functionality via the functional safety I/O terminals as described in Table 3.

The iC7 drive with STO functionality is designed and approved suitable for the requirements of:

- Category 3 in EN ISO 13849-1
- Performance Level "e" in EN ISO 13849-1
- SIL 3 in IEC 61508 and 61800-5-2

The STO safety function is active if one or both of the STO inputs are not connected to a +24 V signal. The frequency converter is not able to go to the RUN state. For more information, see Table 4.

Prerequisites for normal operation (STO function is not active) are:

- STO A and STO B signals are energized.
- No internal faults are active.

All control inputs and outputs are galvanically isolated from supply voltage (PELV) and other high voltage terminals, unless otherwise specified.

Table 3: Functional Safety I/O Terminals in Frequency Converters

Terminal X31			Terminal X32		
Numbering	**Terminal name**	**Functions**	**Numbering**	**Terminal name**	**Functions**
41	24 V	+ 24 V DC Output	45	GND	0 V/GND
42	S.INA+	+ STO Input Channel A	46	S.INA–	- STO Input Channel A
43	S.INB+	+ STO Input Channel B	47	S.INB–	- STO Input Channel B
44	S.FB+	+ STO Feedback	48	S.FB–	- STO Feedback

Table 4: Instances of the STO Function and STO Feedback Output

STO inputs	Operating conditions	STO function	STO feedback signal	Fault or warning text
Both inputs energized with 24 V DC	Normal operation	Deactivated	Deactivated	No faults or warnings
Power removed from both inputs	STO demand	Activated	Activated	"STO activated"(1)
Only 1 input energized	Failure in demand or due to internal fault	Activated	Activated	"I/O failure detected"(2)

1) Regular STO demand: Can be either fault or warning depending on restart settings.

2) Failure in demand or due to internal fault (always a "fault", not configurable). Indicated after discrepancy timer (700 ms) elapsed.

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3.1.2 System Configuration Security

iC7 drives are equipped with mandatory and configurable security features that prevent unauthorized access to the drive, ensure secure connectivity to the drive, and protect the drive against unauthorized software modifications.

For more details on the security features included in the application software, refer to application software documentation.

Configurable security features can be adjusted according to application requirements.

3.1.3 Safe Torque Off (STO)

NOTICE

- Select and apply the components in the safety control system appropriately to achieve the required level of operational safety. Before integrating and using STO in an installation, carry out a thorough risk analysis on the installation to determine whether the STO functionality, and safety levels are appropriate and sufficient.

The Safe Torque Off (STO) function is a component in a safety control system. STO prevents the unit from generating the power required to rotate the motor, which is defined as safe state.

The iC7 drives are available with:

- Safe Torque Off (STO), as defined by EN IEC 61800-5-2:2017
- Stop category 0, as defined in EN IEC 60204-1:2018

3.1.4 STO Activation

The STO function is activated by removing the voltages at the STO inputs of the frequency converter. By connecting the frequency converter to external safety devices providing a safe delay, an installation for a Safe Stop 1 can be obtained. External safety devices must fulfill the required Cat./PL or SIL when connected to STO inputs.

The drive includes internal diagnostics that, in case of a fault detected, will cause a fault reaction entering the safe state.

With default settings, the frequency converter issues a fault, trips the unit and coasts the motor to a stop, when the STO function is activated. Manual restart is required.

Use the STO function to stop the frequency converter in a situation where a safety function is required. In normal operating mode when STO is not required, use the standard stop function instead.

3.1.5 Automatic/Manual Restart Behavior

The STO default state prevents unintended restarts (Restart Prevention Behavior).

NOTICE

The prevention of unintended restart after STO deactivation does not fulfill a SIL 2 or SIL 3 requirement.

- If unintended restart is critical to the installation, this has to be controlled by the use of STO, both after STO activation and at normal startup scenarios, for example, after normal power cycle.

⚠ CAUTION

- The default restart behavior is set to ***Manual***. Before switching to ***Automatic***, ensure that requirements of EN ISO 12100:2011 paragraph 6.3.3.2.5 are fulfilled.

Terminating STO and resuming normal operation

1. Reapply 24 V DC supply to safe inputs.
2. Give a reset signal via fieldbus, digital I/O, or the control panel.

Set the STO function to automatic restart by setting the value of parameter ***7.3.1 Safe Torque Off Response*** from the default value ***Fault*** (manual reset) to value ***Warning*** (automatic reset). Automatic reset means that STO is terminated and normal operation is resumed, when the 24 V DC is applied to STO inputs. No reset signal is required.

3.1.6 STO Properties

For flexible adaptation to the safety system, the STO inputs contain the following properties:

- **Galvanic isolation of terminals**: The functional safety I/O terminal blocks on the control board (X31, X32) have separate, galvanically isolated inputs to allow, for example, interchanging of the polarities of the STO input terminals as shown in Figure 7 and Figure 8.
- **Test pulse filtering**: Several control modules test their safe outputs using Test Pulse Pattern (on/off tests), to identify faults due to either short- or cross-circuiting. When connecting the STO inputs with a safe output of a control module, test pulses shall not activate STO. For that reason, test pulses for no longer than 2 ms is ignored on the STO input lines.

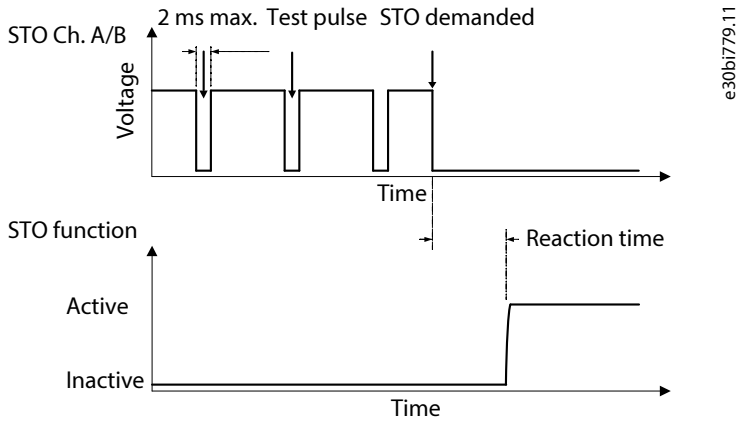


Figure 1: Test Pulse Filtering

- **Asynchronous input tolerance**: The input signals at the STO terminals are not always synchronous. If the discrepancy between the 2 signals is longer than 700 ms, the drive indicates an STO fault as described in Table 4. This feature does not delay the activation of the STO function.

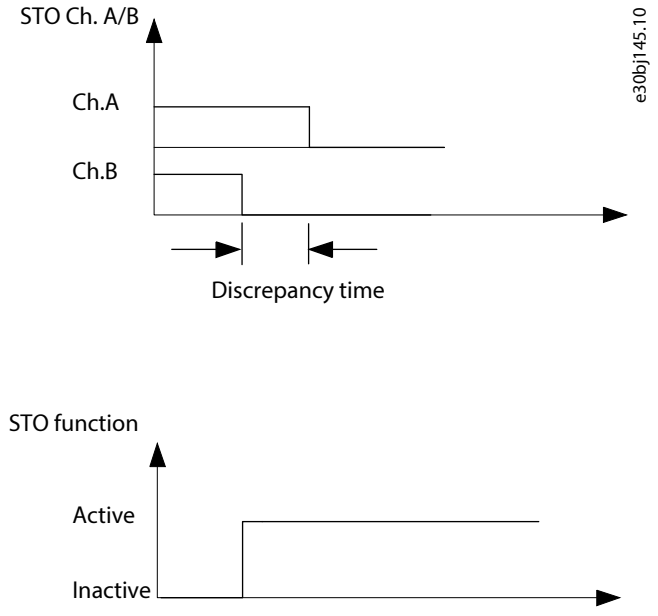


Figure 2: Discrepancy Time

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3.1.7 STO Feedback

STO feedback is a single-channel feedback signal which can be used for diagnostic purposes, and for providing an indication of an active STO. It can help to achieve better safety capability on system level, for example, in retrofit cases, where a diagnostic feedback to the safety system is required.

⚠ CAUTION

- The feedback signal is not designed to be a part of the safety function, and it does not have a Safety Integrity Level.

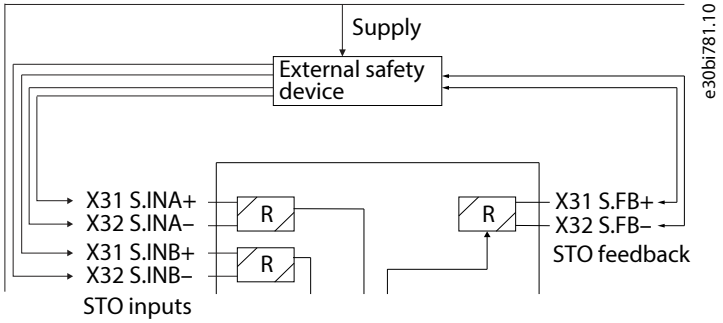


Figure 3: STO Feedback Example for iC7 Frequency Converters

It can also be used as a digital output for providing a status signal. In this case, the load could be a digital input of a PLC.

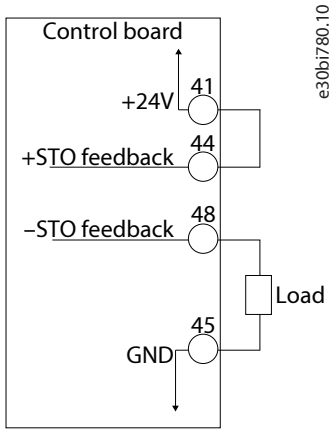


Figure 4: STO Feedback Example for iC7 Frequency Converters

The STO feedback works similar to a contactor which is closed as soon as both STO input channels are de-energized.

3.2 Installation

3.2.1 STO Installation for Frequency Converters with Functional Safety Group 1 (STO - Not Upgradable)

Prerequisites:

For motor connection, AC mains connection, and control wiring, follow the instructions for safe installation in the documentation shipped with the drive.

All functional safety related wiring must be done on terminal blocks X31 and X32. See Figure 5 for the location of the terminals.

NOTICE

If multi-stranded wires are used in the installation, ferrules or other suitable means must be used to prevent a single core from short-circuiting with adjacent pins.

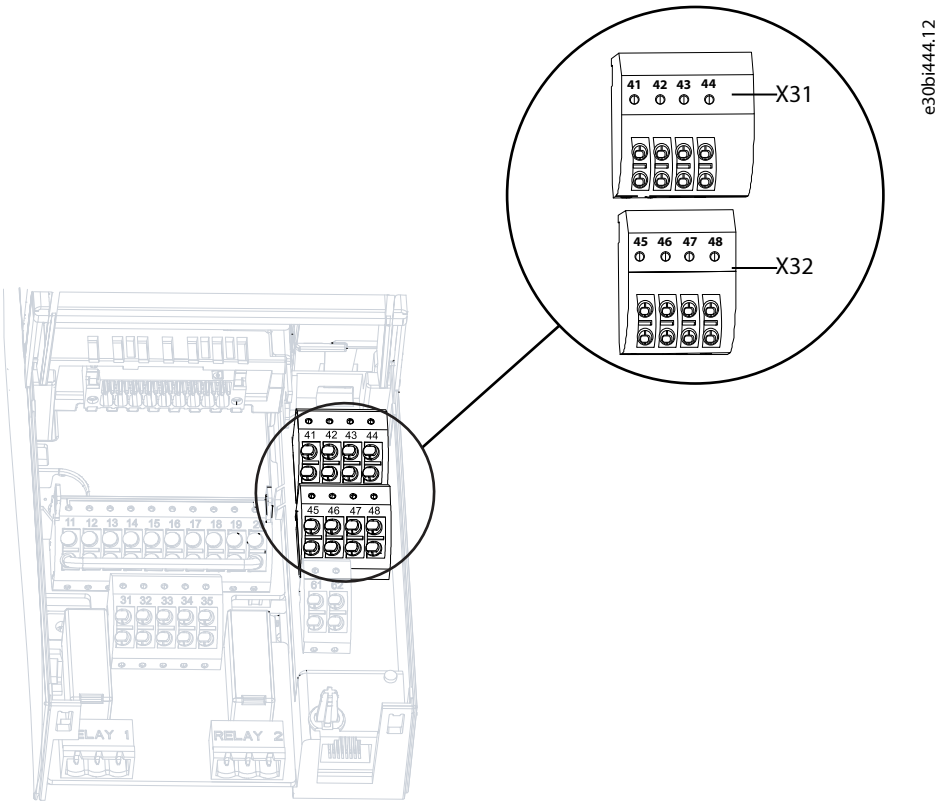


Figure 5: Functional Safety Terminals

Table 5: Functional Safety I/O Terminals in Frequency Converters

Terminal X31			Terminal X32		
Numbering	**Terminal name**	**Functions**	**Numbering**	**Terminal name**	**Functions**
41	24 V	+ 24 V DC Output	45	GND	0 V/GND
42	S.INA+	+ STO Input Channel A	46	S.INA–	- STO Input Channel A
43	S.INB+	+ STO Input Channel B	47	S.INB–	- STO Input Channel B
44	S.FB+	+ STO Feedback	48	S.FB–	- STO Feedback

The frequency converter is shipped without any wiring to the functional safety I/O terminals. As a result, all safe inputs are de-energized and STO is active.

1. If the STO safety function is not needed, wire the terminal block as shown in Figure 6, or use the STO jumper clips from the accessory bag and mount them on X31 and X32. This ensures that both STO inputs are energized with 24 V DC for enabling normal operation.

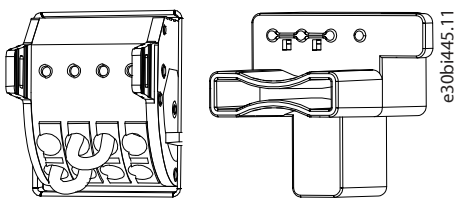


Figure 6: Wired Terminal Block (on the Left) and STO Jumper Clip (on the Right)

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3.2.2 Connection Examples

Due to the galvanic isolation of the STO inputs, various connections and different polarities are possible in the wiring. For example, connect a safety actuator to STO input terminals, and set the voltage references as shown in Figure 7 and Figure 8. Setups with the same voltage level on both channels (+24 V) are supported, but also setups with different voltage levels (+24 V and GND) are supported.

NOTICE

DANGEROUS VOLTAGE LEVEL

- To avoid stacking and drifting of voltages to a dangerous level, interconnect GND PELV of the drive and the external safety device.

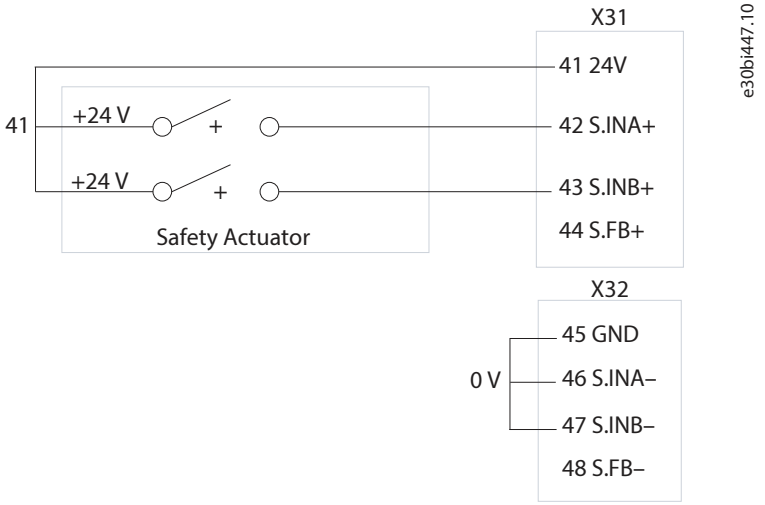


Figure 7: STO Connection Example for Using the Same Polarities (Channel A and Channel B = 24 V)

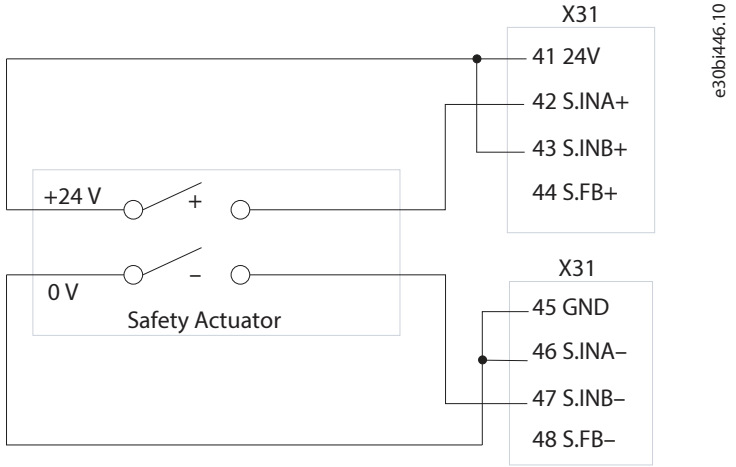


Figure 8: STO Connection Example for Using Different Polarities

For other wiring examples, see application software documentation.

3.3 Commissioning

3.3.1 Safety Instructions for Commissioning

See 2.2 General Safety Considerations and the relevant product-specific guides for more instructions on safety. Always observe the instructions provided by the motor manufacturer.

⚠ WARNING

RESIDUAL ROTATION

The STO function can be used for any type of motors. 2 faults can occur in the power semiconductor of the drive. A residual rotation can result from the faults. The rotation can be calculated to angle = 360/(number of pole pairs).

- Ensure that this residual rotation does not pose a safety risk. The situation is not relevant for induction motors.

3.3.2 Commissioning Test

3.3.2.1 Overview

After installation and before 1st operation, a commissioning test using STO is required. The commissioning test is also required after each modification of the installation or application that involves STO.

NOTICE

COMMISSIONING TEST

After installing the safety functions, perform a commissioning test.

A successful commissioning test is required after the initial installation, and after each change to the installation or application involving functional safety.

If the commissioning test fails, safe operation cannot be guaranteed.

To perform a commissioning test:

- See 3.3.2.2 Commissioning Test for STO Applications in Manual Restart Mode if STO is set to manual restart mode (parameter ***7.3.1 Safe Torque Off Response*** is set to default setting ***Fault, reset required*** (manual reset).
- See 3.3.2.3 Commissioning Test for STO Applications in Automatic Restart Mode if STO is set to automatic restart mode (parameter ***7.3.1 Safe Torque Off Response*** is set to ***Warning, no reset required*** (automatic reset).

3.3.2.2 Commissioning Test for STO Applications in Manual Restart Mode

Table 6: Commissioning Test in Manual Restart Mode

Test procedure		Approved
1	Power on the frequency converter.	☐
2	Check that no safety faults are present.	☐
3	Start the motor.	☐
4	Remove the 24 V DC voltage supply to both STO input terminals using the safety device while the frequency converter drives the motor (that is, the mains supply is not interrupted).	☐
5	Verify that the motor coasts. It may take a long time for the motor to stop.	☐
6	If a control panel is mounted, check if **STO activated** is shown on the control panel.	☐
	If the control panel is not mounted, check if **STO activated** is listed in the event log.	
7	If the STO feedback is used, verify that STO is activated by checking the state of the STO Feedback.	☐
8	Reapply 24 V DC to STO inputs.	☐
9	Ensure that the motor remains in the coasted state, and any connected relays remain activated.	☐
10	Send a reset signal via fieldbus, digital I/O, or the control panel.	☐
11	Ensure that the motor becomes operational and runs within the original speed range.	☐

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3.3.2.3 Commissioning Test for STO Applications in Automatic Restart Mode

Table 7: Commissioning Test in Automatic Restart Mode

Test procedure		Approved
1	Power on the frequency converter.	☐
2	Check that no safety faults are present.	☐
3	Start the motor.	☐
4	Remove the 24 V DC voltage supply to both STO input terminals using the safety device while the frequency converter drives the motor (that is, the mains supply is not interrupted).	☐
5	Verify that the motor coasts. It may take a long time for the motor to stop.	☐
6	If a control panel is mounted, check if **STO activated** is shown on the control panel.	☐
	If the control panel is not mounted, check if **STO activated** is listed in the event log.	
7	If the STO feedback is used, verify that STO is activated by checking the state of the STO Feedback.	☐
8	Reapply 24 V DC to STO inputs.	☐
9	Ensure that the motor becomes operational and runs within the original speed range.	☐

3.4 Operation and Maintenance

3.4.1 Functional Tests

3.4.1.1 Overview of Functional Tests

To comply with EN IEC 61800-5-2 and system level safety standards and to avoid accumulation of potential sleeping faults within the drive, periodic testing of the safety function, by requesting it, is required.

- It is **required** for PL e or SIL 3 to conduct a functional test every 3 months to detect any failure or malfunction of the safety function.
- It is **required** for PL d or SIL 2 to conduct a functional test every 12 months to detect any failure or malfunction of the safety function.

The drive safety system mission time is 20 years. After 20 years, the whole unit must be replaced.

Conduct the functional test like a commissioning test as described in 3.3.2.2 Commissioning Test for STO Applications in Manual Restart Mode and 3.3.2.3 Commissioning Test for STO Applications in Automatic Restart Mode.

NOTICE

If the functional test fails, safe operation cannot be guaranteed.

⚠ WARNING

COMPONENT FAILURE IN FUNCTIONS RELATED TO SAFETY

If a component failure occurs in functions related to safety, the drive must be replaced by authorized personnel.

- It is not allowed to modify or repair the safety circuitry in any way.

3.5 Specifications

3.5.1 Functional Safety Standards and Performance

All safety functions in the iC7 drives meet the requirements of the standards listed in this chapter.

For STO cables (X31 and X32) with lengths above 30 m (98.4 ft) or cables which are located outside of a building, the safety specifications are only valid for shielded cables.

Table 8: Functional Safety Standards and Performance

Directive or Standard		Version
European Union directives	Machinery Directive (2006/42/EC)	EN ISO 13849-1:2015, EN ISO 13849-2:2012
		EN IEC 61800-5-2:2007
	EMC Directive (2014/30/EU)	EN IEC 61800-3:2018 – second environment
		EN IEC 61326-3-1:2017
	Low Voltage Directive (2014/35/EU)	EN IEC 61800-5-1:2017
Safety standards	Safety of Machinery	EN ISO 13849-1:2023, IEC 60204-1:2018
	Functional Safety	IEC 61508-1:2010, IEC 61508-2:2010, EN IEC 61800-5-2:2017
Safety function		EN IEC 61800-5-2:2017 Safe Torque Off (STO)
		IEC 60204-1:2018 Stop Category 0
Safety performance	**EN ISO 13849-1:2023**	
	Category	Cat 3
	Coverage of diagnostic (functional) test	>90% (Medium)
	Performance Level	Up to PL e
	Mean Time to Dangerous Failure	High (100 years per channel)
	IEC 61508:2010	
	Safety Integrity Level	Up to SIL 3
	Probability of Dangerous Failure per Hour	PFH: < 8 FIT
	Probability of Dangerous Failure on Demand	PFD: $< 5 \cdot 10^{-4}$
	HFT	Hardware Fault Tolerance = 1
	Subsystem Classification	Type A
	Proof Test Interval T1	20 years
	Mission time TM	20 years
Reaction time	Input to output response time	< 30 ms
	Internal fault reaction time of the drive	< 1 s
Mode of operation	High demand, Low demand, and Continuous	

3.5.2 Technical Data

Control input and outputs are galvanically isolated from supply voltage (PELV) and other high voltage terminals, unless otherwise specified.

Table 9: 24 V Digital Input for STO Input

Function	Data
Input type	Single-ended/floating
Logic	PNP

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Table 9: 24 V Digital Input for STO Input - (continued)

Function	Data
Voltage level	0–24 V DC
Voltage level, logic 0 PNP	<5 V
Voltage level, logic 1 PNP	>11 V
Maximum voltage on input @ functional	30 V
Maximum voltage on input @ safe state	60 V
Input current	8 mA > I_c > 5 mA @ 24 V
Equivalent input resistance	3 kΩ < Ri < 4.7 kΩ @ 24 V
Isolation	Functional
Reverse polarity protection	Yes
Maximum input current off-state	0.1 mA

Table 10: 24 V Digital Outputs for STO Feedback

Function	Data
Output type	Sink/source
Voltage rating	24 V DC open collector/60 V maximum
Current rating	50 mA
Isolation	Functional
Overload protection	Yes
Reverse polarity protection	Yes
ON state voltage	>17.4 V
Off state leakage current	0.1 mA

Table 11: Auxiliary Voltages

Function		Data
24 V output, functional safety (X31, X32)	Output voltage	24 V ±15%
	Maximum load	100 mA

3.5.3 Operating Conditions

Table 12: Operating Conditions for Functional Safety

Function	Data
Operating temperature	According to the drive specifications.
Storage temperature	-40 °C...+70 °C (-40 °F...+158 °F)
Air humidity	According to the drive specifications (non-condensing).
Operating altitude	According to the drive specifications.
Environmental conditions	The product must be installed in an environment corresponding to EN IEC 61800-5-1:2017 PD2 – non-condensing. For PD2 condensing environments, the product must be installed in IP54/NEMA 12 cabinet as per EN IEC 60529 AMD 2:2013, or equivalent.

Check the operating conditions for each drive from the product-specific design guide or operating guide. Latest versions of Danfoss product guides are available for download at https://www.danfoss.com/en/service-and-support/documentation/.

3.5.4 Cable Specifications

Table 13: Cable Sizing for Connectors X31, X32

Wire type	Cross-section [mm^2 (AWG)]	Stripping length [mm (in)]
Solid	0.5–1.5 (24–16)	10 (0.4)
Flexible	0.5–1.5 (24–16)	10 (0.4)
Flexible with ferrule w/o plastic sleeve	0.5–1.5 (24–16)	10 (0.4)
Flexible with ferrule w plastic sleeve	0.5 (24)	10 (0.4)

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