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Functional Description



JM-2xx Series Option STO –
Safety Function for the JM-2xx Series

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1 Safety function "STO" - Description

1.1 About this document

This document replaces the description Safe Stop (Option) in the user manuals for servo amplifiers of the JM-2xx series. The phrase Safe Stop used in this manual corresponds to the STO function.

1.2 Required hardware

For servo amplifiers of the JM-2xx series an integrated card for the safety function **Safe Torque OFF** is available as option.
The article designation of such servo amplifiers is JM-2xx-...-S1 or JM-D203-...-S1.
This option is available only as a card integrated into the servo amplifier. This means that this module cannot be supplied separately or subsequently.

1.3 Hazard analysis and risk assessment

Users of the safety function STO must follow the provisions set forth in the current version of the Machinery Directive 2006/42/EWG.
The manufacturer or his authorized representative is obliged to carry out a risk analysis as per the current Machinery Directive for the machinery which he wishes to place on the market. He must take measures to reduce or eliminate the hazards. This hazard analysis fulfills the requirements that put you in a position to define the required safety functions.

1.4 Definition of terms

STO = Safe Torque OFF
The safety function STO reliably clears the drive pulses to the motor. Yet, this does not mean that there is a safe electric isolation.
The motor must not generate any torque and thus a dangerous movement.

2 How STO works

2.1 STO

The **STO** module is used to safely remove the torque from the motor if required. The purpose of this function is to safely prevent any personal injury or damage by a rotating motor or a motor starting up unintentionally.
The "Safe Torque OFF" option meets the stop category 0 to DIN EN 60204.
Yet, this does not mean that the module removes dangerous voltages at the drive output. If a safe disconnection is required, install an additional disconnecting device (e.g. main circuit breaker) for interrupting the power supply according to DIN EN 60204.

2.2 Safety circuit requirements

The **Safe Torque OFF** function is intended solely for the purpose of safely removing the torque from a motor and inhibiting its restart.
To achieve the safety level determined by the risk analysis, the safety function must meet all requirements of the relevant standards. This must be substantiated by appropriate verification and validation activities.
DIN EN 61508, DIN EN 61800-5-2 or ISO 13849, for example, serve as a basis for such activities.
The mathematical proof can be provided by applying the formulas of the above mentioned standards or by using a tool such as Sistema.

2.3 Properties of the servo amplifier circuitry

The servo amplifier circuitry has been designed internally in a way that at activating the STO safety function the **torque pulses to the motor are cleared**. When the STO safety function is reset, the motor will not restart by itself, though. The torque pulses to the motor must be re-enabled by the external controller.

2.4 Requirements on the application program

For safety reasons, the motor must not automatically be set in motion by the application program at resetting the STO safety function. The torque pulses to the motor must be re-enabled by the external controller. The application program must meet this requirement.

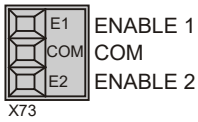
3 Technical specifications - ENABLE inputs

3.1 Terminals

For the safety device to trigger the STO function, the terminals ENABLE1, COM and ENABLE2 are available on the STO module.
In order to enable a two-channel disconnection, the module is equipped with two separate ENABLE inputs and one COMMON ground per axis.

3.2 JM-2xx-...-S1

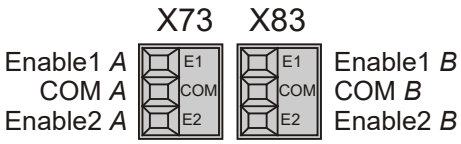
This servo amplifier series lets you connect one motor. The STO module is therefore equipped with one terminal: X73.
This terminal is shown below:



The common ground (COM) of the ENABLE inputs is electrically isolated from the ground of the servo controller.
The common ground of ENABLE inputs may differ by up to +/-100 V from the ground of the controller.

3.3 JM-D203-...-S1

This servo amplifier series lets you connect two motors. The STO module is therefore equipped with two terminals: X73 and X83
These terminals are shown below:



The common ground (COM) of the ENABLE inputs is electrically isolated from the ground of the servo controller.
The common ground of ENABLE inputs may differ by up to +/-50 V from the ground of the controller. The common ground of axis A may differ by up to +/-50 V from the common ground of axis B.

3.4 Technical specifications

The technical data of the ENABLE inputs are listed below:

Terminal on the servo amplifier	Specification	Electrical isolation
X73.ENABLE1 X83.ENABLE1	■ Enabling the output stage = high level (only if a high level is applied to X73/X83 ENABLE 2). ■ Tripping the STO function = low level ■ OSSD-capable ■ U_{IN} = 24 V (DC 20 ... 28.8 V) SELV/PELV ■ Current consumption of 50 mA max. ■ Low level operating point: < 6 V ■ High level operating point: > 15 V	Yes
X73.ENABLE2 X83.ENABLE2	■ Enabling the output stage = high level (only if a high level is applied to X73/X83 ENABLE 1). ■ Tripping the STO function = low level ■ OSSD-capable ■ U_{IN} = 24 V (DC 20 ... 28.8 V) SELV/PELV ■ Current consumption of 50 mA max. ■ Low level operating point: < 6 V ■ High level operating point: > 15 V	Yes

3.5 ENABLE input

Even if the servo amplifier is equipped with the option **-S1**, the function of input X10.ENABLE remains active. The motor can generate torque only if a voltage of 24 V is applied to reference ground ⊥ through this input.

4 Commissioning and checking the STO function

4.1 Checking for proper functioning

Check the correct operation of the STO function in the following cases:

- During commissioning of the machinery
- After replacing assemblies
- After modifications to the wiring
- After installation of a new firmware version
- After changes in parameterization
- Periodically at least once a year
- Document the result of the check

4.2 Applications with functional safety



Danger

Danger in applications with functional safety!

For safety reasons, the functionality of the STO function must be checked at regular intervals.

Otherwise, the use of this STO function in safety functions is not permitted!

➢ Check the functionality of the STO function at least once a year as described below and document the result.

4.3 Commissioning and checking

To commission and check the function proceed as follows:

Step	Action	Check
1	Make sure that the axis can move freely and be stopped during the check.	
2	Slow down the axis until it comes to a standstill (velocity setpoint = 0).	
3	Disable the servo amplifier by clearing the ENABLE signal. In the case of an axis group, all involved axes and their corresponding servo amplifiers must be disabled.	

Step	Action	Check
4	Mechanically secure all suspended loads. Activate the holding brake, if any.	
5	Close the safety circuit.	
6	Enable one axis (ENABLE, ENABLE1, ENABLE2, and software ENABLE). If the torque can not be monitored, make the axis move.	Does the motor generate any torque?
7	Activate the restart inhibit function for this axis by clearing the +24 V signal at X73.ENABLE1.	The axis must immediately be de-energized and stop (no torque)
8	Re-apply +24 V to X73.ENABLE1 and clear the error on the servo amplifier.	
9	Re-enable the same axis (ENABLE, ENABLE1, ENABLE2, and software ENABLE). If the torque can not be monitored, make the axis move.	Does the motor generate any torque?
10	Activate the restart inhibit function for this axis by clearing the +24 V signal at X73.ENABLE2.	The axis must immediately be de-energized and stop (no torque)
11	Re-apply +24 V to X73.ENABLE2 and clear the error on the servo amplifier.	
12	Re-enable the same axis (ENABLE, ENABLE1, ENABLE2, and software ENABLE). If the torque can not be monitored, make the axis move.	Does the motor generate any torque?

4.4 Note on JM-D203-…-S1

With this device, you must check both axes.

5 Safety-related characteristics

5.1 Supported safety functions

This chapter describes the safety functions that are supported by the system. They are based on the standard EN ISO 13849.

The system supports the following safety functions:

- STO to PL "e" acc. to EN ISO 13849

5.2 Stop categories to DIN EN 60204

Implement the STO function according to Stop Category 0 or Stop Category 1 of DIN EN 60204. The device itself only provides Stop Category 0:

- Stop Category 0

When the safety function is activated, the motor is de-energized unconditionally and immediately.
According to IEC/DIN EN 61800 Part 5.2, stop category 0 is also referred to as STO (Save Torque Off).

- Stop Category 1

When the safety function is activated, the motor is stopped in a controlled manner, and, after a defined delay time, is de-energized unconditionally and immediately.
According to IEC/DIN EN 61800 Part 5.2, the SLA (Safely-Limited Acceleration) requirement is not met if a switch-off delay via time-relay is implemented.

5.3 Performance level to DIN EN ISO 13849-1

JM-2xx-S1 and JM-D203-S1 can be used in safety functions up to PL e according to EN ISO 13849. According to category 3, they have a two-channel design. With the STO function, there are no errors that lead to the unsafe state because the error exclusions of tables D.1, D.3 and D.5 of DIN EN 61800-5-2 were applied. A product based solely on the application of error exclusions has an infinite MTTFd value and need not be taken into account in DCavg calculations according to EN ISO 13849 (see chapter E.2 EN ISO 13849-1).

Structure:	Cat 3
MTTFd	Infinite

5.4 CCF portion

Within the framework of this classification, the Common Cause Failure (CCF) referred to in the standard mainly applies to the related application:

The design of your machinery must ensure that the measures taken by R&D and application departments will result in the required score.

5.5 Avoiding CCF

Basically, the following measures make sure that servo amplifiers JetMove 2xx, or JM-D203 avoid Common Cause Failures:

- Galvanic isolation of the power supply units (by optocouplers)
- Compliance with standard clearance and creepage distances (on the printed circuit board, the connectors and optocouplers)
- Overrating and derating of components

6 STO control options

6.1 Control options

The following control options are available:

- Control via safety contacts
- OSSD control

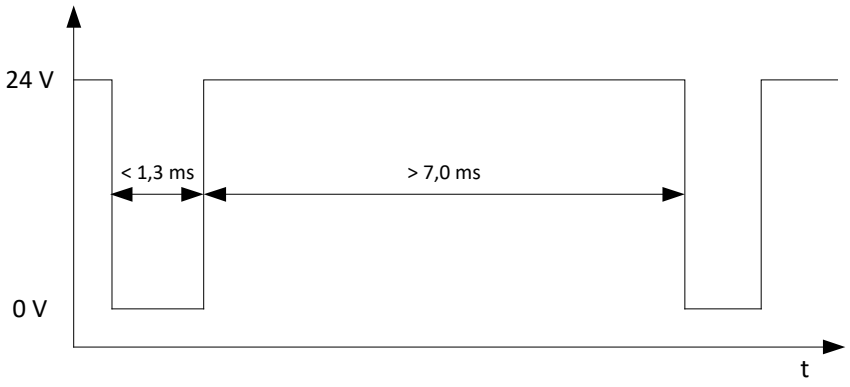
6.2 Definition: OSSD

OSSD is short for **Online Switched Silicon Device**. The STO inputs are controlled by test pulses to detect short-circuits, shorts between contacts and shunts in the control cable. The test pulses have a duration of 1 ms and a repetition frequency of 100 Hz. If an OSSD control logic is used, errors, such as short circuits or shunts, are detected by the logic itself. As a result, both signal paths will be switched off.

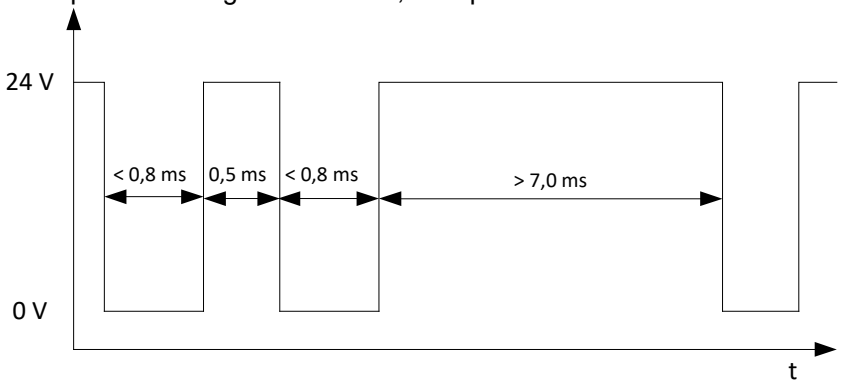
6.3 Accepted OSSD signal waveforms

The following OSSD waveforms are accepted without triggering an error.

Example: OSSD signal waveform, single pulse

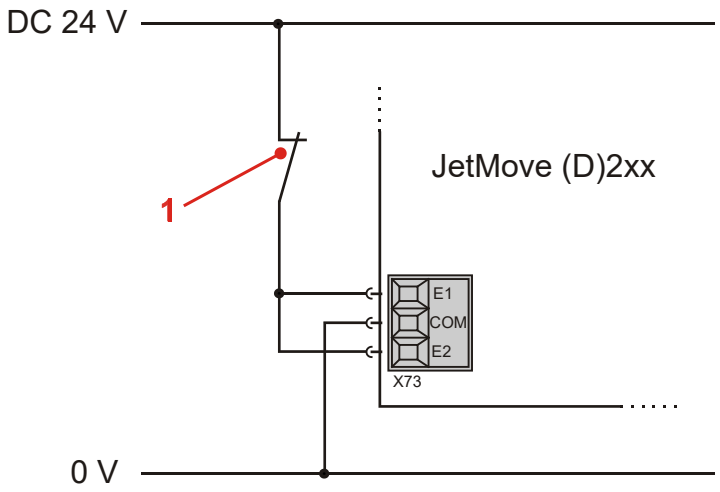


Example: OSSD signal waveform, dual pulse



7 Single-channel control via contacts

7.1 Block diagram



Number	Section	Description
1	NC contact	Contact of safety device

7.2 Operating principle

The safety device applies a +24 V signal for enabling the axis to the two parallel inputs ENABLE1 (E1), and ENABLE2 (E2) of the servo amplifier. When the emergency stop is actuated, the contact opens and thus interrupts the enabling signal. The digital servo amplifier safely de-energizes the motor. The motor stops (stop category 0).

7.3 Requirements on external safety device

Make sure that the external safety devices, e.g. a safety relay, have a sufficient performance level.

7.4 Possible performance level

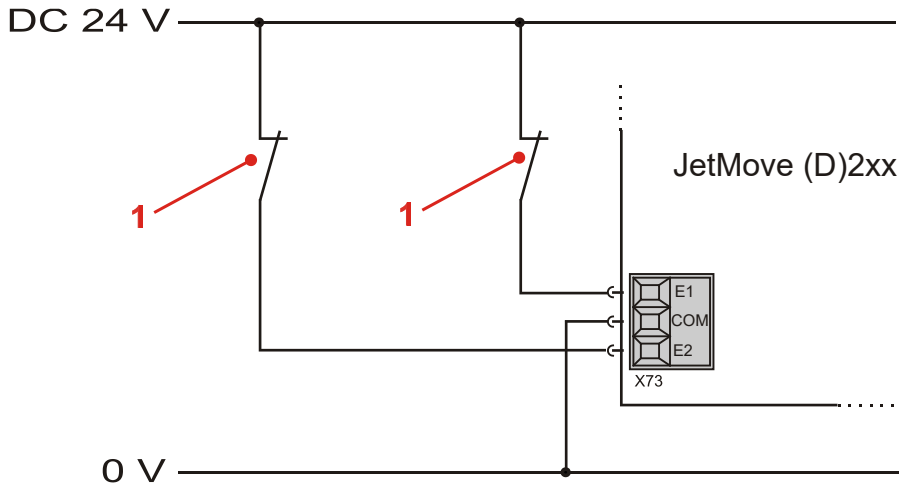
Provided that all safety devices involved meet category 1 (PL b or c), **STO** (according to EN ISO 13849 PL b or c) with stop category 0 according to DIN EN 60204 can be set up with the circuit shown.

7.5 Test specification

The safety function must be tested annually in accordance with the specifications in chapter 1, section *Commissioning and testing*.

8 Dual-channel control via contacts

8.1 Block diagram



Number	Section	Description
1	NC contact	Contact of safety device

8.2 Operating principle

The safety device applies a +24 V signal for enabling the axis independently to any of the two inputs ENABLE1 (E1), and ENABLE2 (E2) of the servo amplifier. When the emergency stop is actuated, both contacts open and thus interrupt the enabling signal.
In case of an error it is sufficient if the following happens:

- Both contacts must open.
- This causes the digital servo amplifier to safely de-energize the motor (dual-channel de-energization). The motor stops (stop category 0).

The wiring technology must be designed in such a way that a cross-circuit between the lines requesting the safety function and a short-circuit between these lines to the 24 V power supply can be ruled out (see EN ISO 13849-2 Table D.5).

8.3 Requirements on an external safety device

Make sure that the external safety devices, e.g. a safety relay, have a sufficient performance level.

8.4 Possible performance level

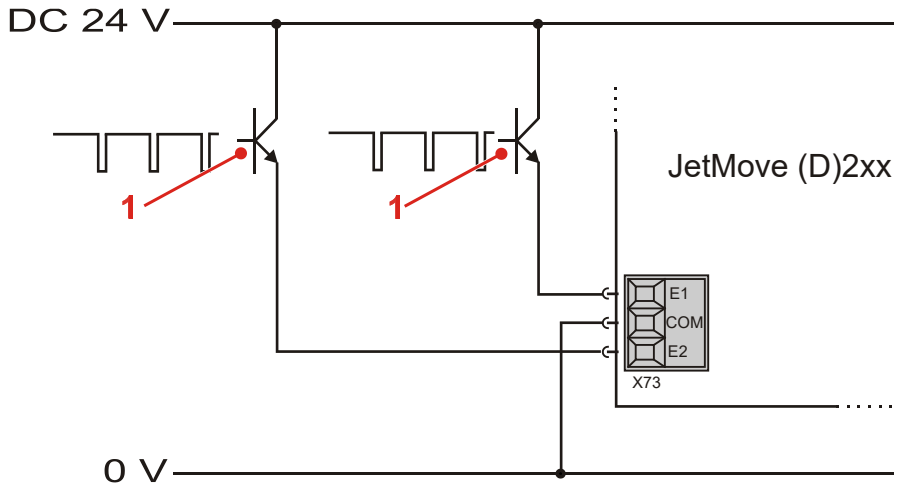
Provided that all the safety devices involved meet the Performance Level c, d or e, **STO** (according to EN ISO 13849 PL c, d or e) with stop category 0 according to DIN EN 60204 can be set up with the circuit shown.

8.5 Test specification

The safety function must be tested annually in accordance with the specifications in chapter 1, section *Commissioning and testing*. The test results must be documented.

9 Dual-channel OSSD control

9.1 Block diagram



Number	Section	Description
1	OSSD control	Switched semiconductor of the safety device

9.2 Operating principle

The safety device applies a +24 V signal for enabling the axis independently to any of the two inputs ENABLE1 (E1), and ENABLE2 (E2) of the servo amplifier.
The signals have alternating interruptions of 1 ms max. which are use to monitor the signals for shorts between contacts, short circuits or external voltage (OSSD signals). These interruptions of 1 ms max. will not cause the servo amplifier to safely clear the pulses to the motor, though.
When the safety device is actuated, both contacts open and thus interrupt the enabling signal.
In case of an error it is sufficient if the following happens:

- Both signals must be cleared.
- This causes the digital servo amplifier to safely de-energize the motor (dual-channel de-energization). The motor stops (stop category 0).

The upstream logic reliably detects errors (such as short circuits, shorts between contacts, or external voltage).

9.3 Possible performance level

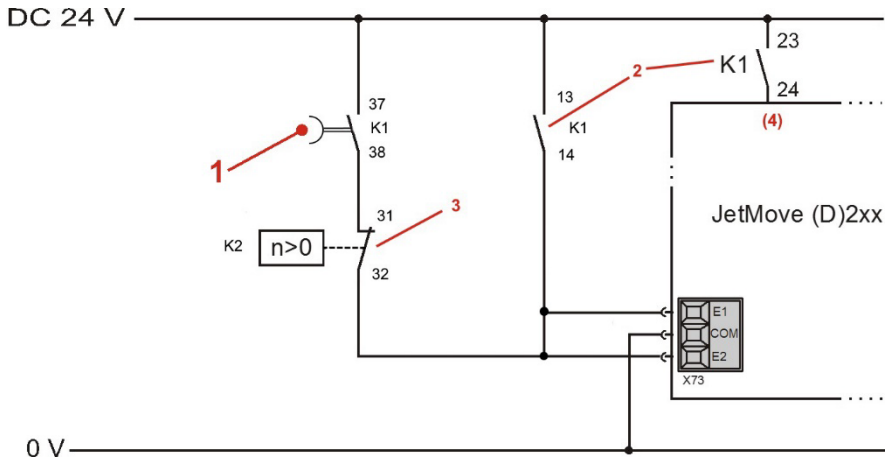
Provided that all the safety devices involved meet Performance Level d or e, **STO** (according to EN ISO 13849 PL d or e) with stop category 0 according to DIN EN 60204 can be set up with the circuit shown.

9.4 Test specification

The safety function must be tested annually in accordance with the specifications in chapter 1, section *Commissioning and testing*. The test results must be documented.

10 SS1 feature

10.1 Block diagram



Number	Component	Description
1	Delayed NC contact	Contact of safety device
2	NC contact	Contact of safety device
3	NC contact	Safe speed monitoring, contact is open at motor standstill.
(4)	Input */Braking*	Control input 0 V at this input triggers braking operation.

10.2 Operating principle

The safety device activates relay K1 which enables the axis via contact 13-14. Relay K1 applies a +24 V signal to control input */Braking* via the second NO contact 23-24. The control input */Braking* must be configured either by the application program or via motion setup in a way that at 0 V signal applied to this input activates the emergency stop function of the servo amplifier.
Simultaneously with relay K1, the dropout-delayed contact 37-38 is activated. This contact is series-connected to contact 31-32 of a safe speed monitor. The contact of the speed monitor is closed while the motor is running; it opens at zero speed.
When the safety function is requested, relay K1 switches off. Contact 23-24 of K1 opens and triggers a controlled braking operation. The axis is still enabled via contact 37-38 of K1 until the drop-out delay has expired or the motor has come to a standstill due to the initiated braking. The +24 V signal at inputs ENABLE1 (E1), and ENABLE2 (E2) is cleared and the digital servo amplifier safely de-energizes the motor. The motor stops (stop category 1).
If the braking process fails, the set drop-out delay limits the maximum time until the safe stop (STO) is triggered.

The option shown in the diagram with stopping via the emergency stop function (contact 23-24 K1) is not mandatory. The motor can also be brought to standstill by a control command or by a mechanical brake.

10.3 Possible performance level

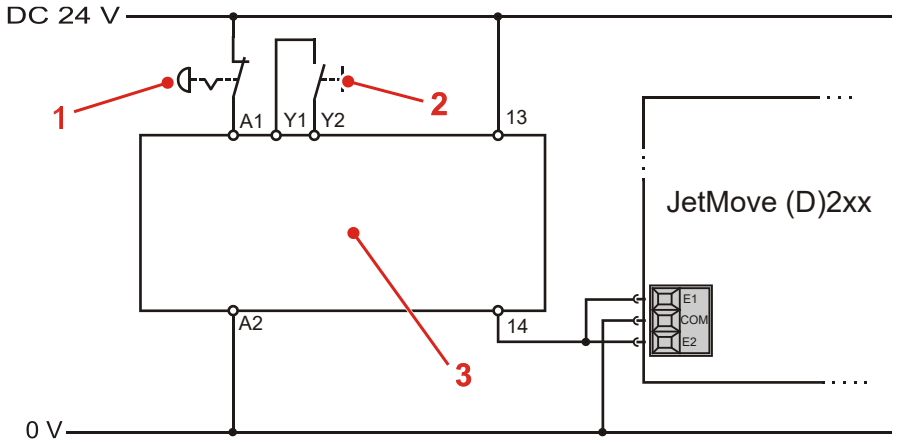
Provided that all safety devices involved meet category 1 PL b or c, **STO** (according to EN ISO 13849 category 1 PL b or c) with stop category 1 according to DIN EN 60204 can be set up with the circuit shown. Yet, the requirements on Safety Limited Acceleration (SLA) are not met.

10.4 Test specification

The safety function must be tested annually in accordance with the specifications in chapter 1, section *Commissioning and testing*. The test results must be documented.

11 Restart inhibit

11.1 Block diagram



Number	Component	Description
1	Pushbutton *EMERGENCY STOP*	Triggers the safety function
2	Pushbutton *START/RESET*	Separate pushbutton required by standard
3	Safety combination	Controls the restart of the motor

11.2 Operating principle

In order to implement the *safe restart inhibit* function, use an external safety combination with restart inhibit. This safety combination is for controlling the restart of the motor via separate pushbutton. For a restart, unlock the EMERGENCY STOP button and press the separate RESET pushbutton to apply a +24 V signal to inputs ENABLE1 (E1) and ENABLE2 (E2). This signal re-enables the axis. The restart inhibit can also be implemented via a safety controller.

11.3 Performance Level achieved

Depending on the category and performance level of the safety combination used and drive control (single/dual channel), a Performance Level between b and e can be achieved.

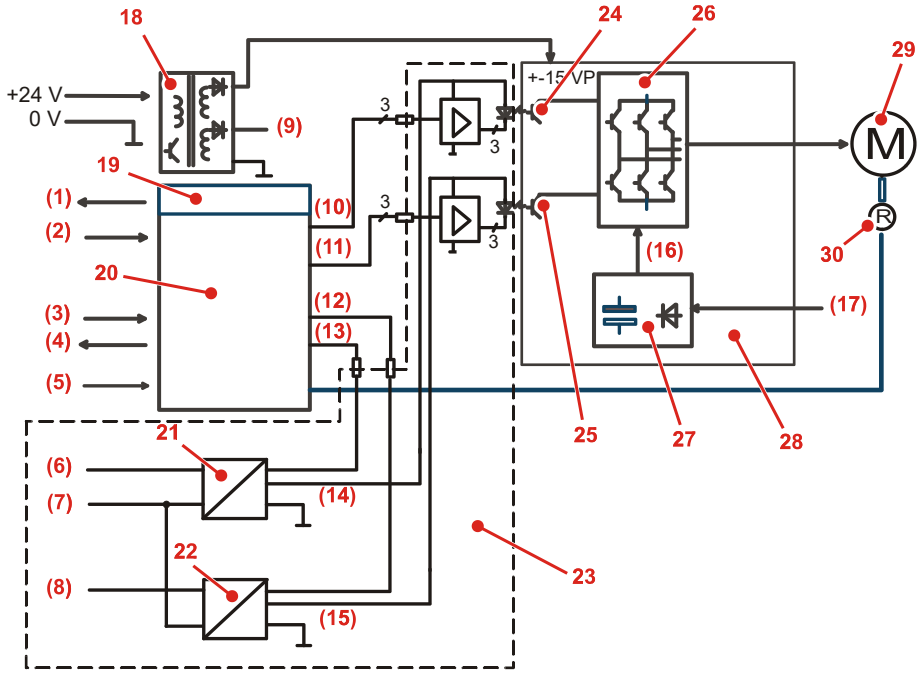
11.4 Test specification

The safety function must be tested annually in accordance with the specifications in chapter 1, section *Commissioning and testing*. The test results must be documented.

12 Block diagram - JM-(D)2xx with STO module

12.1 Block diagram

The figure below shows the block diagram of the servo amplifier JM-2xx-...-S1, and JM-D203-...-S1 with its key components and **Safe Torque OFF** module.



Number	Component	Description
(1)	Status	Output signal of the monitoring functions of the DSP (Digital Signal Processor)
(2)	CAN	CAN bus signals
(3)	Digital IN	Digital input signals
(4)	Digital OUT	Digital output signals
(5)	/Braking	Safe stop signal
(6)	ENABLE1	Enable signal 1 of the STO module
(7)	COM	Common ground of ENABLE inputs The common ground is electrically isolated from the ground of the servo controller.
(8)	ENABLE2	Enable signal 2 of the STO module
(9)	+5 V, +3.3 V	Internal voltages of servo amplifier
(10)	OUT1	DSP output voltage 1 for controlling the power amplifier
(11)	OUT2	DSP output voltage 2 for controlling the power amplifier

Number	Component	Description
(12)	Status IN2	Signal of the STO module for controlling the DSP
(13)	Status IN1	Signal of the STO module for controlling the DSP
(14)	OUT3	Output voltage 1 of the STO module for enabling or disabling the power amplifier
(15)	OUT4	Output voltage 2 of the STO module for enabling or disabling the power amplifier
(16)	320 V=/565 V=	DC link voltage
(17)	1 x 230 V~/ 3 x 400 V~	Mains voltage
18	Switch-mode power supply	
19	Monitoring functions	DSP monitoring functions
20	DSP	Control unit with servo amplifier monitoring functions
21	DC/DC converter 1 24 V/5 V	
22	DC/DC converter 2 24 V/5 V	
23	STO module	
24	Optocoupler *upper* IGBTs	
25	Optocoupler *lower* IGBTs	
26	IGBT module	
27	Rectifier	
28	Power amplifier	Electrically isolated area
29	Motor	
30	Resolver	

12.2 Design

The electrical design of the servo amplifiers JM-2xx-...-S1, and JM-D203-...-S1 can roughly be divided into three areas.
The area up left contains a DSP as a central component. It processes data traffic with the higher-level controller, acquires input signals and sets digital outputs. Out of the information total, it creates the pulse pattern for running the motor. Signals are transmitted into the power amplifier via optocoupler.
On top of this, there is a switch-mode power supply unit for the control electrics.
On the right hand side, there is the power amplifier, which, by means of semiconductor switches (IGBTs), amplifies the created pulse pattern and drives the motor.
Bottom left, the *STO* function is shown. It consists of two mainly identical, yet independent signal paths 1 and 2. Each path consists of a DC/DC converter, which creates an output voltage of 5 Volt out of the applied

input voltage. Further, each converter is equipped with a status output which is connected to the DSP. This way, the DSP recognizes directly, whether the corresponding ENABLE input is enabled or disabled. If the ENABLE input is enabled, the DSP activates the pulse outputs. If the ENABLE input is disabled, the DSP deactivates the pulse outputs. The output voltage *OUT1* leads to a driver stage which takes up the pulse patterns for the *upper* IGBTs and transmits them to the optocouplers. The same way, the optocouplers themselves have been supplied with this voltage. By analogy, the output voltage *OUT2* supplies the driver stages and the optocouplers of the *lower* IGBTs.
This means that for running the motor, both inputs ENABLE1 and ENABLE2 must be supplied with voltage. Once the safety function STO is activated, it must de-energize these inputs. As a result, the driver stages and optocouplers are de-energized, too. The same way, the DSP will recognize emergency mode of the status inputs. Finally, the motor is safely de-energized and the torque pulses are cleared.
In the event of an error it is sufficient to interrupt only one path, as the motor stops rotating even if only the *upper* or only the *lower* IGBTs have been switched off.
To decouple the control signals of the DSP, the corresponding interface is provided with resistors of apt design and resistance values. This prevents a faulty supply of the driver stages/optocouplers by the DSP control signals.
The dashed line marks the border between the safety-relevant assemblies.

12.3 Unwanted jerky motor movement

In spite of the safety precautions mentioned above, the motor may jerk due to defective IGBTs. The possible rotation angle depends on the pole pair number of the motor in use.

Pole pair number of the motor	Possible rotation angle
1	180°
2	90°
3	60°
5	30°

Take this behavior into consideration in your risk analysis. If this behavior can lead to a hazard, the given solution is not apt and must not be used.
The probability that a jerky movement occurs is very low, though.
If the unit for the failure rate of an IGBT is 100 fit (10E-7 per hour), the probability of two IGBTs failing at the same time is 10E-14 per hour. This corresponds to several million years. Out of these, only 6 out of 15 cases lead to jerking. Moreover, the IGBTs are continually being checked at each commutation.

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