Functional Safety

Inductive Slot Sensor SJ2-SN, SJ3,5-S(1)N

Manual

SIL

IEC 61508/61511

ISO9001

SIL 2 / SIL 3

Your automation, our passion.

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1 Introduction

1.1 Content of this Document

This document contains information for usage of the device in functional safety-related applications. You need this information to use your product throughout the applicable stages of the product life cycle. These can include the following:

- Product identification
- Delivery, transport, and storage
- Mounting and installation
- Commissioning and operation
- Maintenance and repair
- Troubleshooting
- Dismounting
- Disposal

Note

This document does not substitute the instruction manual.

Note

For full information on the product, refer to the instruction manual and further documentation on the Internet at www.pepperl-fuchs.com.

The documentation consists of the following parts:

- Present document
- Instruction manual
- Datasheet

Additionally, the following parts may belong to the documentation, if applicable:

- EU-type examination certificate
- EU declaration of conformity
- Attestation of conformity
- Certificates
- Control drawings
- FMEDA report
- Assessment report
- Additional documents

For more information about Pepperl+Fuchs products with functional safety, see www.pepperl-fuchs.com/sil.

1.2 Safety Information

Target Group, Personnel

Responsibility for planning, assembly, commissioning, operation, maintenance, and dismounting lies with the plant operator.

Only appropriately trained and qualified personnel may carry out mounting, installation, commissioning, operation, maintenance, and dismounting of the product. The personnel must have read and understood the instruction manual and the further documentation.

Intended Use

The device is only approved for appropriate and intended use. Ignoring these instructions will void any warranty and absolve the manufacturer from any liability.

The device is developed, manufactured and tested according to the relevant safety standards.

Use the device only

- for the application described
- with specified environmental conditions
- with devices that are suitable for this safety application

Improper Use

Protection of the personnel and the plant is not ensured if the device is not used according to its intended use.

1.3 Symbols Used

This document contains symbols for the identification of warning messages and of informative messages.

Warning Messages

You will find warning messages, whenever dangers may arise from your actions. It is mandatory that you observe these warning messages for your personal safety and in order to avoid property damage.

Depending on the risk level, the warning messages are displayed in descending order as follows:

Danger!

This symbol indicates an imminent danger.

Non-observance will result in personal injury or death.

Warning!

This symbol indicates a possible fault or danger.

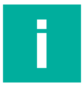
Non-observance may cause personal injury or serious property damage.

Caution!

This symbol indicates a possible fault.

Non-observance could interrupt the device and any connected systems and plants, or result in their complete failure.

Informative Symbols



Note

This symbol brings important information to your attention.

Action

This symbol indicates a paragraph with instructions. You are prompted to perform an action or a sequence of actions.

2 Product Description

2.1 Function

General

The device is an inductive slot sensor. Inductive slot sensors consist of a two coil system sensing across the slot opening.

The device is a NAMUR safety sensor in 2-wire technology. The device transmits the analog signal according to NAMUR to a connected control unit. A control unit can, e. g., be a switch amplifier or an I/O card in a PLC.

In safety applications up to SIL 2, the device must be operated on a control unit according to EN 60947-5-6 (NAMUR). Observe the limitations, see chapter 3.2.

In safety applications up to SIL 3, the device must be operated on a control unit for SIL 3 safety applications. Pepperl+Fuchs offers control units for SIL 3 safety applications, i. e. switch amplifier KFD2-SH-Ex1. Observe the limitations, see chapter 3.2.

SJ2-SN

The sensor has NC function (normally-closed). The device is in high impedance state when the measuring plate is inside of the slot.

The sensor is qualified for safety functions in a temperature range from -40 °C to +100 °C.

The sensor has a slot width of 2 mm.

SJ3,5-SN

The sensor has NC function (normally-closed). The device is in high impedance state when the measuring plate is inside of the slot.

The sensor is qualified for safety functions in a temperature range from -40 °C to +100 °C.

The sensor has a slot width of 3.5 mm.

SJ3,5-S1N

The sensor has NO function (normally-open). The device is in high impedance state when the measuring plate is outside of the slot.

The sensor is qualified for safety functions in a temperature range from -25 °C to +100 °C.

The sensor has a slot width of 3.5 mm.

Note

See corresponding datasheets for further information.

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2.2 Interfaces

The device has the following interfaces.

- Safety relevant interface: device output
- Non-safety relevant interface: none

Note

For corresponding connections see datasheet.

2.3 Marking

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SJ2-SN SJ2-SN-Y89620 SJ2-SN-Y272219 SJ3,5-SN SJ3,5-SN-Y89604 SJ3,5-SN-Y303204 SJ3,5-S1N SJ3,5-S1N-Y303205	273025 282583 272219 273026 282586 303204 273027 303205	Allowed for SIL 2 applications
SJ2-SN SJ2-SN-Y89620 SJ2-SN-Y272219 SJ3,5-SN SJ3,5-SN-Y89604 SJ3,5-S1N	273025 282583 272219 273026 282586 273027	Allowed for SIL 3 applications

2.4 Standards and Directives for Functional Safety

Device-specific standards and directives

Functional safety	IEC/EN 61508, part 2, edition 2000: Functional safety of electrical/electronic/programmable electronic safety-related systems (manufacturer)

3 Planning

3.1 System Structure

3.1.1 Low Demand Mode of Operation

If there are two control loops, one for the standard operation and another one for the functional safety, then usually the demand rate for the safety loop is assumed to be less than once per year.

The relevant safety parameters to be verified are:

- the PFD_{avg} value (average **P**robability of dangerous **F**ailure on **D**emand) and the T_1 value (proof test interval that has a direct impact on the PFD_{avg} value)
- the SFF value (**S**afe **F**ailure **F**raction)
- the HFT architecture (**H**ardware **F**ault **T**olerance)

3.1.2 High Demand or Continuous Mode of Operation

If there is only one safety loop, which combines the standard operation and safety-related operation, then usually the demand rate for this safety loop is assumed to be higher than once per year.

The relevant safety parameters to be verified are:

- the PFH value (**P**robability of dangerous **F**ailure per **H**our)
- Fault reaction time of the safety system
- the SFF value (**S**afe **F**ailure **F**raction)
- the HFT architecture (**H**ardware **F**ault **T**olerance)

3.1.3 Safe Failure Fraction

The safe failure fraction describes the ratio of all safe failures and dangerous detected failures to the total failure rate.

$SFF = (\lambda_s + \lambda_{dd}) / (\lambda_s + \lambda_{dd} + \lambda_{du})$

A safe failure fraction as defined in IEC/EN 61508 is only relevant for elements or (sub)systems in a complete safety loop. The device under consideration is always part of a safety loop but is not regarded as a complete element or subsystem.

For calculating the SIL of a safety loop it is necessary to evaluate the safe failure fraction of elements, subsystems and the complete system, but not of a single device.

3.2 Assumptions

The following assumptions have been made during the FMEDA:

- Failure rate based on the Siemens standard SN 29500.
- Failure rates are constant, wear is not considered.
- External power supply failure rates are not included.
- The safety-related device is considered to be of type **A** device with a hardware fault tolerance of **0**.
- The device will be used under average industrial ambient conditions comparable to the classification "stationary mounted" according to MIL-HDBK-217F.

  Alternatively, operating stress conditions typical of an industrial field environment similar to IEC/EN 60654-1 Class C with an average temperature over a long period of time of 40 ºC may be assumed. For a higher average temperature of 60 ºC, the failure rates must be multiplied by a factor of 2.5 based on experience. A similar factor must be used if frequent temperature fluctuations are expected.

SIL 2 Application

Only use the device in SIL 2 applications in combination with a control unit according to EN 60947-5-6 (NAMUR).

- The device claims less than 25 % of the total failure budget for a SIL 2 safety loop.
- For a SIL 2 application operating in low demand mode the total PFD_{avg} value of the SIF (**S**afety **I**nstrumented **F**unction) should be smaller than 1 x 10^{-2}, hence the maximum allowable PFD_{avg} value would then be 2.5 x 10^{-3}.
- For a SIL 2 application operating in high demand mode the total PFH value of the SIF should be smaller than 1 x 10^{-6} per hour, hence the maximum allowable PFH value would then be 2.5 x 10^{-7} per hour.
- Since the safety loop has a hardware fault tolerance of **0** and it is a type **A** device, the SFF must be > 60 % according to table 2 of IEC/EN 61508-2 for a SIL 2 (sub) system.

SIL 3 Application

Only use the device in SIL 3 applications in combination with a control unit for SIL 3 safety applications from Pepperl+Fuchs, i. e. switch amplifier KFD2-SH-Ex1.

- The device claims less than 25 % of the total failure rate for a SIL 3 safety loop.
- For a SIL 3 application operating in low demand mode the total PFD_{avg} value of the SIF (**S**afety **I**nstrumented **F**unction) should be smaller than 10^{-3}, hence the maximum allowable PFD_{avg} value would then be 2.5 x 10^{-4}.
- For a SIL 3 application operating in high demand mode the total PFH value of the SIF should be smaller than 10^{-7} per hour, hence the maximum allowable PFH value would then be 2.5 x 10^{-8} per hour.
- Since the safety loop has a hardware fault tolerance of **0** and it is a type **A** device, the SFF must be > 90 % according to table 2 of IEC/EN 61508-2 for a SIL 3 (sub) system.

3.3 Safety Function and Safe State

Safe State

The safe state of the device is the high impedance state (low current).

Applications with control units or safety functions where the safe state is the low impedance state (high current) were not evaluated.

Safety Function

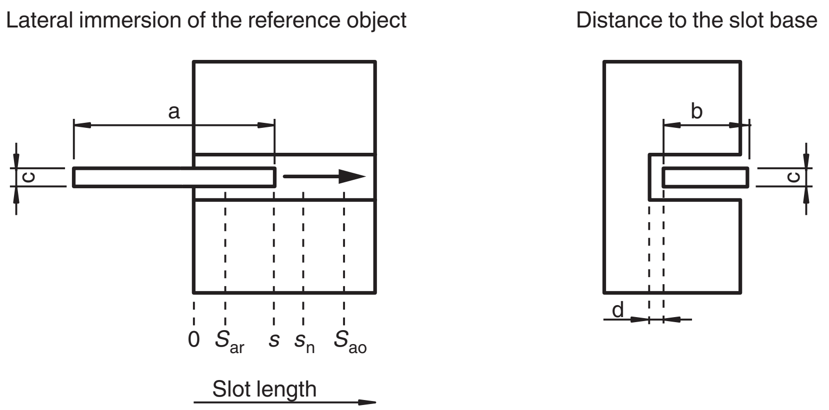

Figure 3.1 Distance values for the design of the safety function (abstract figure)

a Length of the reference object
b Width of the reference object
c Thickness of the reference object
d Distance to the slot base
s Current operating distance (immersion depth)
S_{ao} Assured operating distance (immersion depth) of a PDDB
S_{ar} Assured release distance (immersion depth) of a PDDB
s_n Rated immersion depth (lateral)

The SN sensor signals the safe state when the reference object is inside of the slot ($s > S_{ao}$). The assured operating distance S_{ao} for the SN sensor is 8.0 mm.

The S1N sensor signals the safe state when the reference object is outside of the slot ($s < S_{ar}$). The assured release distance S_{ar} for the S1N sensor is 0.0 mm.

These distances are valid when using the following reference objects:

Sensor	SJ2-SN	SJ3,5-S(1)N
Dimensions of the reference object (a x b x c)	5 mm x 8 mm x 0.5 mm	10 mm x 7 mm x 0.3 mm
Distance to the slot base (d)	≤ 0.5 mm	2.5 mm
Material of the reference object	Aluminum 3.0255.10	Aluminum 3.0255.10

Table 3.1

To ensure the safety of the safety loop according to SIL 2, only use control units according to EN 60947-5-6 (NAMUR).

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To ensure the safety of the safety loop according to SIL 3, only use control units for SIL 3 safety applications from Pepperl+Fuchs, i. e. switch amplifier KFD2- SH-Ex1.

Reaction Time

The reaction time for all safety functions is < 1 ms.

Note

See corresponding datasheets for further information.

3.4 Characteristic Safety Values

Parameters	Characteristic values	
Assessment type and documentation	FMEDA report with proven-in-use assessment [1]	
Device type	A	
Mode of operation	Low Demand Mode or High Demand Mode	
HFT	0	
Safety function	High impedance state, depending on the position of the measuring plate	
SIL (SC)	2 (3) in combination with a control unit according to EN 60947-5-6 (NAMUR)	3 in combination with a control unit for SIL 3 safety applications from Pepperl+Fuchs, i. e. switch amplifier KFD2-SH-Ex1
λ_s [2]	15.3 FIT	24.9 FIT
λ_{du}	9.7 FIT	0.09 FIT
$\lambda_{total\ (safety\ function)}$	25.0 FIT	25.0 FIT
SFF	61.3 %	99.64 %
PFH	9.67×10^{-9} 1/h	9×10^{-11} 1/h
PFD_{avg} for T_1 = 1 year	4.24×10^{-5}	3.94×10^{-7}
PFD_{avg} for T_1 = 2 years	8.47×10^{-5}	7.88×10^{-7}
PFD_{avg} for T_1 = 5 years	2.12×10^{-4}	1.97×10^{-6}
$MTTF_d$	11800 years	
Useful life time	20 years	
Reaction time [3]	< 1 ms	

Table 3.2

1 For the proven-in-use demonstration, sales figures, customer returns and questionnaires filled out by customers were used which show that no unknown systematic faults are expected. The device is based on a former device that was evaluated for a proven-in-use statement by exida.com GmbH.

2 "No effect" failures are not influencing the safety functions and are therefore included into the safe failures.

3 Step response time, also valid under fault conditions (including fault detection and fault reaction)

The characteristic safety values like PFD, SFF, HFT and T_1 are taken from the SIL report/FMEDA report. Observe that PFD and T_1 are related to each other.

The function of the devices has to be checked within the proof test interval (T_1).

3.5 Useful Lifetime

Although a constant failure rate is assumed by the probabilistic estimation this only applies provided that the useful lifetime of components is not exceeded. Beyond this useful lifetime, the result of the probabilistic estimation is meaningless as the probability of failure significantly increases with time. The useful lifetime is highly dependent on the component itself and its operating conditions – temperature in particular. For example, electrolytic capacitors can be very sensitive to the operating temperature.

This assumption of a constant failure rate is based on the bathtub curve, which shows the typical behavior for electronic components.

Therefore it is obvious that failure calculation is only valid for components that have this constant domain and that the validity of the calculation is limited to the useful lifetime of each component.

It is assumed that early failures are detected to a huge percentage during the installation and therefore the assumption of a constant failure rate during the useful lifetime is valid.

The standard EN/ISO 13849-1:2015 proposes a useful lifetime T_M of 20 years for devices used within industrial environments. This device is designed for this lifetime.
Observe that the useful lifetime can be reduced if the device is exposed to the following conditions:

- highly stressful environmental conditions such as constantly high temperatures
- temperature cycles with high temperature differences
- permanent repeated mechanical stress (vibration)

Please note that the useful lifetime refers to the (constant) failure rate of the device. The effective lifetime can be higher.

The estimated useful lifetime is greater than the warranty period prescribed by law or the manufacturer's guarantee period. However, this does not result in an extension of the warranty or guarantee services. Failure to reach the estimated useful lifetime is not a material defect.

4 Mounting and Installation

Mounting and Installing the Device

1. Observe the safety instructions in the instruction manual.
2. Observe the information in the manual.
3. Observe the requirements for the safety loop.
4. Connect the device only to devices that are suitable for this safety application.
5. Check the safety function to ensure the expected output behavior.

4.1 Mounting

Danger!

Danger to life from missing safety function

An incorrectly mounted, incorrectly positioned or missing measuring plate can lead to failure of the safety loop.

- Fasten the measuring plate in a suitable manner.
- For SN sensors: Do not remove the measuring plate.

Mounting the Measuring Plate

1. Mount the measuring plate with the correct rated immersion depth (lateral) s_n and the correct distance to the slot base d, see chapter 3.3. Observe the ambient conditions.
2. Fasten the measuring plate so that the measuring plate does not come loose or get lost.

4.2 Installation

Connecting the Sensor

1. Connect the device in safety applications up to SIL 2 to a control unit according to EN 60947-5-6 (NAMUR).
   Observe the limitations, see chapter 3.2.
2. Observe that the insulation resistance must be greater than 1 MΩ.
   Insulate the single wires from any other electrical connections.
3. Observe that the loop resistance must be less than 50 Ω.
4. Connect the device in safety applications up to SIL 3 to a control unit for SIL 3 safety applications.
   Pepperl+Fuchs offers control units for SIL 3 safety applications, i. e. switch amplifier KFD2-SH-Ex1. Observe the limitations, see chapter 3.2.

4.3 Configuration

A configuration of the device is not necessary and not possible.

5 Operation

Danger!

Danger to life from missing safety function

If the safety loop is put out of service, the safety function is no longer guaranteed.

- Do not deactivate the device.
- Do not bypass the safety function.
- Do not repair, modify, or manipulate the device.

Operating the device

1. Observe the safety instructions in the instruction manual.
2. Observe the information in the manual.
3. Use the device only with devices that are suitable for this safety application.
4. Correct any occurring safe failures within 8 hours. Take measures to maintain the safety function while the device is being repaired.

5.1 Proof Test

If you perform a proof test for the safety loop, the following steps are necessary:

- Check the device for housing damages. If moisture penetrates into the device or internal components of the device are damaged, this can lead to unpredictable effects.
- Check that the device is working correctly. If the device is not working correctly or not working, replace the device.

For this proof test, no proof test coverage (PTC) can be claimed as only a full functional test with the defined reference object over the temperature range can reveal an unacceptable dislocation of the switching point (PTC = 100 %). But the safety characteristic values are considered low enough to continually manage without proof test.

6 Maintenance and Repair

Danger!

Danger to life from missing safety function

Changes to the device or a defect of the device can lead to device malfunction.
The function of the device and the safety function is no longer guaranteed.

Do not repair, modify, or manipulate the device.

Maintaining or Replacing the Device

In case of maintenance or replacement of the device, proceed as follows:

1. Implement appropriate maintenance procedures for regular maintenance of the safety loop.
2. While the device is maintained or replaced, the safety function does not work.
   Exception: The safety function is still guaranteed if the device is operated in redundancy.
   Take appropriate measures to protect personnel and equipment while the safety function is not available.
   Secure the application against accidental restart.
3. Do not repair a defective device.
4. If there is a defect, always replace the device with an original device.

7 List of Abbreviations

d	Distance to the slot base
DC	**D**iagnostic **C**overage of dangerous faults
FIT	**F**ailure **I**n **T**ime in 10^{-9} 1/h
FMEDA	**F**ailure **M**ode, **E**ffects, and **D**iagnostics **A**nalysis
λ_{s}	Probability of safe failure
λ_{dd}	Probability of dangerous detected failure
λ_{du}	Probability of dangerous undetected failure
$\lambda_{\text{no effect}}$	Probability of failures of components in the safety loop that have no effect on the safety function.
$\lambda_{\text{not part}}$	Probability of failure of components that are not in the safety loop
$\lambda_{\text{total (safety function)}}$	Probability of failure of components that are in the safety loop
HFT	**H**ardware **F**ault **T**olerance
MTBF	**M**ean **T**ime **B**etween **F**ailures
$\mathbf{MTTF_D}$	**M**ean **T**ime **T**o dangerous **F**ailure
MTTR	**M**ean **T**ime **T**o **R**estoration
OSSD	**O**utput **S**ignal **S**witching **D**evice
PDDB	**P**roximity **D**evice with **D**efined **B**ehaviour under fault conditions
$\mathbf{PFD_{avg}}$	Average **P**robability of dangerous **F**ailure on **D**emand
PFH	Average frequency of dangerous failure per hour
PL	**P**erformance **L**evel
PLC	**P**rogrammable **L**ogic **C**ontroller
PTC	**P**roof **T**est **C**overage
s	Current operating distance (immersion depth)
$\mathbf{S_{ao}}$	Assured operating distance (immersion depth) of a PDDB
$\mathbf{S_{ar}}$	Assured release distance (immersion depth) of a PDDB
$\mathbf{s_n}$	Rated immersion depth (lateral)
SC	**S**ystematic **C**apability
SFF	**S**afe **F**ailure **F**raction
SIL	**S**afety **I**ntegrity **L**evel
$\mathbf{T_1}$	Proof Test Interval

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