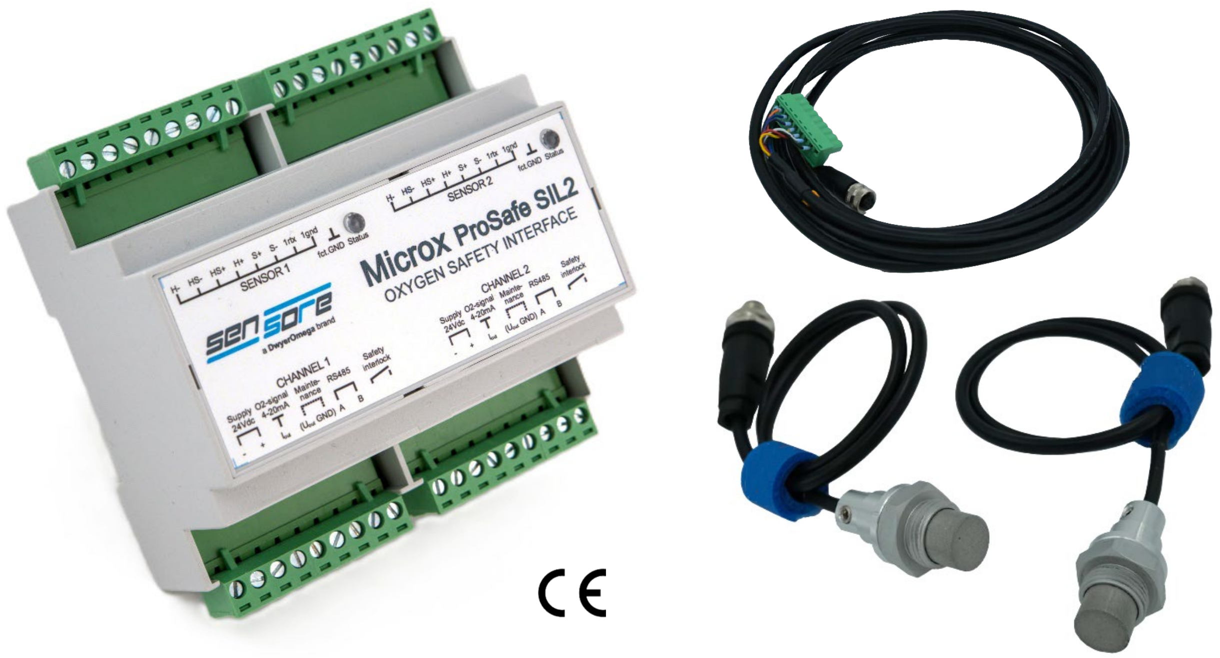
Oxygen Transmitter

Microx ProSafe SIL2

O2-Safety-Device

Safety Manual



Revision History

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Microx ProSafe SIL2

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Abbreviations

λ	Failure
λ_D	Dangerous Failure
λ_{DD}	Dangerous Detected Failure
λ_{DU}	Dangerous Undetected Failure
λ_S	Safe Failure
λ_{SD}	Safe Detected Failure
λ_{SU}	Safe Undetected Failure
β	Common Cause Failure Risk (β-Faktor EN IEC 62061)
/hr	Per Hour
AM	Additive Manufacturing
Ar	Argon
CFSP	Certified Functional Safety Practitioner
DC	Direct Current
DC^	Diagnostic Coverage
EEPROM	Electrically Erasable Programmable Read-only Memory
FS	Functional Safety
FSE	Functional Safety Engineering
FSM	Functional Safety Management
GND	Ground
HFT	Hardware Fault Tolerance
kV	Kilovolt
MTTF	Mean Time To Failure
$MTTF_D$	Mean Time To Dangerous Failure
MTTR	Mean Time To Repair
mA	Milliamp
mV	Millivolt
N_2	Nitrogen
nop	Mean number of annual operations
O_2	Oxygen
O/C	Open Circuit
PELV	Protected Extra Low Voltage

PFH	Probability of Dangerous Failure per Hour
PLC	Programmable Logic Controller
PLd	Performance Level d
PSU	Power Supply Unit
RL	Relay
S/C	Short Circuit
SELV	Safety Extra Low Voltage
SFF	Safe Failure Fraction
SIL	Safety Integrity Level
SIS	Safety-instrumented System

Contents

1 Introduction

This Safety Manual is applicable to the Microx ProSafe SIL2 oxygen transmitter, a 2-channel oxygen monitoring system. It covers functional safety aspects for integrating the transmitter into a larger safety instrumented system (SIS).

For installation, operation, maintenance and troubleshooting information, please refer to the Microx ProSafe User Manual (ES015e).

1.1 Safety guidelines

The system must only be used as follows:

- For the intended safety applications, with consideration given to the constraints outlined in "1.3 Safety applications and constraints"
- Within the permissible operating conditions. Please refer to Technical Specifications in the User Manual
- When correctly installed by qualified personnel as described in the User Manual
- Once a functional safety assessment of its integration into a larger SIS has been carried out, see 1.4 on page 2
- After considering safety parameters and residual risks, see section 2 on page 4
- Following a periodic test, see section 3 on page 8
    - Validation will determine test interval and 'pass' or 'fail' criteria for future periodic tests
- With validation of the system in the application, see section 4 on page 11.

1.2 System Overview

SIL2 rating has been certified for an "O2-Safety-Device", see also EC type examination by TUV AUSTRIA No. IN-AT-AS-MRL-20-00297A. It is based on the following modules:

Module	Description/details	Label
Microx ProSafe SIL2	User interface/controller	O2-Safety-Interface
O_2 Sensor	0.1.. 23.5 % O_2	SO-D3_250-______
O_2 Sensor	0.01…2.35 % O_2	SO-D3_025-______

1.3 Safety applications and constraints

Microx ProSafe SIL2 is designed to monitor atmospheres where safety is ensured by inertization, using nitrogen (N_2) or argon (Ar) including:

- Additive Manufacturing (AM) – powder bed fusion machines, sieving systems for AM metal powder
- Filtration systems
- Glove box and containment solutions

- Inert gas blanketing applications.

NOTE: The sensors are calibrated and specified for N_2 inerting. While the safety integrity level (SIL) is not affected, argon as an inerting gas may introduce minor calibration shifts due to differences in diffusion properties. We recommend ensuring calibration adjustments are made for critical applications if switching between the two gases.

⚠ **For optimal safety, we advise against calibrating the sensors in argon.**

1.3.1 Constraints

- Microx ProSafe SIL2 oxygen sensors are intended for use in conditions that will not contaminate them. Purging with nitrogen or argon will achieve low O_2 concentration however, volatile substances, which might be a by-product of a process should be considered. The sensors should not be exposed to or used in environments that may accelerate sensor drift (e.g. processing plastic powders).
- The system is not approved for use in hazardous locations e.g. ATEX, IECEx, CSA, FM, the sensor is heated up to ca. 600 °C (1112 °F).
- The sensors must not be used in flammable gas mixtures.
- Traces of combustible gases will affect sensor performance, as the measured O_2 concentration is reduced by local combustion. For optimal sensor performance, the concentration of combustible gases must be much lower than the O_2 concentration.
- The transmitter system must only be used for inertization with nitrogen or argon.
- The sensor is not suitable for measuring O_2 concentrations in liquids.

1.4 Functional safety assessment for integration into a larger safety instrumented system

The Microx ProSafe SIL2 system is for integration into a larger SIS, which provides a safety function to protect a machine or process plant from a hazardous event.

The machinery supplier or process plant operator, respectively, have ultimate responsibility to ensure functional safety requirements for the machine or process plant have been addressed under the relevant health and safety legislation applicable for their country, industry and application.

The machinery supplier or process plant operator must complete a functional safety assessment before a machine is supplied to a customer or before a process plant is put into operation. The functional safety assessment confirms that all hazards have been identified and addressed to within a tolerable risk.

SENSORE can provide support to enable the machinery supplier or process plant operator to complete their necessary functional safety validation with respect to the Microx ProSafe SIL2.

1.5 Definitions

1.5.1 Safety function/O_2 safety threshold

The safety function is used to detect a safe state in the application's atmosphere by checking if O_2 concentration is below a predefined O_2 safety threshold (e.g. <2 %).

The safety-critical O_2 threshold value and hysteresis are stored in the EEPROM on the sensor connector. The safety function operates in a continuous demand mode, i.e. O_2 concentration is constantly monitored.

The O_2 safety threshold will be defined at the SENSORE Factory on receipt of an order and cannot be altered by the customer. It must therefore be specified by selecting the corresponding order code when placing an order.

1.5.2 Indication of a safe state

Microx ProSafe SIL2 has two measurement channels, both have a potential-free contact pair (relay). The transmitter indicates a safe state only when both pairs of contacts are closed.

- The relays (RLs) open when the O_2 safety threshold value is exceeded. Exceeding the O_2 safety threshold will not put the system into a fault condition- the system will continue to monitor O_2.
- The relays close when measurement is below the O_2 safety threshold, considering hysteresis.
- For SIL 2/PLd compliance, the contact pairs must be connected in series, or in the case of a single tap, they must be linked to an AND function by the larger SIS.

1.5.3 Larger safety instrumented system (SIS)/target application

Microx ProSafe SIL2 is designed to be integrated into a target application, which then constitutes a larger SIS. This is usually a machine or a process plant.

1.5.4 Periodic test function

The periodic test function for Microx ProSafe SIL2 sensors, which should be implemented into a larger SIS, is to ensure an automated periodic test of sensor performance. The periodic test monitors drift, so that preventive sensor replacement can be carried out, when required, to maintain optimal performance.

1.5.5 Validation

Validation is a procedure used to verify the sensors are operating reliably within the application conditions. It determines the periodic test interval.

1.5.6 O_2 safety margin

O_2 safety margin is the difference between the predefined O_2 safety threshold and the O_2 concentration that could cause a hazard in the application. The SIL certificate assumes a minimum O_2 safety margin of 1 % to allow for residual risks such as response time. Larger O_2 safety margins can be utilized during the functional safety assessment, e.g. to justify extended intervals between periodic tests.

2 Applied Safety Standards and Resulting Safety Parameters

Microx ProSafe SIL2 has been evaluated according to safety standards in the EU Machinery Directive.

The following sections will provide details of the applied structural arrangements and the resulting safety parameters. Mean time to failure (MTTF) and failure rate data for the O_2 sensors always assume preventive sensor replacement, so that sensor failure rates are dominated by random failure modes and not by the effects of sensor drift.

2.1 EN ISO 13849-1

Structural and environmental considerations

- Category 3 unit
  - Dual channel structure, a single fault will not trigger a safety function
  - In addition, most single faults will be detected to avoid the accumulation of undetected faults
- Environmental conditions in the application
  - The PLd rating is based on uncontaminated air purged with nitrogen.
  - Some application conditions may include traces of harmful gases, which can affect sensor measurement performance; therefore periodic checks of the sensor function will be required. If significant signs of deteriorated sensor performance are observed, the sensor must be replaced as a preventive measure. The sensor has a maximum service life of 5 years and must always be replaced when it reaches its service life.

EN ISO 13849-1 Safety Parameters for the Transmitter and Sensor Unit	
$MTTF_D$	19.5 years
DC^	90.5 %
PFH	$4.8 \cdot 10^{-7}$ (1/h)
PL	d
Essential Constraints	
O_2 Sensor	Validated in the application, maximum service life 5 years
Periodic Test Interval	Determined by the validation procedure, maximum 6 months
Relay	Maximum 1000 switching cycles per year/max. 100 mA @ 30 V DC
2-Channel Monitoring	Interlock relay contacts must be connected in series, or in the case of a single tap, they must be linked to an AND function by the larger safety instrumented system

2.1.1 Calculation details

Conformance to EN ISO 13849-1 has been calculated using the tool Sistema (v2.0.8) available from the German Institute for occupational safety (Institut für Arbeitsschutz der DGUV (IFA)).

Table 1: Safety Parameters for Sub-Components (per Channel), According to Sistems Project File

	O_2 Sensor	Electronics (without RLs)	Relays	
$MTTF_D$	21.00	278.26	2000[1]	years
DC^	90.00	97.62	99.00	%
Max. Service Life	5	20	20	years

1. The high $MTTF_D$ is based on significant derating of the relay - 1000 cycles/year, see also derated electrical specification.

Please contact SENSORE if you require more information about the Sistema calculation.

2.2 EN IEC 62061

Structural and environmental considerations

- Basic Subsystem Architecture D: 1oo2D
  - Dual channel structure, a single fault will not lead to a safety function (HFT=1)
  - In addition, most single faults will be detected to avoid the accumulation of undetected faults
- Environmental conditions in the application
  - The SIL 2 rating is based on uncontaminated air respectively purged with nitrogen or argon
  - Some application conditions may include traces of harmful gases, which can affect sensor measurement performance; therefore periodic checks of the sensor function will be required. If significant signs of deteriorated sensor performance are observed, the sensor must be replaced as a preventive measure. The sensor has a maximum service life of 5 years and must always be replaced when it reaches its service life.

EN IEC 62061 Safety Parameters for the Transmitter and Sensor Unit	
PFH	$4.2 \cdot 10^{-7}$ (1/h)
SFF	96.8 %
HFT	1
SIL	SIL 2
Essential Constraints	
O_2 Sensor	Validated in the application: maximum service life 5 years
Periodic Test Interval	Determined by the validation procedure: maximum 6 months. Safety parameters are based on a 2-week test interval
Relay	Max. 1000 switching cycles per year/max. 100 mA @ 30 V DC
2-Channel Monitoring	Interlock relay contacts must be connected in series, or in the case of a single tap, they must be linked to an AND function by the larger SIS.

2.2.1 Calculation details

Table 2: Safety Parameters for Subsystem Elements (per Channel)

Failure Mode	O_2 Sensor	Electronics (without RLs)	RL[1] B10$_d$ (1000 nop)	
Safe Detected Failure (λ_{SD})		$7.10 \cdot 10^{-7}$		1/h
Safe Undetected Failure (λ_{SU})		$4.10 \cdot 10^{-7}$		1/h
Dangerous Detected Failure (λ_{DD})	$4.89 \cdot 10^{-6}$	$4.00 \cdot 10^{-7}$	$5.65 \cdot 10^{-9}$	1/h
Dangerous Undetected Failure (λ_{DU})	$5.44 \cdot 10^{-7}$	$9.76 \cdot 10^{-9}$	$5.71 \cdot 10^{-11}$	1/h
SFF	90.00	99.36	99.00	%
DC^	90.00	97.62	99.00	%
Max. Service Life	5	20	20	years

1. The low failure rate is based on significant derating of the relay - 1000 cycles/year, see also derated electrical specification in the User Manual.

EN IEC 62061 provides a simplified calculation for basic subsystem architecture D, which considers the diagnostic interval, the proof-test/service life interval and a parameter for common-cause failure risk. A precondition for the application of the simplified calculation is a MTTF that is much longer than the maximum service life, for the O_2 sensor this is interpreted as the requirement for a preventive replacement of the sensor.

Combining the subsystem elements of the two channels, e.g. sensor channel 1 (ch1) and sensor channel 2 (ch2), leads to a combined dangerous failure rate for each subsystem. Adding all subsystems (O_2 sensors, electronics, relays) leads to the resulting PFH as stated in the certificate. The periodic test interval is considered to be the diagnostic test interval for the sensors, even if sensor heater-related faults could be detected within seconds.

For the electronics and relay, all diagnostic tests are conducted internally and do not require any external action. An internal diagnostic test interval of 24 hours is assumed, most diagnostic tests will run at a much higher rate (seconds), but some are triggered by events.

Table 3: Parameters for Simplified Calculation: Basic Subsystem Architecture D

Resulting PFH = 4.2×10^{-7}/h	O_2 Sensor	Electronics (without RLs)	RL B10$_d$ (1000 nop)	
Diagnostic test interval	(2 weeks) 24*14	24	24	h
Proof test/max. service life interval	5	20	20	years
Common cause failure risk (β)	5	5	5	%

2.2.2 Derating of safety parameters for a 6-month periodic test interval

As EN IEC 62061 is using diagnostic test intervals to calculate the PFH, an increase of the periodic test interval will change the PFH. So, a worst-case calculation has been performed for 6 months.

Table 4: Derated Parameters for Simplified Calculation: Basic Subsystem Architecture D

Resulting PFH = 5.2 x 10^{-7}/h	O_2 Sensor	Electronics (without RLs)	RL $B10_d$ (1000 nop)	
	O_2 Sensor	Electronics (without relays)	Relay $B10_d$ (1000 nop)	
Diagnostic test interval	(6 months) 24*183	24	24	h
Proof test/max. service life interval	5	20	20	years
Common cause failure risk (β)	5	5	5	%

It is important to understand that the slightly increased PFH only covers the increased risk of random faults due to the longer periodic test interval. A longer periodic test interval will also increase the likelihood of systematic risk due to less frequent checks on the aging sensor.

2.3 Residual Risks

For integration into a larger safety instrumented system, residual safety risks must be considered, e.g.:

- The system's response time may be inadequate, e.g. due to the placement of the sensors, but also due to the inherent response time of the sensors (<10 s).
- Harmful environmental conditions can negatively affect or damage the O_2 sensor system, this is checked during the validation procedure. However, depending on the nature of the application there might be residual risks, e.g. due to reasonable foreseeable misuse by the operator, which are not covered by the validation procedure and cannot be completely excluded. Conditions or events that will affect both sensors are the most critical and could impair the reliable detection of the O_2 threshold value e.g.:
  - Electrode poisoning caused by harmful substances can lead to a permanent drop of the indicated oxygen concentration.
  - Contamination or clogging of the porous sinter cap could significantly reduce sensor response time.
  - Combustible volatile substances can lead to a temporary drop of the indicated oxygen concentration.
- Microx ProSafe SIL2 fulfils the requirements of EN 13849-1, nevertheless (residual) risks due to common cause failures (EN 13849-1 Annex F) or systematic failures (EN 13849-1 Annex G) must also be evaluated as part of the larger safety instrumented system.

2.3.1 Possible measures to address residual risk

- Provide detailed documentation/guidance for the end-user to avoid foreseeable misuse
- Increase the O_2 safety margin, i.e. choose a lower O_2 safety threshold
- Minimize the time between periodic tests e.g. 2 weeks. See "3 Periodic Test of the Sensor Function" on page 8. See also EN 13849-1 Annex F and G.

3 Periodic Test of the Sensor Function

3.1 Primary purpose of the periodic test

The periodic test serves as a preventive measure to monitor sensor performance, so that sensor replacement can take place before a critical loss of the sensor function occurs.

Sensor drift is a systematic issue, which depends largely on application conditions. A precondition of the SIL 2 certificate is that sensor performance in the application is sufficiently monitored with a periodic test. The necessary periodic test interval will therefore depend on the severity of application conditions, which should be evaluated by a validation procedure as described in "4 Validation" on page 11.

3.2 Secondary purpose of the periodic test

The periodic test can also identify random faults in the sensor's function. In case of critical function loss of one sensor, the overall system will still be safe due to the 2nd channel. If this happens, the periodic test acts as a detection measure to avoid the accumulation of undetected failures. If the periodic test detects critical function loss of one sensor, the sensor must be replaced immediately.

The occurrence of a critical function loss should be documented, the failure data can be used to analyze the nature of the fault i.e. random fault or systematic fault due to sensor drift. On a larger scale, such failure data can be used to justify a periodic test interval and to calculate an application-specific $MTTF_D$.

3.3 Implementation of the periodic test into the larger SIS

We strongly recommend implementation of the periodic test as an automated function of the larger SIS. This will ensure a test interval is established and that data from the periodic tests is logged and traceable. The logged data can be used to monitor sensor drift and to trigger/forecast sensor replacement.

The periodic test can be implemented before/during inertization or when aerating the system, see *Figure 1* and *Figure 2 on page 9* respectively.

The periodic test log should include the following:

- Timestamp (date and time)
- O_2 value of the 23.5 % sensor (ch1) if operated in air, prior to inertization or at the end of aeration
  - The ideal value is 20.9 %. Typical sensor drift will cause a drop of the recorded value in air.
- O_2 value of the 23.5 % sensor (ch1) and 2.35 % sensor (ch2) during (slow) inertization/aeration at an O_2 level where both sensors are between 2 % and 2.5 %
  - The signals of both sensors must be within 0.25 % of each other, e.g. ch 1= 2.3 % and ch1= 2.2 %.

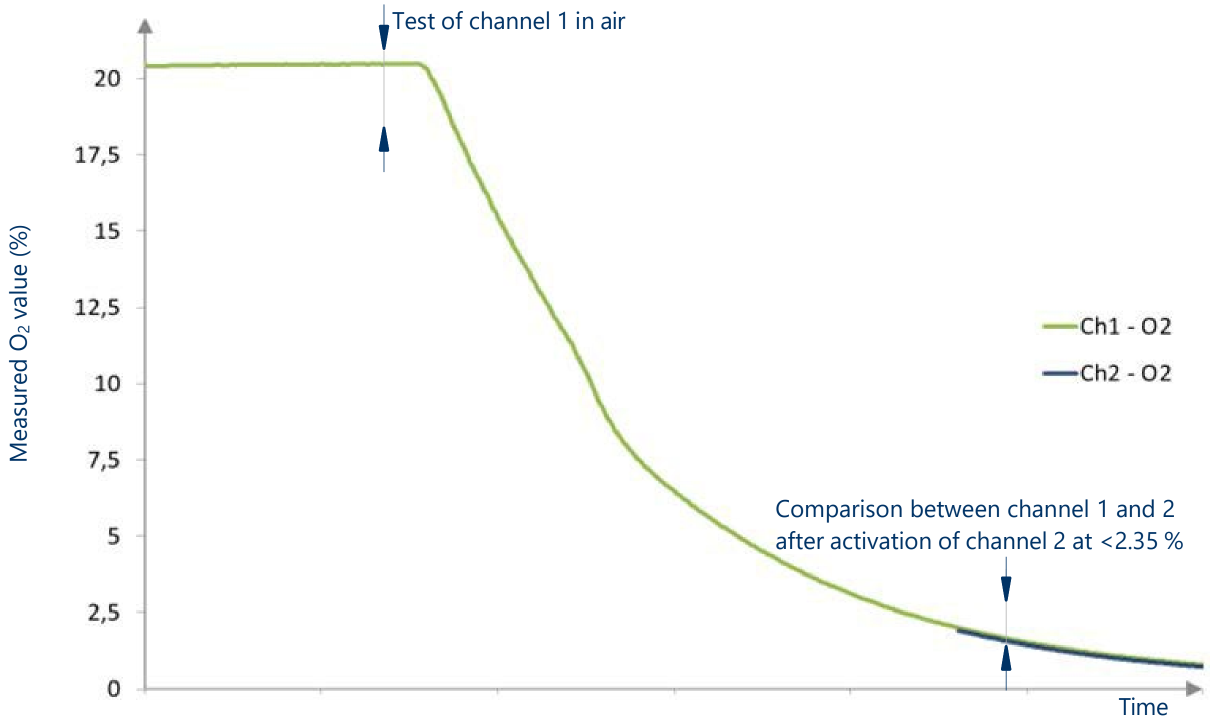

Figure 1. Periodic test before/during inertization

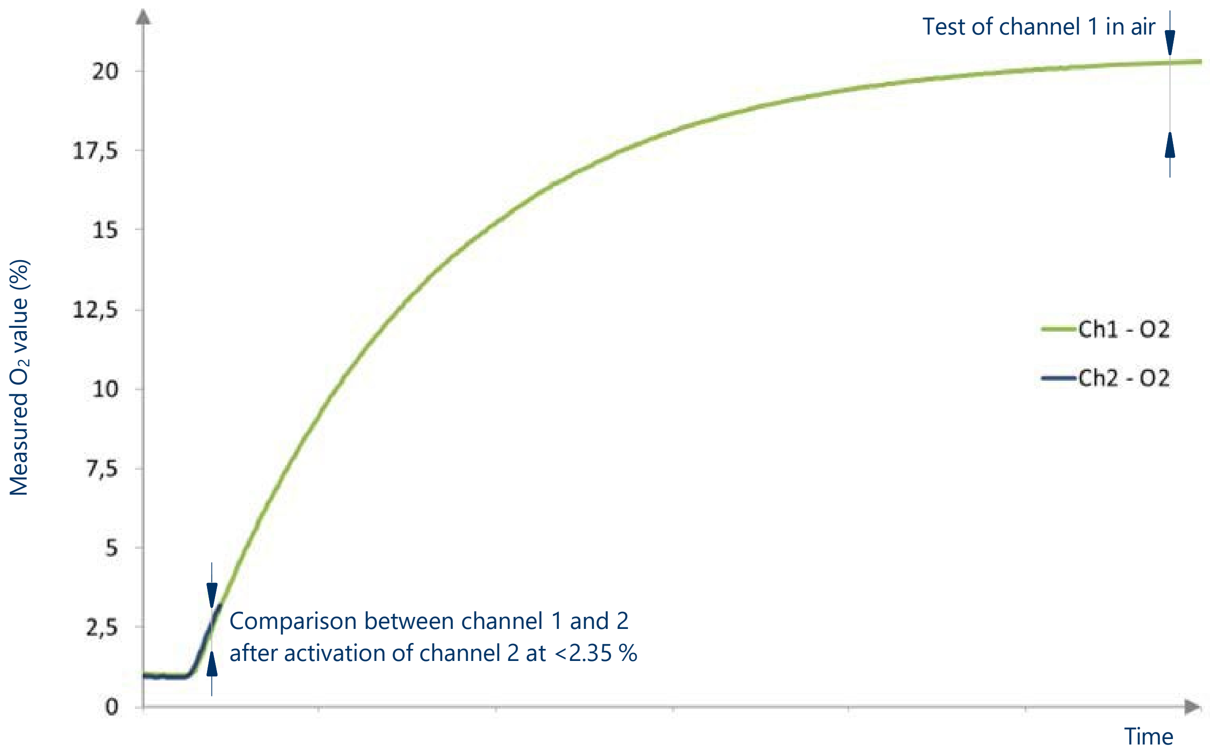

Figure 2. Periodic test when aerating the system

3.3.1 Suggested action following the periodic test

Following the periodic test:

- A visual inspection of the sensor housings should take place. An operator needs to confirm that there is no visible damage or contamination to the sensor. A scheduled visual check is advised, dependent on the risk of contamination or mechanical damage in the application.
- Action based on periodic test results (see "3.4 Pass/fail criteria of the periodic test") should be initiated as follows:
  - Sensor shows only minor signs of drift - No action necessary
  - Sensor shows progressive signs of drift - Schedule a preventive sensor replacement
  - Sensor failure or significant signs of drift - Request immediate replacement of the sensor.

3.4 Pass/fail criteria of the periodic test

Pass/fail criteria will be defined by the results of the validation procedure (see "4 Validation" on page 11), as there will be systematic influences from the larger SIS; pass/fail criteria will also depend on the selected interval of the periodic test.

Table 5: Basic guidance for 23.5 % sensor (ch1) measurement in air (20.9 %)

Results	Sensor Age	Temperature	Relative Humidity (%rh)	Pass or Fail?
20 % < 21 %	New	25 °C	50 %	Pass
19 % < 22 %	Moderately aged	23.5 °C	50 %	Pass
17 % < 19 %	Significantly aged			Pass[1]
22 % < 23 %	Significantly aged			Pass[1]
< 17 %				Fail
> 23 %				Fail

1) The O_2 safety margin of the application must also be considered, to justify the pass rating.
These deviations can also be justified if validation results demonstrate that aging only affects higher O_2 levels, while accuracy <5 % is still within specification.

Basic guidance for 2.35 % sensor (ch2) comparison with 23.5 % sensor (ch1), measured between 2 % and 2.5 %:

- Results within 0.1 % are expected for a new 2.35 % sensor – PASS
- Results within 0.25 % are expected for a moderately aged 2.35 % sensor – PASS
- The most critical criterion for a 2.35 % sensor is its ability to measure above the O_2 safety threshold (e.g. > 2 %), so the absolute value of the 2.35 % sensor during the comparison measurements must be above the threshold, otherwise the 2.35 % sensor must be classified as a failure – FAIL.

4 Validation

4.1 What is the purpose of validation?

The SIL 2 approval/certificate covers inherent random faults of the Microx ProSafe SIL2 and provides a probability of dangerous failure per hour (PFH). It also specifies operating conditions to minimize systematic influences. The safety certificate is based on uncontaminated gas conditions, it does not cover environments that are potentially harmful to the sensor. The User Manual provides best practice guidelines.

The main purpose of the validation is to demonstrate that the (gas) conditions in the end-user application do not harm the oxygen sensors in a way that will void the safety integrity level. Therefore, this validation process must be completed for every end-user application.

The results of the validation should provide the following information:

- Interval of the periodic verification test (standard 2 weeks, maximum 6 months)
- Replacement guidance and pass/fail criteria for results of the periodic verification test
- Estimate for the typical sensor replacement interval
- Specific restrictions and guidelines for the end-user e.g. how to protect the sensor under special conditions, cleaning the process chamber.

4.2 Who should be involved in the validation process?

- The machinery supplier (designer and manufacturer) of the larger safety instrumented system
- The process plant operator, who must ensure acceptable operating conditions in the application.
- If required: The manufacturer of Microx ProSafe SIL2: Sensore Electronic Gmbh

4.3 Validation procedure based on EN 50104

A comprehensive validation may require the oxygen sensors to be tested under application conditions over extended periods of time (>1 year). To reduce the test period to a reasonable time frame, a test standard for oxygen sensors (EN 50104) is applied, which outlines the minimum requirements for signal stability based on a 63-day test, see *Figure 3 on page 14*.

The stability test procedure of EN 50104 has been modified slightly to allow it to be used as validation procedure:

- The equipment (sensors) must be in continuous operation within the actual atmosphere of the target application for a period of 63 days - it must not be a simulated environment
- To check for changes in the sensor, a periodic test should be performed as described in "3 Periodic Test of the Sensor Function" on page 8
  - During the first 7 days, the check should be carried out frequently, e.g. daily, to investigate the measurement repeatability.
  - After the initial 7 days, a 2-week interval between periodic tests will be sufficient

- EN 50104 states a maximum permissible variation/drift over 63 days. This “63-day-drift” provides the framework to assess sensor performance under application conditions, see "4.3.1 Guidance for the result of the 63-day test" below.

NOTE: In order to complete a detailed analysis, it is recommended a data log is kept for both channels over the 63-day test period.

4.3.1 Guidance for the result of the 63-day test

23.5 % Sensor

- 63-day drift is within ± 0.1 %
  - Longer periodic test intervals than 2 weeks are feasible, see "4.4 Extended periodic test interval" on page 13
- 63-day drift is within ± 0.25 %
  - The sensor may be slightly affected by process conditions. Recommended periodic test interval is 2 weeks.
- 63-day drift is within ± 0.625 % but larger than ± 0.25 %
  - The sensor is clearly affected by process conditions, use for SIL applications will require additional justification, e.g. periodic test interval 2 weeks and maximum service life of the sensor 1 year.
  - It is necessary to understand the root cause for the accelerated drift of the sensor, contact SENSORE.
- 63-day drift is larger than ± 0.625 % in air
  - The sensor is significantly affected by the process conditions, the sensor cannot meet the requirements of EN 50104, therefore a SIL rating is not achievable.

It is necessary to detect/remove the root cause for accelerated sensor drift, contact SENSORE.

Deviation of the 2.35 % sensor (ch2) compared to the 23.5 % sensor (ch1).

- It is important to establish an accurate zero hour (0h) offset value between ch2 and ch1 during the first 7 days of the test, which will be the base line for the 63-day Drift. A typically 0h offset will be in the range of ± 0.1 %
- 63-day drift is within ± 0.05 % compared to 0h offset
  - Periodic test intervals longer than 2 weeks are feasible, see "4.4 Extended periodic test interval" on page 13.
- 63-day drift is within ± 0.1 % compared to 0h offset
  - The sensor may be affected by the process conditions. We recommend a periodic test interval of 2 weeks.
- 63-day drift is within ± 0.2 % but larger than ± 0.1 % compared to 0h offset
  - The sensor is clearly affected by the process conditions, use for SIL applications would require additional justification, e.g. a periodic test interval of 2 weeks and a maximum service life of the sensor 1 year.
  - It is necessary to understand the root cause for the accelerated drift of the sensor, contact SENSORE.

- 63-day drift is larger than ± 0.2 % compared to 0h offset
  - The sensor is significantly affected by process conditions and cannot meet the requirements of EN 50104, therefore a SIL rating is not achievable.
  - It is necessary to detect/remove the root cause for the accelerated drift of the sensor, contact SENSORE.

The overall system periodic test interval is determined by the minimum interval from the sensor test results outlined above.

SENSORE can provide the following support during and after the validation:

- Review of results from the initial 7-day test
- Review of the data from the 63-day test
- Support analysis (including physical testing) of the sensors after the 63-day test
  - Check against reference gases, to analyze minor changes in the sensor characteristics
  - Electrical check of sensor parameters, which can reveal early signs of accelerated aging
  - Destructive analysis to check for early signs of accelerated aging of the sensor's subcomponents.

4.4 Extended periodic test interval

The customer may increase the periodic test interval, based on a safety assessment for the application (see "4.3 Validation procedure based on EN 50104" on page 11). Regardless of the application, the periodic test interval must not be longer than 6 months.

An extended periodic test interval may need additional justification, e.g.:

- Test data that demonstrates low aging/drift of the sensor under application conditions over longer periods than 63 days.
- A detailed performance check of sensors after the 63-day test or after longer test periods. SENSORE can provide support with this analysis.
- Utilize the application's O_2 safety margin
  - The minimum safety margin, i.e. margin on top of the O_2 safety threshold is 1 %
  - For applications with a higher O_2 safety threshold, higher sensor drift may be accepted.
- Increasing the O_2 safety margin of the application
  - Reducing the O_2 safety threshold from 2 % to 1.5 % for example
  - Using a lower safety threshold value (e.g. 1.5 %) will significantly increase the 2.35 % sensor's operational life. The periodic test comparison between ch1 and ch2 can then be performed at lower a O_2 concentration, e.g. in case of a 1.5 % threshold between 1.5 and 2 %.
- Down-rating of the SIL 2 requirement to SIL 1
  - The validation procedure and periodic test are also mandatory for SIL 1 requirements, to ensure the correct function of the sensors under application conditions.
  - For SIL 1, however, an undetected fault of one sensor is not as critical as for SIL 2, so longer test intervals are more feasible. A preventive change of the sensors based on the periodic test should still be applied. It is still necessary to ensure that no significant sensor drift is caused by application conditions.

- Introduction of plausibility checks of the sensor signal to detect rare random fault conditions
  - For Microx ProSafe SIL2, the failure detection of an open sensor cell circuit or a completely defective electrode is usually disabled, both failures would result in sensor currents close to 0. Sensor currents close to 0 will also occur at very low O_2 concentrations, so enabling the failure detection could lead to false alerts at low O_2 levels.

    A broken sensor cell wire would be an example of a random fault, which would only be detected during the periodic test. The system will still be safe as long as there is no further fault on the other channel of the system. But extending the periodic test interval would increase the risk of an undetected error. Depending on the application's inertization purity, it may be possible to introduce a plausibility check if the sensor signal is not expected to be close to 0 ppm, and such a plausibility test would then detect a broken sensor wire or a completely defect electrode.
- Introduction of alternative diagnostic functions during operation below the O_2 threshold level
  - An example would be introducing a crosscheck of channel 1 and channel 2 at levels between 2000 ppm_V and 2 %
  - Introduce dynamic changes in the O_2 concentration and monitor the response with the sensors

⚠ **The above actions will not guarantee correct sensor operation at the safety threshold value, but can reveal changes in the sensors' characteristics.**

- Introduction of alternative diagnostic functions during crossing of the O_2 threshold level
  - A simple plausibility test involves checking if both channels are detecting O_2 concentrations above the O_2 threshold value when purged with air

⚠ **This will not guarantee correct sensor operation at the safety threshold value but may detect critical sensor aging on channel 2.**

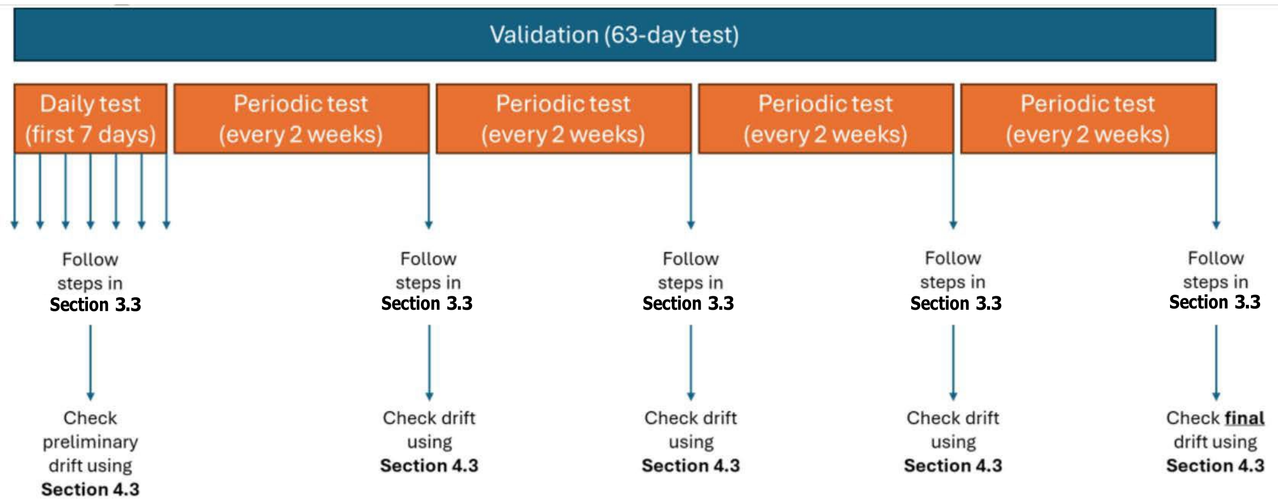

Figure 3. Validation procedure

5 Appendices

Appendix A - Checklist

1. Installing the Microx ProSafe SIL2 (Control Unit)	
Microx ProSafe SIL2 control unit must be placed in an electrical cabinet, mounted upright on a DIN rail as pictured in the User Manual. The electrical cabinet provides protection against pollution (dust) and reduces electromagnetic interference.	☐
The temperature inside the electrical cabinet should be between +10 and +50 °C (+50 and +122 °F). Respectively, <+85 °C (+185 °F) at the internal PCB hot spot must not be exceeded. The internal PCB temperature can be monitored via RS485, see user manual.	☐
The recommended distance to the neighboring modules on the DIN rail is 50 mm.	☐

2. Power Supply/Electrical Interfaces/Electrical Insulation	
The Microx ProSafe SIL2 transmitter must be powered by a dedicated power supply of 24 V DC/500 mA, which must be compliant with SELV/NEC Class 2. The power supply is part of the safety system.	☐
The complete circuitry connected to Microx ProSafe SIL2 must maintain protection against hazardous voltages (PELV).	☐
The transmitter must have a functional connection to PE, i.e. the GND of the Microx ProSafe SIL2 must be tied to PE (So that overall it will be PELV, not SELV).	☐
The RS485 interface is intended as a maintenance and debug interface; it should not be permanently connected. If a permanent RS485 connection is required, the RS485 lines into the Microx ProSafe SIL2 must be protected by external means, e.g. an optocoupler. NOTE: An unprotected connection to an RS485 network will void SIL classification.	☐
In general, safety-related circuits must be sufficiently separated from non-safety circuits.	☐

3. Location and Orientation of the O_2 Sensors	
The O_2 sensor will measure oxygen in the gas that passes it. For accurate measurement, the gas that passes the sensor must be representative of the process. E.g. measurements near an N_2 inlet, may lead to artificially low O_2 concentrations, measurements near an outlet may lead to artificially high readings due to diffusion. Locate the sensor accordingly.	☐
Location can influence the sensor's response time in the case of a sudden O_2 inrush into the larger system, e.g. via an opened door. Locate the sensor accordingly.	☐
Positioning must not expose the sensor to mechanical shock and vibration.	☐
The sensor can be operated in any orientation, but to minimize pollution risks an upside-down mounting from the top is favorable. Refer to *Figure 1 on page 3* in the User Manual.	☐
Thermal influences should be minimized, i.e. the sensor must not be located in proximity to air fans, heaters etc.	☐
Sensors should be screw-mounted into a grounded metal enclosure (ESD).	☐

4. Operating Conditions of the O_2 Sensors	
Allowable gas temperature range at the O_2 sensor is between +10 and +100 °C (+50 and +212 °F)	☐
Allowable pressure is 700...1300 mbar (10...19 psia); fast pressure changes should be avoided as they could cause short spikes in O_2 reading	☐
The sensors are intended to be used in air and under inertization with nitrogen or argon. Traces of other gases should be considered during validation, as they could influence the O_2 measurement or the life-time of the sensor.	☐

5. General Limitations	
The system has no hazardous area classification e.g. ATEX/IECEx/FM/CSA, the sensor is heated up to ca. +600 °C (+1112 °F), and must be used only in non-hazardous installations.	☐
The sensor must not be exposed to liquids or to condensing humidity.	☐
If the heated sensor can be accessed by the end-user, a hot surface warning may be necessary.	☐
All installations must be performed by qualified personnel under standard precautions.	☐

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