The

SIL O_2 Analyser

Safety Manual
Supplemental to the User operation Manual
With OC-25 and OC-26 Sensors

Rev. 1.2

NTRON Gas Measurement
A PST BRAND

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Revision History

Description.	Rev.	Date.
First issue	1.0	15/03/2024
Added EN 50402 reference to page 5. SELV reference page 13. Added Analogue manual reference to page 12	1.1	07/06/2024
Error correction table 10, page 22, from 69 to 79.	1.2	22-07-2024

CLASSIFICATION OF THE SAFETY INSTRUCTIONS

This manual contains instructions that you have to observe for your personal safety as well as to avoid material damage. These instructions are highlighted using a triangular warning sign and shown as follows, depending on the degree of risk.

HAZARD

means that death or severe physical injury will occur if the appropriate precautionary measures are not taken.

WARNING

means that death or severe physical injury may occur if the appropriate precautionary measures are not taken.

CAUTION

with a warning triangle means that a slight injury may occur if the appropriate precautions are not taken.

CAUTION

without a warning triangle means that a material damage may occur if the appropriate precautions are not taken.

ATTENTION

means that an undesired result or state may ensue if the corresponding instruction is not followed.

NOTE

denotes important information about the product, handling of the product or the respective part of the documentation, is aimed at drawing special attention to the latter and should be complied with.

In addition to the instructions in this manual, the generally applicable safety and accident prevention regulations must be observed. If the information contained in this document should not be sufficient in any specific case, you can obtain more detailed information from our telephone service.

Please read this manual carefully prior to installation and commissioning.

CE mark

This product meets the specifications according to the EMC standard EN 61326-3-2 and the Low Voltage Directive 2006/95/EC.

General Instructions

WARNING

Devices with the type of protection designated as "intrinsic safety" lose their conformity certification as soon as they have been operated in circuits that do not meet the values specified in the test certificate. Flawless and safe operation of this device requires proper transport, proper storage, installation and assembly as well as careful operation and maintenance. The device may only be used for the purposes specified in this operating manual.

Note: Note: Programming of all Alarm levels and other necessary functionality is not a user enabled function and is undertaken by Ntron prior to delivery of the device. Should any changes be necessary to the programming, please contact Ntron. Software can be supplied to customers on request to allow programming of alarm levels and other functionality via a separate PC. It is the customers' obligation to protect and control access to the software supplied as per EN 50402 (2017) part 6.1.

DISCLAIMER

All modifications to the device fall within the responsibility of the user unless expressly specified otherwise in the operating manual.

Qualified PERSONNEL

are persons who are familiar with installation, assembly, repair and operation of the product and have the qualifications necessary for their work, such as:

- Training, instruction and/or authorization to operate and maintain equipment/systems in accordance with the standards of safety technology for electrical circuits, high pressures and corrosive as well as hazardous media.
- In the case of equipment with explosion protection: training, instruction and/or authorization to perform work on electrical circuits for potentially explosive equipment.
- Training or instruction in accordance with the standards of safety technology regarding care and use of appropriate safety equipment.

CAUTION

- Potentially electrostatic components may be destroyed by voltage that is far below the limits of human perception. Such voltage occurs even when you touch a component or electrical connections of a component and are not electrostatically discharged. The damage that occurs to a component because of overvoltage usually cannot be detected immediately and does not become noticeable until after a longer operating period.

- No software development is possible. The required competence is limited to understanding and following the procedures documented in the Safety Manual.

INTRODUCTION

Intended use and scope of this manual

This manual details the safety related data required to implement this product into a Safety Instrumented System.
This Manual does not contain the technical specifications or operating instructions for this product. Consult the SIL O2 User Operation and maintenance Manual for that information. Basic system outline and connectivity information is given in this Manual as an aid to system design and implementation.

Roles and Responsibilities.

The Oswald Partnership Ltd	Performed the hardware assessment according to IEC 61508:2010. The Oswald Partnership Limited provides Functional Safety Engineering (FSE) and Functional Safety Management (FSM) services. Certified Functional Safety Practitioner (CFSP) status was granted from CFSE in 2010.
Ntron Limited	Supplier of the Ntron OC-25/26 Oxygen Sensors and Ntron 01-758 Oxygen Analyser.

Standards used in this report.

IEC 61508:2010	Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems
IEC 61511:2004	Functional Safety - Safety Instrumented Systems for the Process Industry Sector
EN 50104:2019	Electrical equipment for the detection and measurement of oxygen — Performance requirements and test methods
EN 50402:2019	Electrical apparatus for the detection and measurement of combustible or toxic gases or vapours or of oxygen - Requirements on the functional safety of gas detection systems

FUNCTIONAL SPECIFICATION

SYSTEM CONFIGURATION

Hardware

In this Manual, the SILO Analyser and OC-25 and OC-26 Sensor will be referred to in full as just stated or simply as ‘Analyser’ and ‘Sensor’ including suffix ‘M’ models.
The complete SILO2 An Analyser and Sensor system comprises of the following components.

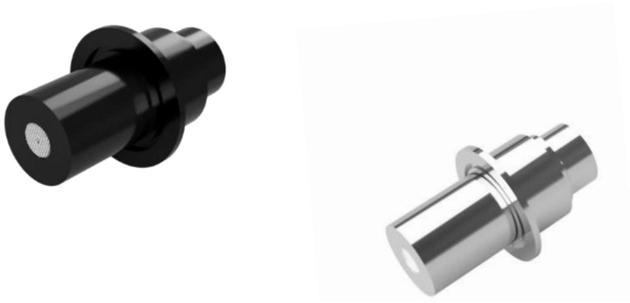
1. SILO2 Analyser Model part number 01-758 with integral I.S.** Isolation Barrier Ex output rated II (1) GD.
2. Solid State Oxygen Sensor of model number OC-25 or OC-26 Ex rated II 1 GD
3. Extension cable with electrical connector (to mate with Sensor connector)*
4. The combination of the above parts can be supplied under an Ntron assembly part number specific to Sensor, Cable length and alarm level configuration pre-programmed at Ntron.

*Available with options of connector types, extension cable lengths and process fittings so part numbers will vary accordingly and are available on request from Ntron.

** I.S. = Intrinsically Safe Ex protection protocol.

System Components Drawing

SILO2 Analyser



OC-26 & OC-26M Sensor

OC-25 & OC-25M Sensor

Product Identification

When first supplied as new, The Sensor and Analyser are matched and calibrated as a pair together. Both Analyser and Sensor have unique serial numbers printed on their labelling and these serial numbers are recorded on the calibration documentation issued with the products along with the assembly part number. These printed serial numbers along with the related calibration certificate allow the user to check that the pairing of Analyser and Sensor is correct.

When the Sensor requires periodically replacing, following connection to the Analyser, a re-calibration will be required by the user. The user should prepare for themselves, a new calibration document listing the new Sensor serial number, Analyser serial number and other relevant information.

The connecting cable, Sensor to Analyser, follows the model number sequence

OC-22x for Plastic housing models and is provided according to customer cable length requirements and a specific designated part number for cables for Metal housing models.

System Software

SILO2 Firmware

The SILO2 Analyser has integral operational Firmware which contains variable settings to allow the configuration of specified to input and output elements meet the required application. Such settings have a bearing on the internal signal processing and hardware interfaces.
The variable settings can only be accessed and changed by means of a PC running dedicated interface software. Both the device Firmware and Interface software are revision controlled.

Current Version:
Firmware Version No.: 4.20.

Interface Software

This Interface software is used for the factory configuration of each SILO2 Analyser but is also available to end users allowing onsite setting and adjustment of certain operational settings. This software allows configuration of both electronic and hardware input and output interface elements to the required application specific settings. Once a given configuration is downloaded to the SILO2 Analyser, the interface software is disconnected from the Analyser and shut down.
Current Version:
Software Version No.: Version 8 Release 0.8. Earlier models than firmware version 4.20 can be programmed using this version.

Interface Software Communications

The PC based interface software communicates with the SILO2 ZR Analyser by means of a dedicated RS232 connection cable assembly. See the Technical Data section of this manual for the RS232 communication settings.

Security

Without connection to the Interface Software and hardware, no configuration changes can be made to the SIL O2 Analyser.
The Interface software has two level password protection which can be set and changed by the user.
Password level 1: Allows access to all variable parameter settings except 'Calibration'.
Password level 2: Allows access to 'Calibration' only.

The SILO2 Analyser is designed for mounting within Enclosures or control panels. Such Enclosures or control panels should have restricted user entry to specified key holders. This can prevent unauthorised calibration adjustment to the SILO2 Analyser via the manual calibration buttons on the device.

Recommended Configuration

The only configurable parameters that should be adjusted by the customer/user are those involving the operation of the user interface relay outputs. These are as follows.
1- Relay Alarm Levels; 2- Relay Hysteresis; 3 -Relay operation delay time, 4- Rising Oxygen level operation*, 5- Energised(fail safe) or de-energised state when healthy.
The foregoing settings values are typically determined by the customer/user and transmitted to Ntron for configuring during the production process.

*Whilst the Relay/alarm setpoints can be set to act upon both rising and falling Oxygen concentrations, this SIlO2 Analyser system is assessed for the detection of **Rising Oxygen concentrations only,** for Inerting explosion protection applications.

Software development

The software element of the SILO2 Analyser is a fixed program language (FPL) with no user access for coding development. User access is limited to entering data as instructed by operation and maintenance procedures.

Compatibility

Firmware Backwards compatibility:
The SILO2 Analyser Firmware version 4.20 is has version-limited backward compatibility with earlier versions. Contact Ntron for further information.
Remote Interface Software backwards compatibility:
Earlier models than firmware version 4.20 can be programmed using version Version 8 Release 0.8. .

Compatibility with other systems:
The SILO2 Analyser System is a Stand alone solution and no compatibility concerns with other systems are relevant.

Change control
Should any changes to the programming be necessary, please contact Ntron.

Factory defaults
No automatic device restore to a design safe state is supported. A Configuration Reload would be required.

User interface
User access is limited to entering data as instructed by operation and maintenance procedures.

DESCRIPTION OF THE ANALYSED SYSTEM

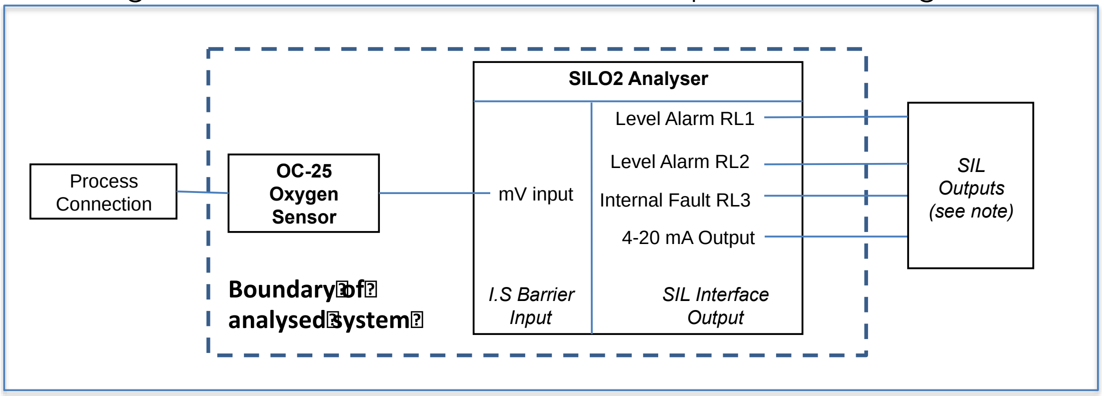
The oxygen Sensor is provided in two configurations that differ only in the options for process connections. Throughout the report, the term OC-25/26 will be used for features that apply to both models.

The OC-25 requires a screw-on base, which can be tri-clamp, flow-through, weld-on or ANSI flange. The OC-26 comes with a KF flange, only.

The Ntron SILO2 01-758 Oxygen Analyser converts the mV signal from the integral amplifier into a 4-20 mA output and provides three configurable trip points. These trip points are assigned to two electro-mechanical alarm relays RL1 and RL2 and to one solid state transistorised output. For the purposes of this safety manual, only the electro-mechanical relays are considered as available for use in an SIS. The main functional safety trip element is a non-configurable electro-mechanical relay designated RL3.

The largest most complex system configuration is 1 out of 2 .

Block diagram of all elements connected in an operational configuration.



Note: See safety Functional Specification point 4.

PRINCIPLE OF OPERATION

The Ntron OC25/26 Oxygen Sensors are amperometric 2-electrode Sensors that convert oxygen concentration by volume directly into a low-level electric current with a mV output proportional to the volumetric oxygen concentration. The effective operating range is 0-30% O2 Vol with a maximum deviation from linearity of 0.3% O2 Vol.

The OC25/26 is a self-powered, diffusion-limited, metal-air battery type Sensor. It contains an anode, solid state electrolyte, and a noble metal air cathode, to which the diffusion of oxygen is severely restricted by a diffusion barrier. The output signal is amplified by means of an integral op-amp and lithium battery. The Sensor is designed to be used in conjunction with the Ntron SILO2 01-758 Oxygen Analyser.

The OC25/26 Sensor also contains a wire-monitoring diagnostic circuit that allows the Ntron SILO2 01-758 Oxygen Analyser to automatically detect a wire-break or short circuit in the interconnection between the Ntron OC25/26 Sensor and the Ntron SILO2 01-758 Oxygen Analyser. The wire-monitoring diagnostic circuit has two failure modes, short circuit and open circuit, both would cause the output of the Sensor to drive 'high', causing the SIS to maintain or move into a safe state, which would constitute an undetected safe failure, or 'false trip'. This Safe Failure is part of the diagnostic function only and to be conservative it has been omitted from the SFF calculation.

SAFETY FUNCTION SPECIFICATION

1. **De-energise alarm relay(s) RL1 and RL2 on detection of high oxygen level**
   The OC25/26 Sensor generates a mV output that is proportional to the oxygen concentration in a process gas. The SILO2 Analyser interprets the mV input signal from the Sensor and calculates the oxygen concentration using a calibration function. The Analyser then compares the calculated oxygen concentration with a pre-determined threshold value that is defined by the user. When the calculated oxygen concentration exceeds the threshold value, the SILO2 Analyser de-energises two alarm relays (R1 and R2), which may be used either singly or together as part of a SIS to actuate the Final Element(s) and put the equipment under control into a safe state or maintain a safe state.

2. **De-energise fault relay RL3 on detection of fault by SILO2 internal diagnostics**
   The SILO2 Analyser has an automatic on-line diagnostic monitoring system that will de-energise a fault relay (RL3) on detection of a Wire Break in the cable to the Sensor, a disconnected Sensor, a break in the Analogue output circuit connection or a failure within the SILO2 Analyser itself. This will move the Analyser into a safe state. A wire break event, short circuit of the Sensor connection or disconnected Sensor will drive the Analyser measurement circuit to a 'High' measurement alarm condition along with the de-energising of the fault relay RL3.

3. **De-energise alarm relay(s) RL1 and RL2 when certain faults occur**
   The alarm relay(s) RL1 and RL2 will de-energise with a fault event as described in (2) above.

NON-SAFETY FUNCTION

1. **Provide an analogue 4-20 mA output proportional to the measured oxygen concentration of the process gas**
   The SILO2 Analyser provides a 4-20 mA output that is proportional to the oxygen concentration derived from the mV input signal from the Sensor. Whilst the 4-20 mA output signal is SIL capable, practical application presents the user with certain onerous requirements to comply with applicable SIS related legislation. Therefore, this output can primarily be utilised in a non-SIL portion of a control system for monitoring purposes without further assessment requirements. The user should consult the relevant legislation for use of this output in an SIS and the supplementary SILO2 Analogue manual, part number 08-419.

CONSTRAINTS OF USE

Functional safety can only be achieved if the following constraints are observed:

- Functional safety is only valid for applications where Oxygen is the target measurement gas in the percentage volume range.
- Functional safety is valid only for Ex area applications where the Oxygen level is not enriched, i.e. not greater than 21% by Volume.
- Functional safety is only valid for applications where the safe state is an Oxygen concentration that is below a pre-determined threshold, i.e. a low Oxygen concentration is safe. The presence of oxygen above a critical limit presents an unsafe state which results in a high input (trip on high).
- The system can only be used where the safe state is below a pre-determined oxygen concentration threshold that generates a mV signal from a Sensor correctly calibrated to the SILO2 Analyser. The Sensor operation must be verified on a regular basis by means of a partial proof test. This will establish that the Sensor is responding correctly to changes in Oxygen concentration and that the maximum allowable Sensor drift has not been exceeded.
- For functional safety to be achieved, the fault relay R3 must be used as part of the SIS in event of a fault detected by internal diagnostics to actuate the Final Element(s) and put the equipment under control into a safe state or maintain a safe state.
- One or both of alarm relays R1 and R2 must be designated to de-energise to trip when the measured oxygen concentration is above a pre-determined user-defined set-point programmed into the Analyser and selected to ensure process safety. De-energising the relay(s) must result in an action that puts the Equipment Under Control into a safe state or maintain a safe state.
- All of the supplier’s installation, commissioning, operation & maintenance and conditions of use must be followed.
- For Explosion prevention applications, the SIlO2 Analyser as a safety device, has to function independently of any controls used for operation of the equipment, so

the equipment would function safely under normal operation in the absence of the safety device. (Atex directive 2014-34-EU clauses 1.5; 1.5.1.)

- The Analyser and Sensor should not be stored or operated outside the environmental ranges given in table 2 of this document. See the User Operation Manual for full technical operational parameters.
- The OC-25 and OC-26 and suffix 'M' models must be operated within their temperature and pressure ranges as specified in the User Manual specifications section.
- The OC-25 and OC-26 and suffix 'M' models must be operated within their Ex certified capabilities as regards EX zone and temperature rating.
- For Sensor models with plastic Housings, the special conditions 'x' on the EC-Type Examination Certificate must be observed as follows: The plastic enclosure of the OC-25 and OC-26 Oxygen Sensors must be installed in such as way so as to be protected from any situations that could cause a build-up of static charge. They must not be installed in locations where the plastic housings could come into contact with, through normal or abnormal circumstances, fast moving dust laden air/gas or non-conductive fluids. The Sensors should be cleaned only with a damp cloth.
- The non-intrinsically safe supply circuit and the non-intrinsically safe digital output circuit must be connected to Safety Extra-Low Voltage (SELV) circuits.
- For Sensor models with metal Housings (suffix 'M'), the special conditions 'x' on the EC-Type Examination Certificate must be observed as follows: The metal enclosure of the OC-25M and OC-26M Oxygen Sensors are a potential source of electrostatic discharge. They must be installed in their end use application in a manner where the metal enclosure is earthed.

FAILURE MODE, EFFECTS AND DIAGNOSTICS ANALYSIS (FMEDA)

METHODOLOGY

Failure Mode, Effect and Diagnostics analysis is a systematic procedure for the analysis of a system to identify the potential failure modes, their causes and effects on system performance and functionality, including the immediate assembly and the entire system or process. The term system is used as a representation of the hardware, software (with their interaction), or a process. There are wide variations in the manner in which an FMEDA may be conducted and presented. The FMEDA conducted here follows guidelines presented in IEC 60812 (2nd Ed) Analysis Techniques for System Reliability- procedure for Failure Mode and Effect Analysis (FMEA). In addition to the formal guidelines, faults revealed by both on-line automatic diagnostics and periodic proof testing are also identified.

SYSTEM FAILURE MODES

The failure modes of the OXYGEN ANALSER SYSTEM due to random hardware failures and the behaviour of the system following failure of the function are described in the following tables.

Table 1 describes the failure modes when the safety instrumented system is being used where a safe state is maintained when the oxygen concentration is below a predetermined threshold that must be less than the Lower Explosive Limit (LEL) of the Oxygen and gas mixture being measured.

Table 1

Mode	**Description**
Safe State	The oxygen concentration of the Equipment Under Control is below a pre-determined safe threshold that is defined by the user.
Dangerous State	The oxygen concentration of the Equipment Under Control is above a pre-determined safe threshold that is defined by the user.
Safe Failure	A failure that causes the safety instrumented system to cause the equipment under control to go into a safe state or maintain a safe state without a demand from the process to do so.
Safe Failure (Detected)	A safe failure that is detected by automatic internal diagnostics.
Dangerous Failure	A failure that prevents the safety instrumented system from operating as designed and causing the equipment under control to go into a safe state or maintain a safe state when there is a demand from the process to do so.
Dangerous Failure (Detected)	A dangerous failure that is detected by automatic internal diagnostics and causes either: the output signal from the Analyser to be driven above a pre-determined safe threshold defined by the user, or de-energises fault relay (RL3).
Fail High	A failure that causes the output signal from the Analyser to go above 20 mA.
Fail Low	A failure that causes the output signal from the Analyser to go below 4 mA.
No Effect Failure	A failure of part of the system that has no effect on the safety function and is neither a safe failure, nor a dangerous failure. It is not included in the SFF calculation.
No Part Failure	A failure that is not part of the system and does not affect the safety function.

ENVIRONMENTAL PROFILE

For the purposes of the FMEDA, environmental profiles were chosen to represent the more severe characteristics of typical locations for the products, of which these components are part. The profiles are not intended to represent average conditions, but rather conditions estimated such that 90% of installations will be in environments that are less severe than the profile. It is assumed that process-wetted components are compatible with the physical and chemical surroundings. A list of physical and chemical compatibilities of the process-wetted components is presented in appendix 01.

These profiles provide component-level environmental conditions inside the product. It must be noted that the component environmental conditions -mounted on a circuit board, inside an enclosure, inside a cabinet- will be different to the product's external environment.
The environmental profiles of the system are shown in the following table:

Table 2

Sub assembly:	SILO2 PSU	OC25/26 electrical (non-process wetted)	OC25/26 mechanical (process wetted)
Profile no.	1	3	6
Profile description	Cabinet mounted/climate controlled	General field mounting (self-powered)	Process wetted
IEC 60654-1 profile designation	B2	C3 / D1	NA
Average ambient temperature °C	30	25	25
Average internal temperature °C	60	25	NA
Daily temperature excursion (pk-pk) °C	5	25	NA
Seasonal temperature excursion °C	5	40	NA
Exposed to elements/weather?	No	Yes	Exposed to process conditions
Humidity[1]	0-95% non-condensing	0-95% non-condensing	0-95% non-condensing
Shock[2]	10g	15g	15g
Vibration[3]	2g	3g	3g
Chemical corrosion[4]	G2	G3	See appendix 01
Surge[5]			
Line-Line	0.5 kV	0.5 kV	NA
Line-Ground	1 kV	1 kV	
EMI Susceptibility[6]			
80MHz-1.4GHz	10 V/m	10 V/m	NA
1.4GHz-2.0GHz	3 V/m	3 V/m	

2.0GHz-2.7GHz	1 V/m	1 V/m	
Electrostatic Discharge (air)[7]	6 kV	6 kV	NA

FAILURE RATE DATA

The failure rate data used in the FMEDA assumes a constant failure rate, independent of wear-in (infant mortality) effects and wear-out (end of life) effects. It is important therefore to ensure that commissioning checks are completed on installation and components are replaced within the suppliers recommended lifetime figures.

Component-level failure rate data and related information was obtained for this product from the documents listed in the table below. The data was derived using field data from various sources and failure data from various databases. The rates were chosen in a way that is appropriate for safety integrity level verification calculations. It is anticipated that the actual number of field failures due to random hardware failures will be less than the number predicted by the failure rates used in this study.

Table 3

Electrical & Mechanical Component Reliability Handbook, 2nd Edition, 2008	Exida L.L.C, Electrical & Mechanical Component Reliability Handbook, 2nd Edition, 2008, ISBN 978-0-9727234-6-6
MIL-HDBK-217F published by the U.S. department of defence	Provides methods on the calculation of component failure rates.
Bellcore/Telcordia Standard TR-332 Issue 6	Provides methods on the calculation of component failure rates.
Ntron Report: SILO2 01-758, document BA 7.01 rev. 1.1.	Provides information and failure rate data on the Ntron SILO$_2$ 01-758 Oxygen Analyser
Ntron Report: IR03049, rev 1.0.	Provides information and failure rate data on the Ntron OC25/26 Oxygen Sensor.
Electrical & Mechanical Component Reliability Handbook, 2nd Edition, 2008	Exida L.L.C, Electrical & Mechanical Component Reliability Handbook, 2nd Edition, 2008, ISBN 978-0-9727234-6-6
MIL-HDBK-217F published by the U.S. department of defence	Provides methods on the calculation of component failure rates.
Bellcore/Telcordia Standard TR-332 Issue 6	Provides methods on the calculation of component failure rates.
E325-Din Rail SilO2	Provides a SILO2 electrical connection diagram.
PS-SILO2-002-12	Provides information on the 01-758 SILO2 Analyser
BA 7.01 Rev 1.1	01-758 SILO2 Analyser safety Manual.
5/2014 Wire Monitoring	Provides information on the SILO$_2$ 01-758 Oxygen Analyser wire-break monitoring function.
IL1776C	Details of OC-25/26 Op-Amp.
Ox 4 Cr1025	Details of OC-25/26 Battery.
AIOB3.0.0 Cb	Details of OC-25/26 Sensor.
Datasheet mini OX[2]	Details of OC-25/26 Sensor.
E195-OC21-25; E523-OC-26	Details of OC-25/26 Sensor
Panasonic Lithium Handbook August 2005	Details of OC-25/26 Battery

Sensor and Battery Reliability Calculation – OC-17, OC-24 and OC-25/OC26 Sensors (Ntron) 08/May/2015	Details of OC-25/26 Battery
Contact No 101100 (Panasonic)	Statement of OC-25/26 battery failure frequency

ASSUMPTIONS

The following assumptions have been made during the Failure Mode, Effects and diagnostics Analysis of the OC25/26, SILO2 assembly:

- There is zero fault tolerance; a single component failure will result in loss of the safety function of the OC25/26 and the SILO2.
- Constant failure rates are assumed. Wear-in and wear-out mechanisms are excluded.
- Propagation of errors by the device in the system are not taken into consideration
- Components that are not part of the safety function, or which have no effect on the safety function have been recognised during the analysis but are excluded from reliability calculations.
- Component stress levels are considered 'average' for industrial applications. The OC25/26 'process-wetted parts' environment is comparable to Exida Profile 3, whereas the non-process-wetted parts of OC25/26 environment is comparable to Exida Profile 6 and. The SILO2 is intended to be cabinet mounted in an environment comparable with Exida Profile 1.
- De-energising either alarm relays or fault relays will cause the SIF to put the equipment under control into a safe state, or maintain a safe state.
- All 'process-wetted' parts are compatible with the process conditions in terms of materials, erosion, corrosion and function.
- The system is installed and operated in accordance with the supplier's instructions.
- Maintenance schedules are observed, including replacement parts, calibrations and proof-testing.
- The system is not subject to abuse or sabotage.
- The time required to detect a fault by internal automatic diagnostics is between 0.25 and 1 second. The time required to detect an external input fault is $</=$ 30 seconds.

RESULTS

Annex D of IEC61508-2 requires that all failure modes of the compliant item due to random hardware failures are identified and made available to the user in a safety manual, including:

- the failure rates for each failure mode,
- the effects of each failure mode and the associated outputs,
- whether each failure mode is detected by either internal or external on-line diagnostics,

The user of these numbers is responsible for determining their applicability to any particular installation or environment. Accurate plant specific data may be used for this purpose. If a user has data collected from a good proof test reporting system that indicates higher failure rates, the higher numbers must be used. Some industrial plant sites may have higher levels of stress than those assumed in this analysis. Under such conditions, the failure rate data should be adjusted to reflect the specific conditions of the installation.

Failure data obtained from the FMEDA is presented in the following tables:

Table 4

OC25/26 Sensor		
Failure Mode	**Failure rate (failures per 10^9 hours)**	**Output of failure mode**
Fail safe	612	De-energises alarm relay(s) R1 and/or R2 and fault relay, R3
Fail dangerous detected	300	De-energises fault relay, R3
Fail dangerous undetected	307	Unable to de-energise alarm relay(s) R1 and/or R2 and fault relay, R3 when required to do so by a process demand.
No effect / No part	0	No effect on safety function

Table 5

OC26/26 Sensor interconnection to SILO2 Analyser		
Failure Mode	**Failure rate (failures per 10^9 hours)**	**Output of failure mode**
Fail safe	124	De-energises alarm relay(s) R1 and/or R2 and fault relay, R3
Fail dangerous detected	124	De-energises fault relay, R3
Fail dangerous undetected	0	Unable to de-energise alarm relay(s) R1 and/or R2 and fault relay, R3 when required to do so by a process demand.
No effect / No part	0	No effect on safety function

Table 6

SILO2 Analyser		
Failure Mode	**Failure rate (failures per 10^9 hours)**	**Output of failure mode**
Fail safe	404	De-energises alarm relay(s) R1 and/or R2 and fault relay, R3
Fail dangerous detected	381	De-energises fault relay, R3
Fail dangerous undetected	19	Unable to de-energise alarm relay(s) R1 and/or R2 and fault relay, R3 when required to do so by a process demand.
No effect / No part	2.5	No effect on safety function

Table 7

SILO2 Analyser with Sensor System Totals		
Failure Mode	**Failure rate (failures per 10^9 hours)**	**Output of failure mode**
Fail safe	1140	De-energises alarm relay(s) R1 and/or R2 and fault relay, R3
Fail dangerous detected	805	De-energises fault relay, R3
Fail dangerous undetected	326	Unable to de-energise alarm relay(s) R1 and/or R2 and fault relay, R3 when required to do so by a process demand.
No effect / No part	2.5	No effect on safety function

APPLYING THE FMEDA RESULTS

IEC 61508-2 2010 Clause 7.4.4: in the context of hardware safety integrity, the highest safety integrity level that can be claimed for a safety function is limited by hardware safety integrity constraints which shall be achieved by implementing one of two possible routes (to be implemented at system or subsystem level). These are:

Route 1_H based on hardware fault tolerance and safe failure fraction concepts; or, Route 2_H based on component reliability data from feedback from end users, increased confidence levels and hardware fault tolerance for specified safety integrity levels (Proven in Use).

In the absence of reliability data feedback from end users, Route 1_H will be used to determine the hardware safety integrity architectural constraints.

Under the requirements of IEC61508 and prior to loop calculations (PFD) it is necessary to determine the absolute minimum architecture that is required. This is determined by the 'safe failure fraction' (SFF) which can be expressed by the formula:

Equation 1 SFF

$$SFF = \frac{\lambda_{SD}+\lambda_{SU}+\lambda_{DD}}{\lambda_{SD}+\lambda_{SU}+\lambda_{DD}+\lambda_{DU}}$$

This equation can only be used if dangerous detected failures (λ_{DD}) are detected by automatic online diagnostics for low-demand mode applications and where detection of the dangerous failure causes the Equipment Under Control to go into a safe state, or maintain a safe state.

Table 8

Safe Failure Fraction SFF	
OC25/26 Sensor and Interconnection	79.1%
SILO2 Analyser	97.7%

The safe failure fraction is component specific and is completely independent of maintenance criteria such as Proof Test Interval (PTI) and MTTR. Failure to meet the required SFF for a given SIL level can only be resolved by adding redundancy and not by changing the maintenance variables.

Under the safe failure fraction there are two defined types of components/devices: type 'A' where full Failure Mode and Effect Analysis (FMEA) is available and where fault behaviour can be determined and where field data is available or type 'B' where either one or more of these criteria is missing.

Table 9a and 9b

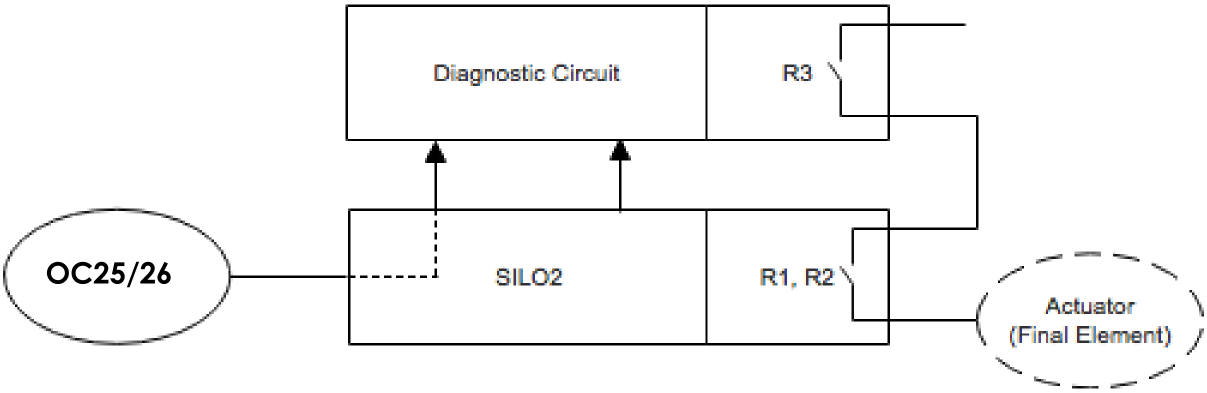
Type 'A' devices			
SFF	Hardware fault tolerance		
	0	1	2
<60%	SIL 1	SIL 2	SIL 3
60%<90%	SIL 2	SIL 3	SIL 4
90%<99%	SIL 3	SIL 4	SIL 4
≥99%	SIL 3	SIL 4	SIL 4

Type 'B' devices			
SFF	Hardware fault tolerance		
	0	1	2
<60%	-	SIL 1	SIL 2
60%<90%	SIL 1	SIL 2	SIL 3
90%<99%	SIL 2	SIL 3	SIL 4
≥99%	SIL 3	SIL 4	SIL 4

IEC61508:2010 Part 2 Tables 2 &3

1oo1D Architecture

1oo1D architecture uses a single controller channel with diagnostic capability and a second diagnostic channel wired in series to utilise the diagnostic signal to de-energise the output. Diagnostics allow a detected dangerous failure to be converted into a safe failure. 1oo1 architecture has a fault tolerance of zero.



1oo1D Safe Failure Fraction

The OC25/26 Sensor element is defined as 'Type A', however the SILO2 Analyser is a 'Type B' element. The maximum safety integrity level that can be claimed based on the hardware fault tolerance in a system with 1oo1D architecture is given in the following table:

Table 10

Element	Fault Tolerance (1oo1D)	Element Type	Safe Failure Fraction (%)	Maximum allowable SIL
OC25/26	0	A	79	2
SILO2	0	B	97	2

1oo1D Calculation of Average Probability of Dangerous Failures

The Low Demand Mode of operation requires that the frequency of demands on the SIS to protect the EUC occurs less than once per year. Allowance is made for on-line repair of dangerous detected failures provided all such failures are repaired in less time than the MTTR to restore the SIS to working order following a safe failure, typically 4 to 8 hours. Diagnostic failures would not directly affect the operation of either the SIS or the EUC, but would affect the future ability of the SIS to detect failures. It is presumed for the purpose of this exercise that faults in the Diagnostic systems would be detected and rectified during routine proof testing. Similarly, undetected dangerous failures would also be identified and repaired during proof testing.

For the purpose of the exercise it is assumed the proof testing has complete coverage and is 100% effective. In practice, the effective proof test coverage will depend on factors such as the competence of maintenance staff and the safety culture within the organisation where the SIS is installed and must be established on a case-by-case basis.

The 1oo1D architecture has a second diagnostic channel that will de-energise when failures are detected by automatic on-line diagnostics. Therefore, the only failures that cause system with outputs energised are dangerous undetected failures. The equation for PFD_{avg} for a 1oo1D architecture is:

$$PFD_{avg} = 1 - e^{-\lambda_{DU}\frac{T}{2}}$$

Where T = Proof test interval

Average Probability of Failure on Demand (PFDavg)

IEC61508:2010 part 1 section 7.6.2.9 provides guidance on the PFDavg that must be achieved to meet a defined SIL.

Table gives the Safety Integrity levels-target failure measures for a safety function operating in low demand mode of operation.

Table 11

Safety Integrity Level (SIL)	**Average Probability of Dangerous Failure (PFD_{avg})**
4	$\geq 1x10^{-5}$ to $<1x10^{-4}$
3	$\geq 1x10^{-4}$ to $<1x10^{-3}$
2	$\geq 1x10^{-3}$ to $<1x10^{-2}$
1	$\geq 1x10^{-2}$ to $<1x10^{-1}$

a) SIL 1 target PFD_{avg} = 0.35×10^{-2}
b) SIL 2 target PFD_{avg} = 0.35×10^{-3}
c) SIL >2 Not Applicable with 1oo1D architecture due to safe failure fraction requirements. See table 12 .

Proof Test Philosophy.

The greatest source of undetected dangerous failures is due to Sensor drift or reduced sensitivity, which together account for a combined failure frequency of 307 failures per 10^{9} hours. A convenient procedure may be used to reveal these faults as part of a partial proof test (calibration stability check). This procedure is described in the Proof Test part of the Maintenance section in this document. Note that this will only test the function it is designed to examine.
It is recommended that the partial proof test is done once every two weeks and a full proof test of the entire system is done at a frequency determined by the user's target PFDavg using the following equation:

$$PFD_{avg} = 1 - e^{-\lambda_{Drift}\frac{T_B}{2} + (\lambda_{DU} - \lambda_{Drift})\frac{T}{2}}$$

Table 12

T	= Full proof test interval	1 Year
T_B	= Partial proof test(calibration stability) interval	Every 2 weeks
λ_{Drift}	= Failure frequency due to Sensor drift/ reduced sensitivity	$307/10^{9}$ hours
λ_{DU}	= Total dangerous undetected failure rate	$326/10^{9}$ hours
PFD_{avg}	=Average probability of dangerous failure	0.0003 SIL 2
		0.002 SIL 1

Calculating the Re-calibration intervals.

The maximum allowable Sensor drift is +/-2.5% within the full proof test interval. This equates to +/-0.625% Vol. O2.
For the OC-25/26, the maximum Sensor drift annually is 8%.
Assuming as a worse case, the maximum drift, the recalibration period is determined As follows: 0.625 / ((8/100) . 25 (max. range) / 12(months)) = 3 months (rounded down to lower full number)
So the SIL O2 Analyser/Sensor combination will require recalibrating every three months to maintain operation within the PFDave values given.

Should a partial proof test reveal a Sensor drift value in excess of +/-0.625% O2 before the re-calibration interval is reached, the Sensor should be considered to have failed and should be replaced.

Allowance must be made for the contribution the user's logic solver and final element(s) will make towards the total PFD_{avg} of the entire SIS It is reasonable to consider the PFD_{avg} of the Sensor element will comprise 35% of the available SIL range, the logic solver 15% and the final element 50%. Therefore, the target of the Sensor will be restricted to 35% of the available SIL range to allow development of the remaining SIS elements:
See the User Operation manual for calibration instructions.

Response time Check

All Sensor models have a nominal T90 response time of <20 seconds. For Safety operational purposes to EN 50104 a maximum step change in gas level at the Sensor measuring point, from Zero (less than 0.01%) to 20.9%, the maximum time it should take to reach a displayed Oxygen measurement of 18.8% O2 would be less than 45 seconds. If this time is exceeded, the Sensor should be considered to have failed and should be replaced.
During the calibration process, this transition of rising Oxygen level can be timed against the foregoing maximum reference time. The total time to a stable reading of 20.9% can then be recorded.
Most step changes during the application of 20.9%O2 calibration gas will be typically less than the range discussed above and therefore would be expected to fall within the maximum T90 response time.
A failure to achieve the 20.9%O2 displayed measurement within the maximum period would indicate a potentially failed Sensor and the Sensor should be replaced.

Safety Integrity Level	Full Proof Test Interval (years)*		PFD_{avg}
SIL 1 Range	Maximum allowable[1]	35	0.35×10^{-1}
	Minimum practical[2]	3.5	0.35×10^{-2}
SIL 2 Range	Maximum allowable[1]	3.5	0.35×10^{-2}
	Minimum practical[2]	4 months	0.35×10^{-3}

Note: The calculated proof test intervals are for indication only, the system developer must calculate the required proof test interval for the complete system, including Sensor, logic solver and final element. The actual proof test interval required may be higher or lower than those stated in this report.

Calculation of PFH

The average frequency of dangerous failure per hour (PFH) is used for situations where a safety instrumented system is operating in high demand, or continuous demand modes of operation. In this case, any dangerous failure has the potential create a hazard. With a 1oo1D architecture, dangerous detected failures may be assumed to be safe failures only if the detection is by automatic online diagnostics, detection of a fault results in an action to put the equipment under control in to a safe state, or maintain a safe state and the time taken to detect a fault and put the equipment under control into a safe state is less than the process safety time (the time between loss of process control and a hazardous event occurring).

[1] Exceeding the maximum allowable proof test interval increases the PFD_{avg} beyond the limits of the safety integrity level.
[2] Decreasing the proof test interval below the minimum practical value reduces the PFD_{avg} below the allowable limits of the safety integrity level

The PFH is given by the dangerous failure rate per hour.

Safety Integrity Level (SIL)	Average frequency of a dangerous failure of the safety function (h^{-1})
4	$\geq 1x10^{-9}$ to $<1x10^{-8}$
3	$\geq 1x10^{-8}$ to $<1x10^{-7}$
2	$\geq 1x10^{-7}$ to $<1x10^{-6}$
1	$\geq 1x10^{-6}$ to $<1x10^{-5}$

Allowance must be made for the contribution the user's logic solver and final element(s) will make towards the total PFD_{avg} of the entire SIS It is reasonable to consider the PFH of the Sensor element will comprise 35% of the available SIL range, the logic solver 15% and the final element 50%. Therefore, the target of the Sensor will be restricted to 35% of the available SIL range to allow development of the remaining SIS elements:

a) SIL 1 target PFH = 3.50×10^{-6}
b) SIL 2 target PFH = 0.35×10^{-6}

PFH (credit taken for failure detection) = 0.94×10^{-6}

Therefore, the system being studied is capable of use in a compliant safety instrumented system operating in continuous or high demand mode of operation without redundancy for SIL 1 applications only.

Note: care must be taken when using oxygen Analysers in continuous demand mode as some standards, such as Directive 2014/34/EU (ATEX) prohibit the use of safety devices in this mode of operation.

Diagnostics
Diagnostic measures related to the monitoring of safety functions are provided via the SILO2 Analyser and also by the OC85 Sensor in combination with the SILO2 Analyser. The diagnostic test interval is dictated by the clock-speed of the SILO2 Analyser.
The response time for the release of the Safety Function on detection of a fault is: <30 s.

Diagnostics provided by the SILO2 Analyser:

- Measurement of loop resistance
- Diagnostics of the output current (4-20 mA) by feedback measurement
- Diagnostics of the alarm relay output by feedback contact
- Supervision of supply voltages (under and overvoltage)
- Plausibility checks of parameters and measured values
- RAM-Test
- ROM and EEPROM consistency check by CRC
- Program sequence monitor combined with watchdog functionality

- CPU test

Output on detection of a fault is the de-energisation of relay R3

ALTERNATIVE ARCHITECTURES

This report describes the use of the ANALYSER SYSTEM in 1oo1D architecture. The system may be used in alternative architectures, but these are outside the scope of the Safety Manual. The design of alternative architectures and assessment of the associated SIL must be completed by individuals competent in functional safety.

Using alternative architectures to improve PFH or PFD_{avg}

The PFD_{avg} or PFH may be reduced by combining the ANALYSER SYSTEM in redundant architectures, such as 1oo2D. This also allows the possibility of using the 4-20 mA analogue output signals from the SILO2 to be used to provide an additional diagnostic function to detect loss of calibration, or drift, of one Sensor or the other.

Using alternative architectures to improve plant availability

The number of spurious trips may be reduced by using the ANALYSER SYSTEM in a 2oo2D architecture requiring both systems to respond to a demand before putting the equipment under control into a safe state, or maintain a safe state. However, such a configuration will have a significant detrimental effect on the PFD_{avg} and PFH.

Limitations of alternative architectures due to systematic capability constraints

The Systematic Capability of the ANALYSER SYSTEM is adjudged to be SC2 (see section xxx). The maximum SIL that can be claimed for a combination of elements each of systematic capability SC2 can be no more than SIL3. It is not permitted to achieve a higher SIL than SIL3 by successively building elements of Systematic Capability SC2.

SYSTEMATIC CAPABILITY

The systematic capability is a measure (expressed on a scale of SC1 to SC4) of the confidence that the systematic safety integrity of an element meets the requirement of the specified SIL. The systematic capability is determined with reference to the requirements for the avoidance and control of systematic faults. The requirements for systematic safety integrity (systematic capability), can be met by achieving one of the following compliance routes:

- Route1_S: compliance with the requirements for the *avoidance* of systematic faults as detailed in IEC 61508-2, 7.4.6 (hardware) and IEC 61508-3 (Software) and the control of systematic faults as detailed in IEC 61508-2, 7.4.7 (hardware) and IEC 61508-3 (Software).
- Route 2_S: Compliance with the requirements for evidence that the equipment is proven in use as detailed in IEC 61508-2, 7.4.10 (hardware and software)
- Route 3_S for pre-existing software elements only: Compliance with IEC 61508-3, 7.4.2.12.

The relationship between SC and SIL are shown in the following table:

Systematic Capability (SC)	Safety Integrity Level (SIL)
4	4
3	3
2	2
1	1

In the absence of data to provide evidence for proven in use, the systematic capability was assessed using Route 1_S for the avoidance and control of systematic faults.

The systematic capability assessed for each phase of the design process are shown in the following table:

<table>
<tr><th>Phase</th><th>Systematic Capability (SC)</th><th>Assessment</th></tr>
<tr><td>Design Specification</td><td>2</td><td rowspan="7">Validation Assessment</td></tr>
<tr><td>Design & Development</td><td>2</td></tr>
<tr><td>Integration</td><td>2</td></tr>
<tr><td>Validation</td><td>2</td></tr>
<tr><td>Hardware Design (control)</td><td>2</td></tr>
<tr><td>Environmental Stress</td><td>2</td></tr>
<tr><td>Operational</td><td>2</td></tr>
<tr><td>Software</td><td>2</td><td>Risknowlodgy assessment of Analyser transmitter</td></tr>
</table>

QUALITY DOCUMENTATION

Each SILO2 and Sensor Analyser assembly, models 01-758 Analyser and OC-25 or OC-26 Sensor will be supplied with the following Documentation.

Calibration Certificate
EU Certificate of Conformity
EC-Type Examination Certificate
Process Fitting Material Certificate if applicable
SIL O2 user Operation and maintenance Manual
SILO2 Safety Manual
SILO2 Software Manual (Remote software option)

PROOF-TESTING

(See also page 24 of this manual)
Periodic proof tests must be conducted at specified intervals to reveal undetected faults that would otherwise prevent the system operating in accordance with the user's Safety Requirement Specification. Different parts of the system may require different proof test intervals and the frequency of the proof test interval must be decided by the PFDavg calculation (see section "Applying FMEDA Results").The entire system must be tested, including Sensor(s), logic solver and final element(s), either end-to-end or in parts. Where the interval between scheduled process downtime is greater than the proof test interval, then on-line testing facilities must be provided.
The user must maintain records that certify that proof tests were completed as required. These records must include the following information as a minimum:

- a description of the tests
- dates that the tests were done
- name of the person(s) who performed the tests
- serial number or other unique identifier of the system tested
- results of the test

PARTIAL PROOF TEST PROCEDURE

A regular check of the SIL O2 Analyser operation is a requirement, to confirm the calibration stability and the correct operation and safety related functionality of the Sensor. The following partial proof-test procedure should be carried out the interval recommended in table 12 and observing the maximum Sensor drift limits of +/-0.625%O2. See the user Operation manual for detailed instructions.

Note: This procedure should be arranged so as not create a Hazardous condition for personnel or equipment. (This procedure may be able to be carried out whilst the system and host equipment is in operational mode or it may require putting the host equipment Into an offline mode and in some applications this may require removing the Sensor from the equipment or process)

1. Apply a Check Gas of 20.9% O2 to the Sensor. (Certified gas preferred for accuracy)
2. Observe the display on the SIL O2 Analyser. It should read 20.9% or be within a tolerance band of 20.27% O2 and 21.52% O2.
3. If the display reads below 20.27% O2 then the Sensor is demonstrating excessive drift and must be replaced, or re-tested against a certified gas (if not done so already). If the Sensor still reads below 20.27% when tested against a certified gas, it must be replaced.
4. Remove the Check gas and return the Analyser/Sensor and Host equipment to operational mode.

Warning!: It is not possible to correct a failure that causes excessive drift by re-calibrating the Sensor! A Sensor that has failed the partial proof test within the specified calibration interval must be replaced.

A comprehensive Proof Test and Compliance Document SILO2-001 is available from Ntron.
The following elements should be included in any proof test procedure to be undertaken.

- Disconnect the Sensor from Analyser to initiate a fault alarm. Main Trip/Diagnostic Relay de-activates. (simulated wire-break) Analyser resets when Sensor is re-connected.
- Analyser measured oxygen concentration is within (X)% of a reference gas concentration (check for Sensor drift).
- Selected alarm relay goes into alarm state when supplied oxygen concentration rises above alarm set point (full functional check)

NOTE: All failures, whether revealed by diagnostics, maintenance tasks or proof testing must be documented and reported to Ntron for investigation.

REFERENCES AND SUPPORTING DOCUMENTATION

Supporting documentation reviewed in preparation of the safety manual.
System Specification
Design requirement specification
Validation plan
Validation assessment
FMEDA
Risknowlogy Report
User IO&M Manual
EMI Report

APPENDIX 01

1. OC-25 & OC-26 Sensor Wetted parts Substance tolerance and Cross Sensitivities chart

Tolerance without damage or deterioration to the following substances. In some case the substance concentration is not verified.

Chemical Substance	concentration
PW1	Not Verified
Acetone	Not Verified
Ethanol	Not Verified
Isopropanol	Not Verified
Methanol	Not Verified
NaOH	1M, 2M
Cosa CIP 95 (alkaline)	0,5%, 2%
Sakonat RS (acidic)	1%, 5%
Phosphoric acid	5%
nitric acid	2%
Hydrogen peroxide	1%
KOH	1M, 2M
H_2O_2	0,5%
Toluene	Not Verified
Diisopropyl ether	Not Verified
Ethyl acetate	Not Verified
Petroleum gasoline	Not Verified
NH3	</= 25ppm
Ethyl methyl carbonate $C_4H_8O_3$	Low ppm range
Dimethyl carbonate $C_3H_6O_3$	Low ppm range
Ammonia (NH3)	Low ppm range, typ. <25ppm
Hydrogen Sulphide (H2S)	Up to 8% by Volume

All the above at humidity of </=60%RH. Above this, with some acidic gases, deterioration may Occur.

In cases of uncertainty of chemical concentration, pre-conditioning/filtration of the sample gas may be beneficial/required.

Cross Sensitivities

Chemical Substance	concentration
Carbon Monoxide	10%
Carbon Dioxide	30% ok with >60% but cross sensitivity will increase.
Hydrogen	30%
Saturated Hydrocarbons	% range

<0.05% Vol O2 signal change for the above concentrations.

The OC-25 & OC-26 Plastic housing Oxygen Sensors consist of:-
Housing of Acetal Co-Polymer (POM C Black) contain a Potting Compound and Solid State Electrochemical Cell.
The potting compound is Stycast 2651 Epoxy Resin. (Atmospherically Cured)
An EDPM material Sealing Ring, Part No.:01-997 is included with the Sensor.

The OC-25M & OC-26M Stainless Steel housing Oxygen Sensors consist of:-
Housing of 303 Grade Stainless Steel contain a Potting Compound and Solid State Electrochemical Cell.
The potting compound is Stycast 2651 Epoxy Resin. (atmospherically cured)
An EDPM material Sealing Ring, Part No.:01-997 is included with the Sensor.

Wetting of the process-facing (wetted parts) of the Sensor is to be avoided as this can seriously affect the performance and life of the Sensor.

PTFE filter Disks are available for certain process connections as an interface between the Sensor and the process to present a barrier to moisture entering the Sensor. Contact Ntron for details.

Manufactured by:
Ntron Limited
(A PST Brand)
Mullaghboy Industrial Estate,
Navan,
Co. Meath
Ireland.
00353 46 9071333
www.processsensing.com