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Functional Safety Manual
Liquiline M CM42

Memosens Transmitter

Application

Used to run a Memosens sensor to satisfy the particular requirements for safety related systems as per IEC 61508.

The measuring device meets the following requirements:

- Functional safety in accordance with IEC 61508
- Explosion protection
- Electromagnetic compatibility in accordance with EN 61326 and NAMUR-recommendation NE 21
- Electrical safety in accordance with IEC/EN 61010-1
- Ingress protection IP66/IP67 in accordance with DIN EN 60529

Your benefits

- For all Memosens compatible systems up to SIL 2
- Independently assessed (Functional Safety Assessment) by TÜV Süd in accordance with IEC 61508
- Permanent self-monitoring
- Permanent connection monitoring
- Safe Parameterization
- Safe calibration and adjustment

SD153C/07/EN/14.15 71298904

ZERTIFIKAT ◆ CERTIFICATE ◆ 認証証書 ◆ СЕРТИФИКАТ ◆ CERTIFICADO ◆ CERTIFICAT

CERTIFICATE

No. Z10 11 04 30266 019

Holder of Certificate: **Endress + Hauser Conducta GmbH + Co. KG**
Dieselstraße 24
70839 Gerlingen
GERMANY

Factory(ies): 30266

Certification Mark:

Product: **pH measuring equipment**
Memosens Transmitter

Model(s): **Liquiline M CM42-MGx4xxEBxxxx**

Parameters:

Software	SIL3
Structure - SIL:	1oo1 - SIL2
Input voltage:	12.5V - 30.0V
Nominal current range:	4 to 20mA
Transmitter failure mode:	<=3.6mA or >=21mA
Protection degree:	IP 66 / IP 67
Temperature range:	-20°C to 55°C

x - order options (not safety-relevant)

Tested according to:
IEC 61508-1:1998
IEC 61508-2:2000
IEC 61508-3:1998
IEC 61508-4:1998
IEC 61010-1:2010
EN 60529:2000

The product was tested on a voluntary basis and complies with the essential requirements. The certification mark shown above can be affixed on the product. It is not permitted to alter the certification mark in any way. In addition the certification holder must not transfer the certificate to third parties. See also notes overleaf.

Test report no.: EG83500T

(Günter Greil)

Date, 2011-04-29

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472013

TÜV SÜD Product Service GmbH · Zertifizierstelle · Ridlerstraße 65 · 80339 München · Germany

SIL Konformitätserklärung / SIL Declaration of Conformity

Funktionale Sicherheit nach IEC 61508 / Functional Safety according to IEC 61508

Endress+Hauser Conducta GmbH+Co. KG, Dieselstr. 24, D-70839 Gerlingen

erklärt als Hersteller die Richtigkeit der folgenden Angaben. /
declares as manufacturer the correctness of the following data

Gerät/Product	**Liquiline M CM42**
Schutzfunktion / Safety function	1: Sichere Übermittlung des gemessenen mV-Wertes und Ausgabe als Messwert in pH auf den Stromausgängen / Safe transmission of the measured mV value and output of the converted pH value on both current outputs 2: Grenzwertüberwachung des pH-Wertes / Limit monitoring of pH value 3+4: Sichere Kalibrierung, Justierung / Safe calibration, adjustment
Systematischer SIL / Systematic SIL :: Software SIL / Software SIL	2 :: 3
HFT	0
Gerätetyp / Device type	B
Betriebsart / Mode of operation	Low demand mode
SFF / MTTR	94.8 % / 8 Stunden/hours
Prüfintervall T_1 / Proof Test Interval T_1	Empfohlen / recommended: T_1 = 1 Jahr / year
λ_{SD} / λ_{SU} / λ_{DD} / λ_{DU}	688 FIT / 947 FIT / 2667 FIT / 236 FIT
PFD_{avg} T_1 = 1 Jahr / year	1.03×10^{-3}
MTBF / $MTBF_{DU}$ (reciprocal of λ_{total} / λ_{DU}, assuming constant failure rate)	25 Jahre / years / 483 Jahre / years

Das Gerät wurde in einem vollständigen Functional Safety Assessment unabhängig bewertet.

The device was assessed independently in a complete Functional Safety Assessment.

In the event of device modifications, a modification process compliant with IEC 61508 is applied.

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Note!

General information about functional safety (SIL) is available at www.endress.com/SIL and in the competence brochure CP002Z "Functional safety in the Process Industry - risk reduction with Safety Instrumented Systems".

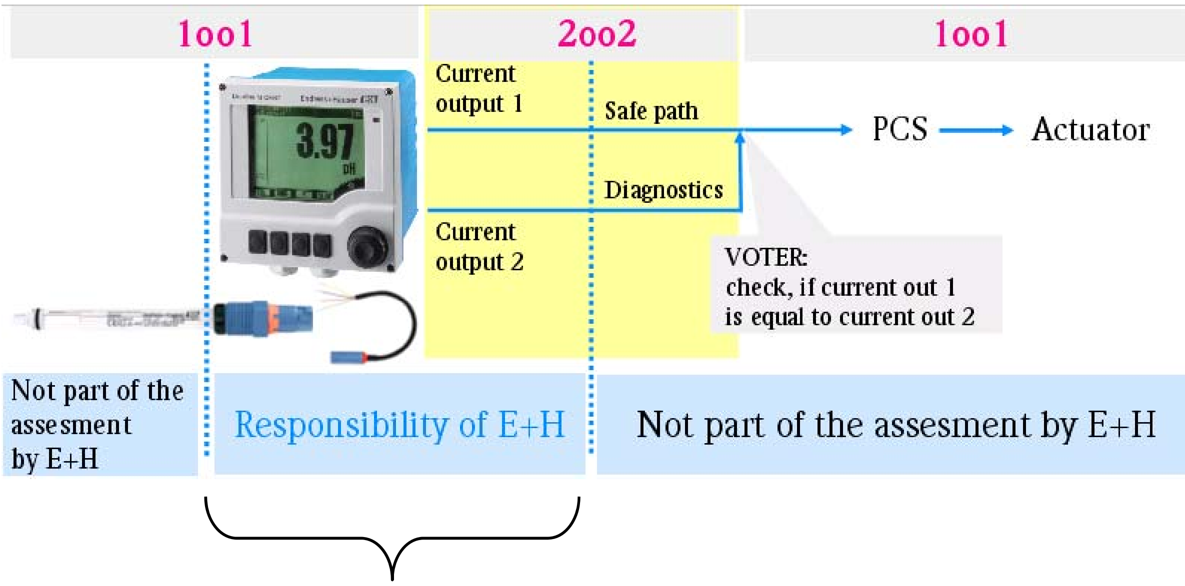
Note!

For general and technical information please read the Technical Information and Operating Instructions of Liquiline M CM42.

1 Structure of measuring system using a Liquiline M CM42 SIL transmitter

1.1 System Components

A system using CM42 looks for example like the following:



This part is covered by this document.

1. Memosens pH glass sensor, SIL
2. Memosens cable CYK10, SIL
3. **Memosens transmitter Liquiline M CM42, SIL**

The transmitter produces an analogue signal (4..20 mA) proportional to the measured voltage at the sensor element. This signal must be processed by a logic component (e.g. a PLC rated SIL2 or higher), which in turn uses maybe some actors to realize the safety function.

The Liquiline M CM42 display is not safe and therefore all operations using the display as an interface to the user are specially secured. It has been shown, that the display hardware and software is reactionless regarding safety to the CM42 system.

The transmitter is always only a part of the complete safety function. The transmitter is a compliant item according to IEC 61508.

1.2 Description of the application as a safety related system

To use the Liquiline M CM42 safety related system, you need for example a safe Memosens sensor and a safe Memosens cable of Endress+Hauser Conducta GmbH & Co. KG. The display (GUI) hardware and software of the CM42 is reactionless for the safety function of the transmitter.

The transmitter must be connected to a safe PCS by using both analogue current outputs. The voter can for example be realized by safe function blocks inside a PLC or by a hardware based 2oo2 voter.

The logic component must be able to handle LO- and HI-alarms (≤ 3.6mA, ≥ 21.0mA).

The CM42 system has several **modes of operation**:

1. Classic mode
2. SIL mode – Active safe state mode (referred to as "active safe state")
3. SIL mode – SIL measurement mode
4. SIL mode – Passive safe state mode (referred to as "passive safe state")

In Classic mode the system behaves almost like a traditional well-known CM42 system. It is NOT executing any safety related functions and can therefore NOT be used in a safety chain in this mode!

In Active safe state mode the system produces the error current on the current outputs and waits for a manual switch to the SIL measurement mode or the Classic mode.

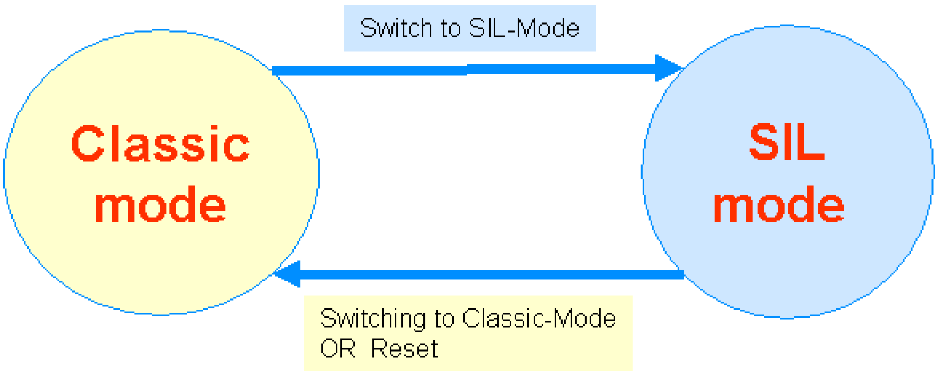
In SIL measurement mode the system is executing the safety function SAF1 or SAF2 (see later on). Only in this mode, the system operates in a safe manner and only in this mode you can start a safe calibration or adjustment (SAF3/SAF4 – see later on).

In Passive safe state mode the system is staying in the safe state until you restart/reset the system physically or return to the safe measurement mode.

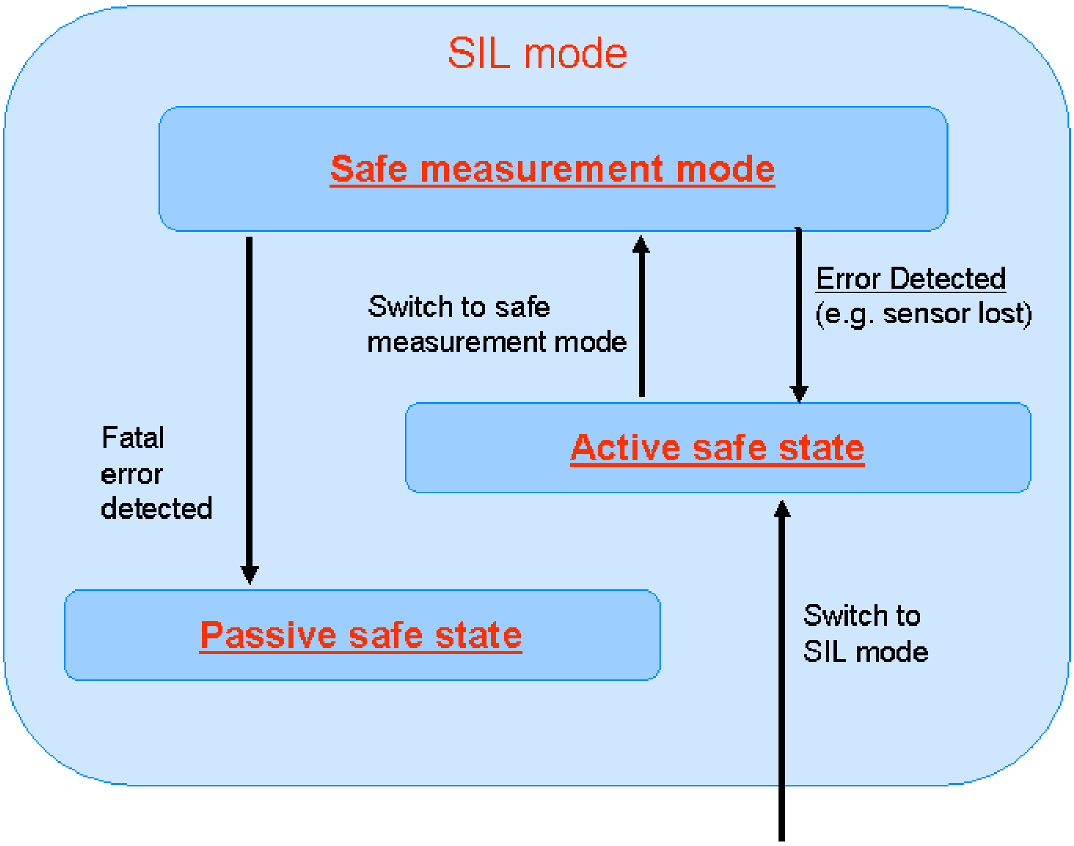
Attention:
The transmitter must be switched to the SIL measurement mode, only then the safety func-

tion is active. Without switching the system to SIL measurement mode, the system is not safe and therefore not executing the safety functions! After a reset/power-on the system is NOT in SIL measurement mode!

The following diagram gives an overview of the two states of the system:



And the following diagram shows the possible states inside the SIL mode.



1.3 Valid device types

The information in this manual pertaining to functional safety applies to the device versions listed below and is valid from the stated software and hardware versions.

Unless otherwise indicated, all subsequent versions can also be used for safety functions. If in doubt, call Endress+Hauser service.

Device versions valid for use in safety-related applications: CM42-MGx41xEBxxxx

Valid Hardware-Versions (electronics) currently:

FMIH1 module:		Version 71131717
	FC2W1:	Ex Rev 07,
	FBIH1:	Ex Rev 05,
FSDG1 module:		Ex Rev 04, Version 71132960

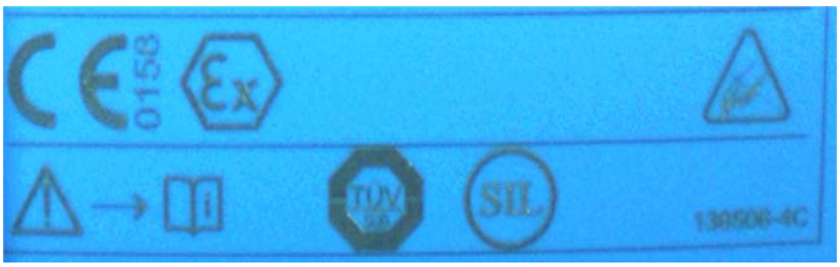
Valid Firmware/Software versions currently:

FMIH1 module:		Projecting: 11.00.00
	FC2W1:	V1.00.01-0001
	FBIH1:	V3.03.08
FSDG1 module:		V1.01.00

All versions can be looked up in the CM42 software menu. Please consult the manual of the CM42 on how to do that. When switching to SIL mode the system itself checks for these versions and denies the switch, if not all versions are correct.

The CM42 SIL transmitter is distinguishable from Non-SIL versions by the nameplate with the TÜV logo and the Endress+Hauser SIL logo and can be identified using the order code.

Order code: Liquiline M CM42-MGx**4**1xEBxxxx (4 refers to SIL)



In the event of device modifications, a modification process compliant with IEC 61508 is applied by Endress+Hauser.

1.4 Applicable device documentation

With Liquiline M CM42 additional documentation is delivered. Please see the TI and the Operating Instructions of Liquiline M CM42.

Documentation	**Contents**
Technical Information TI381CEN 1310 TI381CDE 1310 and future editions	- Technical data - Details to accessories
Operating Instructions (Depends on the order code of CM42)	- Identification - Installation - Cabling - Usage - Commissioning - etc.
Ex Information XA381CA3 1008 and future editions	- Safety instructions - Technical Data - Electrical Data

2 Description of safety requirements and boundary conditions

2.1 Safety Functions (SAF) – SIL measuring mode

The safe output values on the two current outputs are always produced conforming to NAMUR NE43.

0,0 mA	**No power, safe state for minimum 4 s**
0,0 mA - 3,6 mA	**Safe state: „lower error current“ for minimum 4 s**
3,6 mA - 3,8 mA	Interpretation as a valid measured value (4mA), is not allowed to be put out directly (see Namur NE43).
3,8 mA - 4,0 mA	Interpretation as a valid measured value (4mA), is not allowed to be put out directly (this is the failure interval of the current out – Range Overshoot Detection).
4,0 mA - 20,0 mA	**Valid value (measurement information)**
20,0 mA - 20,5 mA	Interpretation as a valid measured value (20mA), is not allowed to be put out directly failure interval of the current out – Range Overshoot Detection).
20,5 mA - 21,0 mA	Interpretation as a valid measured value (20mA), is not allowed to be put out directly (see Namur NE43).
>21,0 mA	**Safe state: „upper error current“ for minimum 4 s**

The device has a few safety functions (SAFs).

Attention: All safety functions do not take into account any physical or chemical influences of the medium in contact with the sensor on the measured value. This has to be done by the operator of the safety relevant measurement point. So we are here never talking about accuracy, but always about precision!

To use the safety functions, the device has to be switched to the safe "SIL mode" and "SIL measurement mode" using the display and the keys/navigator. After switching to SIL mode the device is able to execute safety functions.

Note!

If not otherwise stated, all comments/remarks/restrictions/etc. of this document refer to safety functions SAF1 and SAF2. SAF3 and SAF4 are special safety functions, which are not executed constantly like SAF1 or SAF2.

Note!

In SIL measuring mode the following formulas are used:

The pH value is computed for a measured voltage U at temperature Tk by using:

$$pH = -(U / S_{Tk}) + pH_{NP}$$

S_{Tk} = slope at temperature Tk, zero-point pH_{NP}: both from pH adjustment.

The pH value is always automatically temperature compensated (ATC) using the formulas from chapter 4.7.1.

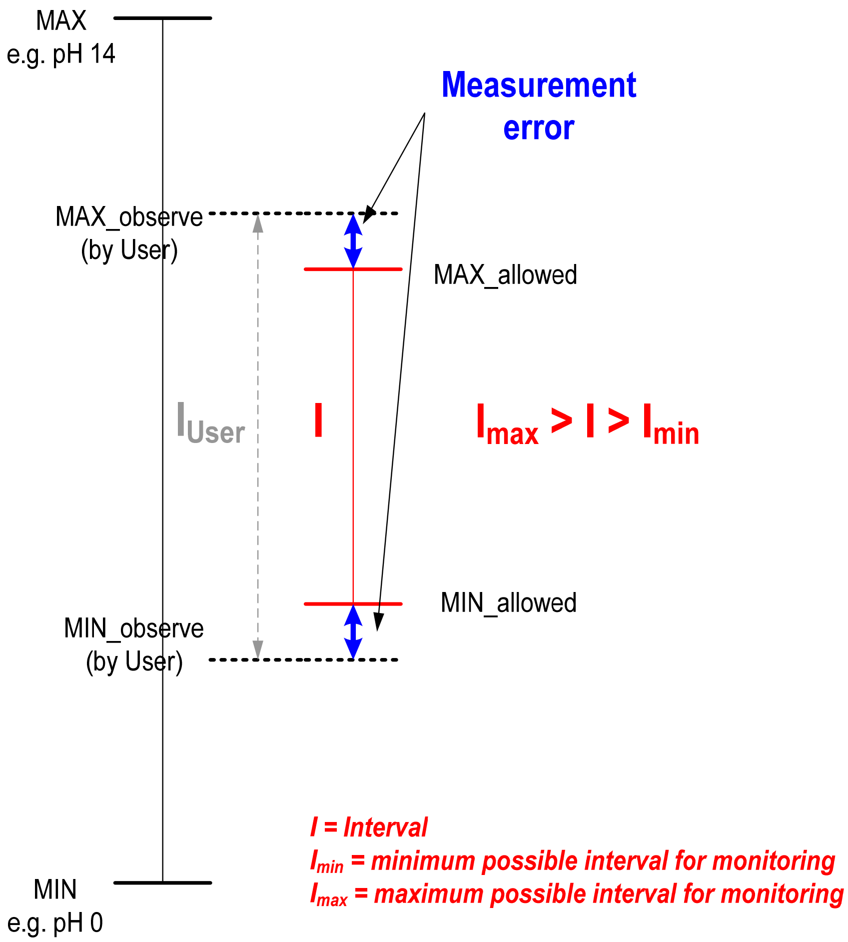
The system does only allow slopes between 50.0 and 61.0 and zero points between 6.0 and 8.0. All other values will not be accepted. Sensors with slope or zero point outside these ranges can not be used.

2.1.1 Safety Function 1 (SAF1) – limit value monitoring

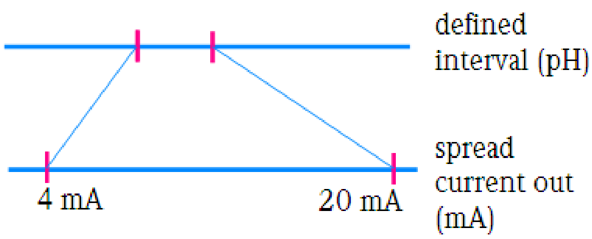
Monitoring of the measured value (internally converted from voltage to pH value):
If leaving a user-defined pH-interval I = [M min, M max], an error current is set.

Instead of an interval it is also possible to define an upper or a lower limit only. Then the other limit is equal to the minimum (4.0 mA) or maximum (20.0 mA) possible measured value.

The value of I_{min} in the figure below is 0.0 pH, the value of I_{max} is 14.0 pH (0.0 pH up to 14.0 pH).



The defined interval I of the monitored measured value is transferred automatically in an optimum way (with respect to resolution) to the current outs using a lower limit of 4 mA and an upper limit of 20 mA (see picture below).



The precision is therefore dependant on the spread configuration of the current outputs.

2.1.2 Safety Function 2 (SAF2) – safe measurement

The safety function of the measuring chain is the output of the pH value on the current output. To that end the mV and T value is received from the sensor with a given precision and resolution, the pH value is computed and finally converted to a mA value, which is then put out to the current output.

All errors (rounding, computations, conversion from pH to mA, etc.) caused by the Liquiline M CM42 transmitter can be completely neglected compared to the errors on the current output and the sensor.

The mV value from e.g. the Orbisint CPS11D sensor (communicated by the Memosens protocol to the transmitter) has a resolution of ±0.1mV, the temperature ±0.01K, the pH value ±0.01pH, the slope ±0.001pH/mV and the zero point ±0.001pH. The precision of all values is given in the safety manual of the sensor head.

2.1.3 Precision and Timing of SAF1 and SAF2

For all information or results given here, we assume slope and zero point of the sensor are correct.

The error of the Liquiline M CM42 transmitter on the current output caused by the hardware is **below ±0.05 mA** for the complete range from 4-20 mA and for all possible allowed EMC/environment conditions. See the table in chapter 2.2 for the dependency of current output spread and the precision.

If we assume that the slope, the zero point and temperature offset (= all sensor adjustment values) have no errors, we get:

Error limit for zero point is ±0.001 pH
(= resolution of storage in sensor),

Error limit for the slope at 25°C/77°F is ±0.001 pH/mV
(= resolution of storage in sensor),

Error limit for voltage value U from sensor is denoted as DU
(= resolution storage is ±0.1 mV),

Error limit for temperature value T from sensor is denoted as DT
(= resolution storage is ±0.01 K).

All errors due to the finite resolution of the values can always be neglected; they are well below the measurement errors. Additionally, as stated already, all rounding errors of the software can be neglected too; they are far below the measurement errors.

So the relative error limit of the calculated pH value D_{pH} is just given by the temperature measurement and the voltage measurement relative errors of the sensor:

$$D_{pH} / pH = DU / U + DT / T.$$

For Orbisint CPS11D (with KSG2-SIL head), the values are for example:

$D_{pH}/pH = 1.1\% + 0.3\% = 1.4\%$

(for the temperature range 0°C/32°F to 60°C/140°F, see safety manual of sensor).

That means DpH is 0.2 pH for the temperature range 0°C/32°F to 60°C/140°F.

The complete detailed results are given in the next table about the complete measuring chain.

The time for a measurement to be visible on the current output is in the worst case scenario **5 seconds** (for example a change from 4 mA to 20 mA and communication problems, etc.).

This value is only valid for the transmitter. They do not include delays caused by the cable (almost zero for Memosens cable) or sensor (about 1 second see safety manual of the sensor head).

Endress+Hauser pH measuring chain

If you are using a Endress+Hauser pH measuring chain using the SIL Memosens CYK10 cable and the pH glass sensor (with KSG2-SIL head), the following figures apply to the whole pH measuring chain:

The **time** for a measurement to be visible on the current output is in the worst case scenario **<6 seconds, most of the time it is <2 seconds.**

The **precision** depends on the temperature and the current output spreading (for the values 0.3% and 4.0% used here, see the table and description in chapter 2.2):

Temperature (°C)	Temperature (°F)	Precision in pH (= DpH)	Relative error on current output at a spread of 1 pH	Relative error on current output at a spread of 14 pH
-20°C – 0°C	-4°F – 32°F	±0.30	30% + 4% =34%	2.2%+0.3% = 2.5%
0°C – 60°C	32°F – 140°F	±0.20	20% + 4% =24%	1.5%+0.3% = 1.8%
60°C – 90°C	140°F – 194°F	±0.30	30% + 4% =34%	2.2%+0.3% = 2.5%
90°C – 110°C	194°F – 230°F	±0.40	40% + 4% =44%	2.9%+0.3% = 3.2%
110°C – 125°C	230°F – 257°F	±0.45	45% + 4% =49%	3.3%+0.3% = 3.6%

This table includes all uncertainties (including EMI) except the precision of the slope, zero point and temperature offset.

2.1.4 Safe calibration and adjustment (SAF3 and SAF4)

The safe calibration executes a safe calibration sequence, safe value computations and safe interactions with the user for the calibration results using the display of the device.

The errors of all computations in the transmitter used for the slope and zero point of the sensor are negligible, because they are well below the resolution used to store the values in the sensor (slope ±0.001pH/mV and zero point ±0.001pH). This also refers to the pH values needed for the used pH buffers at the given temperature.

The safe adjustment does store the results of the calibration in a safe manner into the sensor interacting in a safe way with the user.

The safely calibrated and adjusted values in the sensor can then be used for the SIL measurement of the pH value using SAF1 and/or SAF2.

Both safety functions can only be used in SIL mode and started in SIL measurement mode. Both safety functions need the user to do some checks. To that end special screens are used to communicate with the user in a safe way (see for example chapter 4.4).

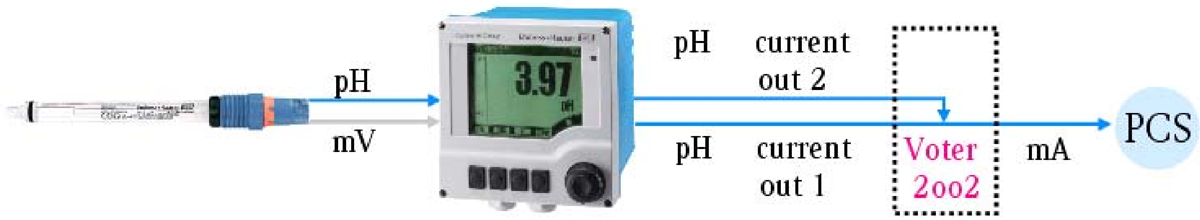
2.2 Safety-related signal and safe state

The safety-related signal is the analogue output (4..20 mA) on **both** current outputs. There are no other safe outputs of the device.

The safe state is defined as either:

- No current output at all (0 mA) or
- Low error current (3.6 mA) on one of the outputs or
- High error current (>21.0 mA) on one of the outputs.

The safe signals have to be processed by a connected logical component PCS.



Why a 2oo2 voter?

The pH value is calculated in two ways:

1. traditional calculation of the mV value to pH in the transmitter.

2. independently from this and in parallel to it the pH is calculated directly in the intelligent sensor head. This value is delivered to current output 2.
So from the sensor head to the voter it is a 2oo2 system. But as the source of the two values is the same sensor glass element, the whole measuring is defined as 1oo1 in total (see also graphic in chapter 1.1).

The voter can be a standalone voter realized in hardware and/or software or a software voter integrated into a control system like a PLC.

Anyway the signal has to be voted by a 2oo2 voter using the following algorithm:

- If any of the current outs shows a HI or LO error current, an error current has to be set.
- If any current out delivers a signal below 3.6mA (e.g. 0 mA), an error current has to be set.
- If the both current outputs **differ by more than ±0.04 pH from each other for longer than 1 second,** an error current has to be set.

The allowed current output difference is then dependant on the current output spreading used.

E.g. for a given spread interval of 1pH we get an allowed difference of
0.04 pH×16 mA/pH = 0.64 mA (= 4.0% of full span),
for an interval of 14 pH the allowed difference is
0.04 pH×1.143 mA/pH=0.04572 mA (≈ 0.3% of full span; you have to use 0.05 because of the given physical resolution of the current outputs).

The pH-difference mentioned only refers to the inaccuracy of both ways to calculate the pH value (calculation in the transmitter and independently from this in the sensor head) up to the current outputs of the device.

<u>This means that the individual cable length and is quality (2-wire) is NOT included. This influence is to be added to +/- 0,04 pH as an additional source of inaccuracy.</u>

The table below shows values for different spreading.

Spread [pH]	1.0	2.0	3.0	4.0	5.0	6.0	7.0
Allowed difference [mA]	0.64 = 4 %	0.32	0.21	0.16	0.13	0.11	0.09
Spread [pH]	8.0	9.0	10.0	11.0	12.0	13.0	14.0
Allowed difference [mA]	0.08	0.07	0.06	0.06	0.05	0.05	0.05 ≈0.3 %

The device is leaving the safe state when being restarted. After the device has booted correctly and has detected a sensor, all start up self tests have been successfully executed. The device is not automatically entering the safe SIL mode after a reboot (e.g. after a power breakdown), even if it has been correctly working in SIL mode before the reset has taken place.

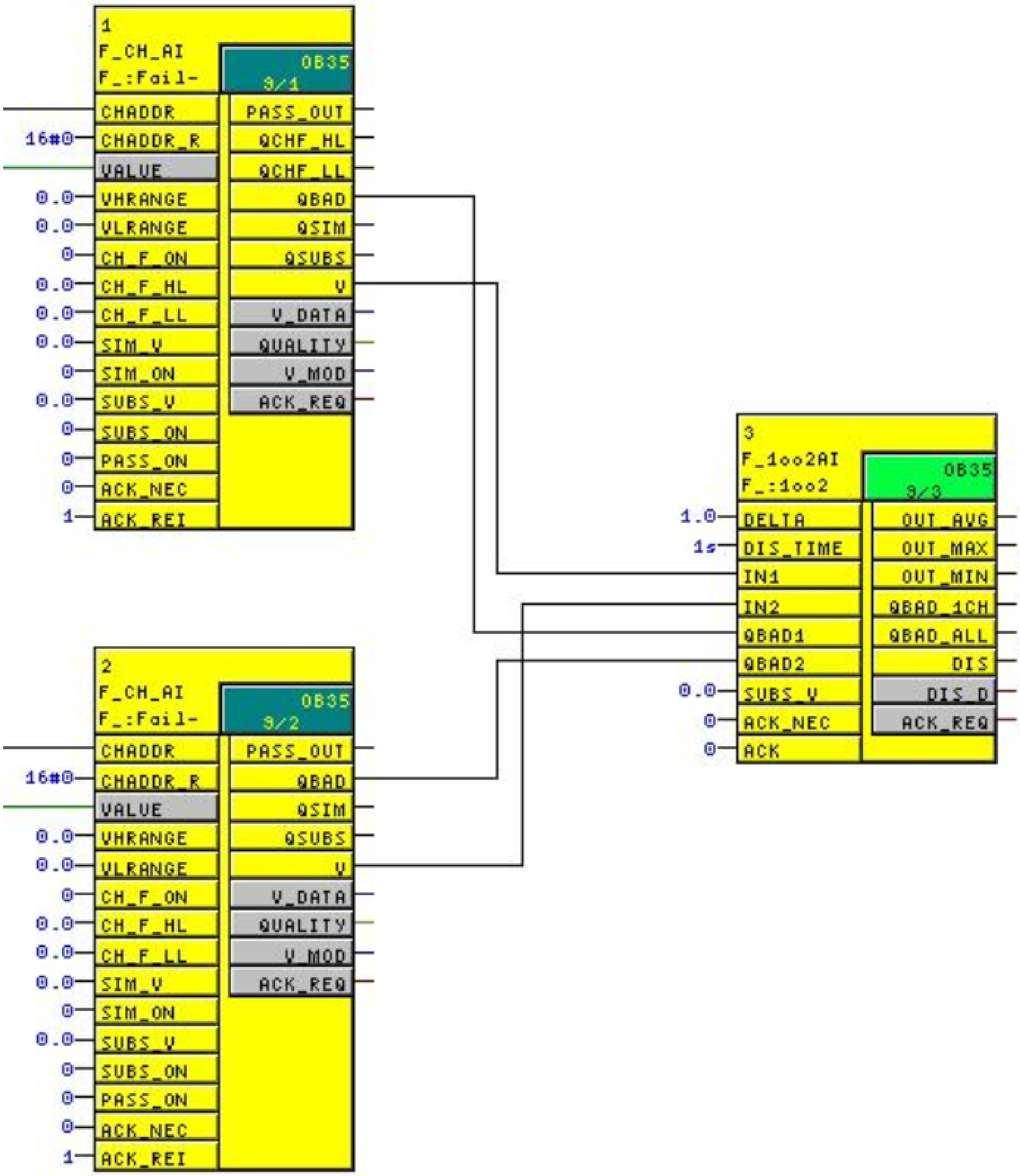
Note!

After the safe state has been detected by the logic component of the PCS, the CM42 has to be manually switched to the safe SIL mode back again. This is necessary, because the logic component does not know, if the transmitter has been "repaired" after the safe state has been reached at the logic component. The logic component just detects a measuring value after the error current has been seen for at least 4 seconds.

Example for a voter realized in a PCS as a function block

This is the safe function block F_1oo2AI of a Siemens PLC:

This function block checks for valid inputs, compares the two inputs against a configured delta tolerance and checks for a discrepancy time. See the manuals of the used PCS for more information. The allowed deviation is set to "DELTA" = 1mA and "DIS_TIME" = 1 second.



2.3 Restrictions for the use in safety related applications

The given environmental conditions have to be obeyed at all times. All remarks in the CM42 Operating Manual and Installation Instructions (see chapter 1.4) have to be obeyed.

Additional mandatory restrictions for the use in safety related applications:

- Installation, commissioning, operation and maintenance of the safety measuring system must only be carried out by trained technical personnel. The technical personnel must be authorized to perform the tasks at the safety relevant system by the owner-operator.
- Use of the device at a maximum average environment temperature of 60°C/140°F (the calculation of the failure rates have been based on this assumption). Please attend to the temperature limitation for Ex devices!
- It has to be checked, that at all times a SIL capable cable is used (e.g. CYK10 SIL - look for the nameplate with the SIL- and TÜV logo). This can not be checked by the transmitter or the sensor in operation.
- Before going into operation, it has to be checked, if metal masses are close to the transmitter or the sensor head, which can influence the inductive transmission of the cable and the transmitter.
- It is not allowed to use the system in a radioactive environment (apart from natural radioactivity).
- Strong magnetic fields are not allowed in the neighborhood of the device.
- The device must be protected against lightning or strong electromagnetic disturbances.
- The connections of the cable to the transmitter and the sensor have to be checked thoroughly before going into operational state.
- The connection of the Memosens cable to the transmitter has to be carefully checked, see CM42 installation instructions.
- The environmental conditions from IEC 61326-3-2 have to be obeyed.
- The voter and its configuration have to be checked for, before going into operation. A 2oo2 voter must be used.
- A shield connector at the transmitter must be used. You have to use two-wire cabling shielded on both sides, "hard grounding".
- Functional grounding must be used for the stainless steel housing.
- Please check the polarity of the connections carefully.
- The display is NOT safe, even not in SIL mode.
- If used outside, the weather protection must be used.

  Reason: At temperature > 55°C/131°F a measurement with a reliability required for SIL applications can no longer be guaranteed. A weather protection roof enables using the CM42 SIL in many regions also under insolation.

- The environmental pressure has to be checked against the values given in the Operating Instructions. Do not use outside the allowed ranges.
- If using a different sensor as the Endress+Hauser ones like the CPS11D-8* (SIL sensor), the manufacturer has to make sure, that the sensor uses the exact same calculations of the pH-value as the Endress+Hauser one. If not, the two current outputs might differ systematically and your voter will detect the difference and enter the safe state. To be sure, check with Endress + Hauser, if the sensor is to be used safely with the Liquiline M CM42 transmitter.
- The used sensor must not be older than 3 years, starting from the day of production. This is checked by the transmitter Liquiline M CM42. Reason: The quality of the measured value of an older sensor does not meet the high requirements of a safety related measuring point. As long as the SIL mode is not left after the 3 years, the measurement is running.
- Storage temperature: see operating instructions.
- Environmental temperature: ATEX II (1) 2G: -20 °C/-4° F to 50 °C/122 °F (T6) or rather to 55°/131°F (T4)
- The LED on the display is never used to display any relevant state of the system. It is not part of the safe path and therefore deactivated.
- DAT modules are for safety reasons not allowed to be connected to the ports of the display when in SIL mode and must be removed. This will be checked by the software of the transmitter.
- The service interface is turned off in SIL mode for safety reasons and switched back on, when leaving SIL mode. It can be used for service personnel of Endress + Hauser to diagnose the system. It is not meant to be used in other circumstances.
  Therefore Memobase cannot be used with safe calibrations/adjustments. But you can still do non safe calibrations in Classic mode using Memobase and use these sensors for SIL measurements.
- For safe calibrations/adjustments in the laboratory a SIL transmitter, e.g. Liquiline M CM42 SIL, is necessary. After a successful adjustment the data can be read out by Memobase Plus CYZ71D and stored in the database.
- To store the settings (all parameters) of the used transmitter, you can use a Copy-DAT CY42-C1 (see operating instructions).
- The system needs 15,5V to output all error currents (LO and HI) and all measurement values. Below 9V the system can not guarantee that there is an error current on the outputs. Between 9V and 15,5V the system is always able to output the HI error current, but not the LO error current.

Voltage supervision:

(The following statements can be used for a FMEDA of the complete safety function including the PLC, etc.)

- If you are using the LO error current, you must use a voltage supervision on both outputs and drive the system to a safe state, if the voltage drops below 15,5V.
- Scope of a voltage supervision: permanent check of the supply voltage, delivered by the PCS. It must be > 15,5 V, otherwise an alarm is set.
- If you are using the HI error current, you must use voltage supervision on current output 2 and drive the system to a safe state, if the voltage drops below 9V. The current output 1 is supervised by the Liquiline M CM42 system and is reset if the voltage on output 1 drops below 9V.
- We **recommend using two independent voltage supplies** for the two current loops. Then all errors lead to a safe state, except if the voltage supply on current output 2 has an error and there is an error current on current output 2 or a measurement signal (4-20 mA) on both outputs. For these two cases, the voter detects the error with a DC of 90%.
- If you are using just one voltage supply for both current outputs, the following applies: If the voltage supply has an error, the voter detects all voltage errors with a DC of 60%.

The following table gives an overview of the device status in SIL mode:

Device status	Status bar of CM42	Current output 1	Current output 2	Control room	SIL mode
Safe Measurement	SIL OK	pH-value	see current output 1 due to SIL mode on	Measured value OR voter detects error!	on
Safe Calibration/ Adjustment	SIL OK	pH-value	see current output 1 due to SIL mode on	Measured value NO Hold available in SIL mode! (for safety reasons)	on
Change of settings in SIL-mode	SIL	SETUP – any menu item for safety reasons settings are visible, but not editable in SIL mode			on
Simulation	SIL	DIAG – Service – Simulation for safety reasons not available in SIL mode			on
Sensor change (menu item not visible in SIL mode) Please just disconnect the sensor for change	SIL	Error current	see current output 1 due to SIL mode on	Error current: NO Hold available in SIL mode! (for safety reasons)	on
Switch to SIL-mode OR Calib/adj. finished OR error detected	SIL	Error current	see current output 1 due to SIL mode on	Error current: You can switch back to safe measurement by starting the switch sequence (SETUP – Functional safety – SIL meas mode…).	on

Functional safety parameters

Specific functional safety parameters for single-channel device operation:

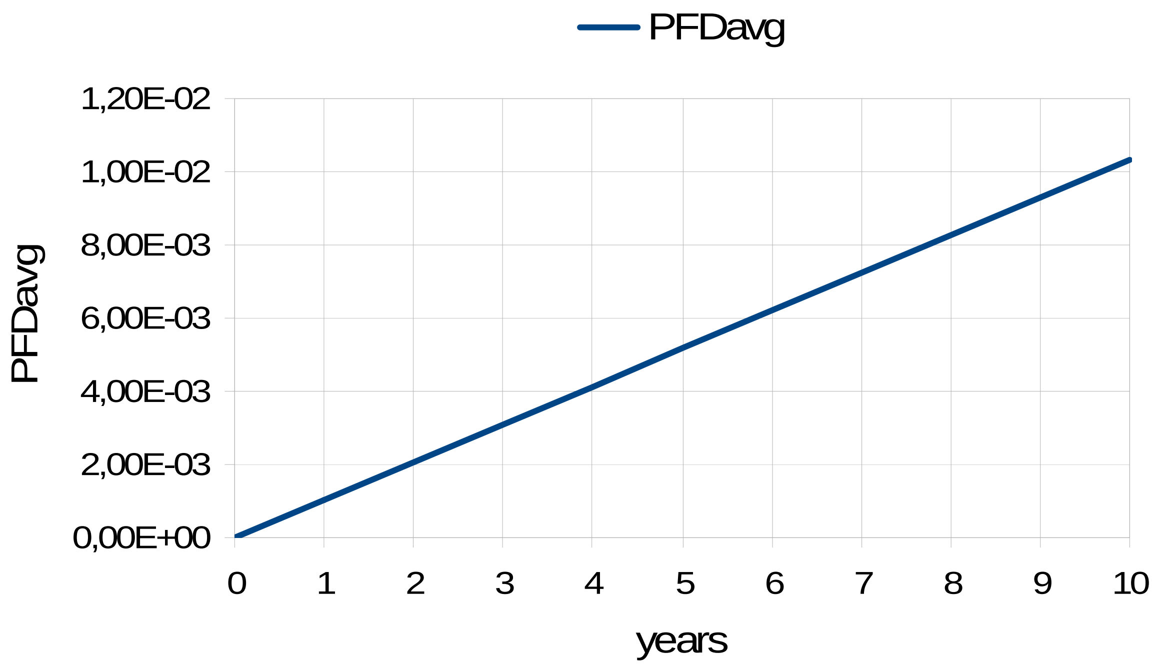
Parameters according to IEC 61508	Liquiline M CM42, Memosens
Safety function	1: pH limit monitoring 2: pH value measurement 3 and 4: safe calibration / adjustment
SIL	Hardware: 2, Software: 3 in homogenous redundancy: 3
HFT	0
Device type	B
Mode of operation	Low demand mode
SFF	94.8 %
MTTR (used for PFD calculation)	8 h
T_1 (Proof test interval)	Recommended 1 year (see chart below)
λ_{SD}	688 FIT
λ_{SU}	947 FIT
λ_{DD}	2667 FIT
λ_{DU}	236 FIT
λ_{Total} *1	4549 FIT
PFD_{avg} (for T_1 = 1 year) *4	1.03×10^{-3}
PFH	2.36×10^{-7}
MTBF / $MTBF_{DU}$ *1	25 years / 483 years
Diagnostic test interval *2	< 60 min (without RAM-test: <10 min)
Error reaction time *3	< 1 second
DC_D (Diagnostic coverage dangerous)	92 %

*1 According to Siemens SN29500 at 60°C/140°F. MTBF calculated as reciprocal of PFH/ λ_{Total} , assuming constant failure rate.

*2 During this time all diagnostic functions are completed at least once.

*3 Time between failure detection and failure reaction (here this is the error current).

*4 Of course you can choose different (e.g. longer) proof test intervals. Choose the one suited for your application by using the chart given below.



Proof test interval depending on PFD_{avg} for the 1oo1D structure.

Years = "examples of proof test intervals"

Note!

These values do NOT include the PFD_{avg}/SFF values of the used voter and for external power supplies or external voltage supervisions.

Note!

For the calculation of the PFD_{avg} a Markov model for a 1oo1D system was used.

Dangerous undetected failures in this scenario:

A dangerous undetected failure λ_{DU} is defined as a wrong measurement signal on the current outputs in the range of 4..20 mA, whereas a wrong measurement value is a value departing for more than the given precision (see chapter 2.1.3) from the true measurement value.

Some dangerous undetected failure can be found by the voter – but not all of them. In these cases, the transmitter does not show an error message or an unusual behaviour.

Useful lifetime of electronic components:

The underlying failure rates apply within the useful lifetime according to IEC 61508-2 Clause 7.4.7.4 Note 3 [IEC61508:2000] or Clause 7.4.9.5 Note 3 [IEC61508:2010]. Other values can be used from experience of the previous use in a similar environment.

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

According to IEC 61508-2 section 7.4.7.4 a useful lifetime based on experience should be assumed.

Note!

Safe operation of the device requires a correct installation according to chapter 2.3.

2.4 Behavior of the device when in operation and in case of failure

2.4.1 Behavior of the device when switched on

When starting the device, loading the software takes about 40-60s. Safety related internal tests are carried out. During that time the current output is held at the **high error current (>21.5 mA)**.

The power to the Memosens cable and Memosens sensor is switched on after the boot phase, not earlier.

2.4.2 Behavior of the device on demand

If an internal error is detected, the device enters the safe state within the error reaction time (see chapter 2.2).

In case the device reaches the active safe state, the SIL measurement mode is left, but the SIL mode is still active. So the SIL icon remains visible in the status bar.

In case of the passive safe state, the system stops completely and displays some information. You have to repower the system to get it running again, but keep in mind that a passive safe state indicates a serious problem with the system.

The display in the passive safe state looks like this:

Please use this information for your potential report to E+H service.

If the RAM- or ROM/Flash-Test detects an error, the system stops working and sets the error currents without any information on the display (passive safe state).

2.4.3 Behavior of the device in the event of alarms and warnings

Error current

The alarm current can be chosen to be **low or high error current**. But most internal errors are signalled by using the high error current.

To that end the logic component has to handle both cases: low and high error currents.

Warnings

For warnings, see the Operating Instructions of the transmitter.

Resets

The system only resets, if the watchdog of the system is activated or the system detects a power failure (or the system is physically reset or powered down).

3 Installation

3.1 Mounting, wiring and commissioning

The mounting, wiring and commissioning of the device is described in the Operating Instructions and TI of the device (see chapter 1.4).

All remarks in chapter 2.3 have to be obeyed.

3.2 Orientation

There are no restrictions to the orientation of the device, except the restrictions in chapter 2.3 and the ones stated in the documentation (see chapter 1.4) and the installation manual.

4 Operation

All screenshots shown in this chapter are done using an English version of the Liquiline M CM42. Depending on your language the screen might differ slightly.

4.1 Basics of safety relevant operations

For all safety relevant operations: The SETUP menu has an additional item called "Functional safety". This has to be used for almost all safety relevant operations.

To enter or leave the SIL mode you need the user management to be switched on and you need an expert password, which is not set to "0000". See the manual of the Liquiline M transmitter on how to do this.

The CM42 SIL software in SIL mode slightly differs from the standard software (Classic mode): For safety reasons the only possible calibration is a 2 point pH calibration, which can be only carried out using E+H buffers pH 7.00 and pH 4.00 (<u>only exactly in this sequence</u>) and using automatic temperature compensation. The only temperature calibration is the one-point calibration.

4.2 Calibrating the measuring point

Calibration of the transmitter is not necessary, but calibration of the used sensor is mandatory. Please see Operating Instructions part 2 of Liquiline M CM42 and chapter 4.7.1.

4.3 Method of device parameterization

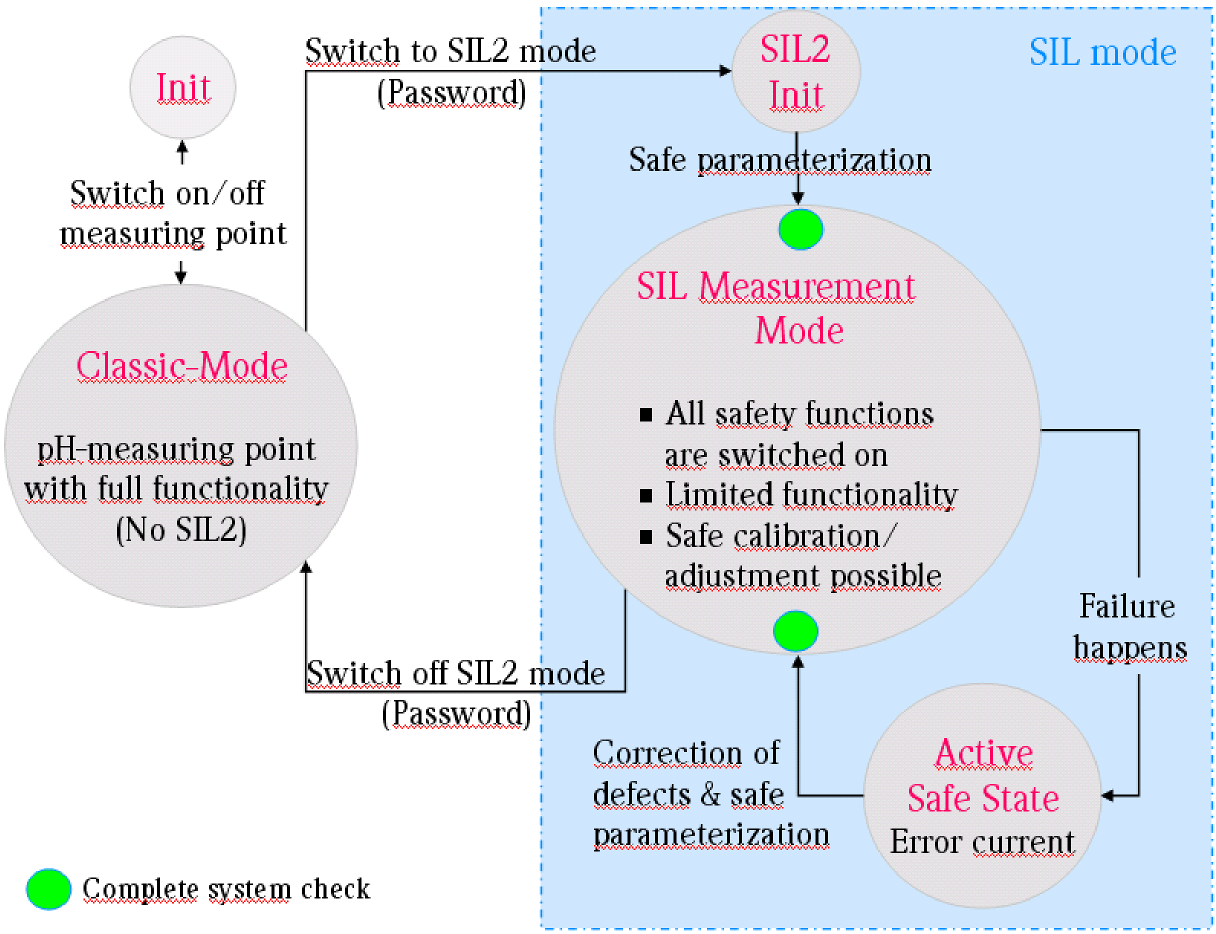
The usual parameterization is described in the standard documentation (see chapter 1.4). Some settings are mandatory for the SIL mode. They are listed up on the next but one page.

4.4 Using the SIL mode and the Classic mode – Switch to SIL mode

The classic mode is the default mode of the device after a reset or power on sequence. It is the non safe mode of the "traditional" Liquiline M CM42. Only in this mode parameter settings can be changed. The SIL mode is the operating mode for the safety functions. Only in SIL mode the system can be regarded as safe.

Switching the mode always asks for the expert password using a special safe screen.

Overview: Classic Mode , SIL Mode and Safe Measurement Mode



Entering SIL mode:
After password confirmation the software leads you to check and confirm the values of the lower and upper current output value in [pH] and the pH alteration rate in [pH/s]. These values are shown three times on random positions to eliminate the influence of possible display errors.

Push the “Yes” soft key for confirmation and the "No" soft key, if there is something wrong with the values. The "Yes" soft key is always randomly placed.

Now the SIL mode is active, and in the status bar the SIL icon is shown:

Now both current outputs show a high error current until you switch into the SIL measurement mode!

Leaving SIL mode:
After selecting this from the Setup - Functional Safety menu just enter the password and you will leave the SIL mode (the SIL icon is gone). Note that the **error current is set on the current outputs for at least 4 seconds**. After that time, the Classic mode is responsible for both current outputs and the **outputs are no longer safe**!

The SIL mode requires for certain settings which have to be set in case the operator changed the default settings. If any for the SIL measurement mode relevant condition is not fulfilled, a pop-up window will indicate this.

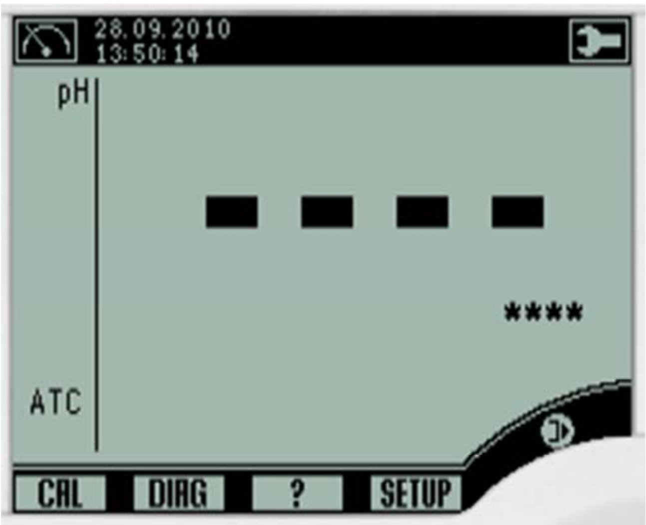
Settings needed to switch to SIL mode:

pH offset	0
MEAS temperature compensation mode	ATC
CAL temperature compensation mode	ATC
CAL buffer recognition	fixed
Buffer manufacturer	E+H
Sensor diagnostics	on
2 point calibration	on
Error 011	F
Error 012	F
Error 377	F
Current output 1	Main value

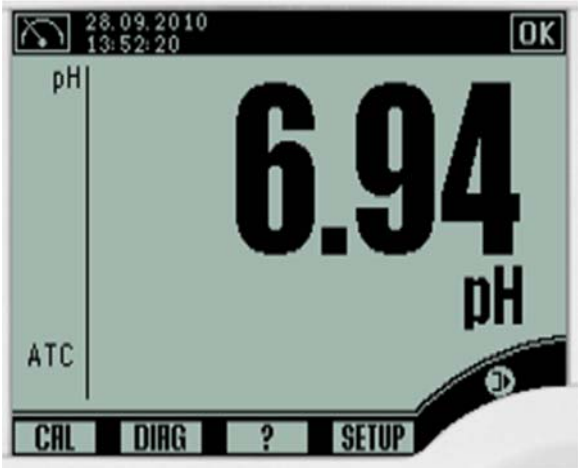
Current output 2	Main value
Error current	21.5 mA
Simu current output 1	off
Simu current output 2	off
CAL hold	off
SETUP hold	off
DIAG hold	off
Logbooks	on
Lab device	off
Correct hardware and software versions	See chapter 1.3
Lower Limit current output 1 and 2	Identical
Upper Limit current output 1 and 2	Identical

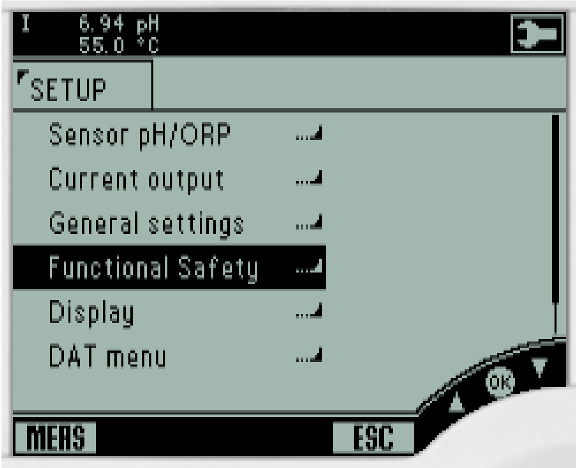
The fastest way to default settings required for SIL mode: Use factory settings (DIAG – Service – Factory default).

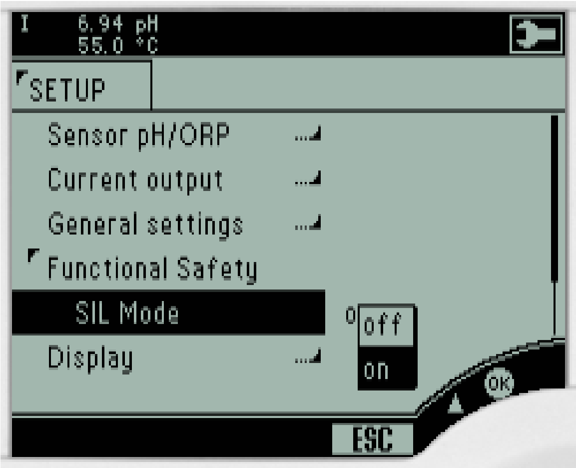
The following screenshots give an impression how it looks like on the display:
First you probably start with no sensor connected:



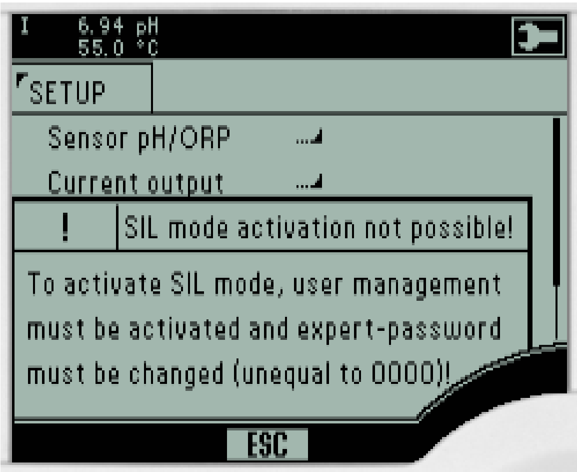
Then after you have connected the sensor and the sensor has been found and the first measurement has been done, you see:



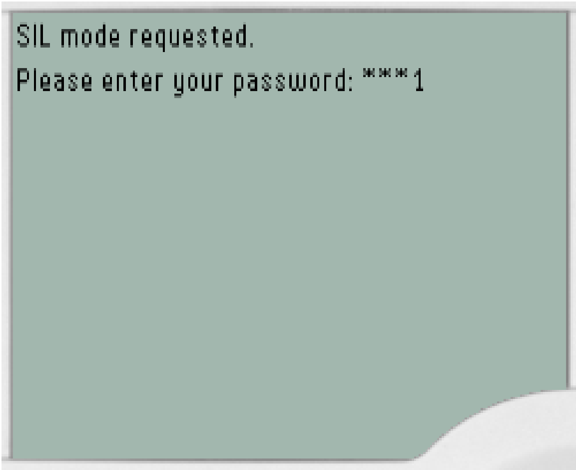


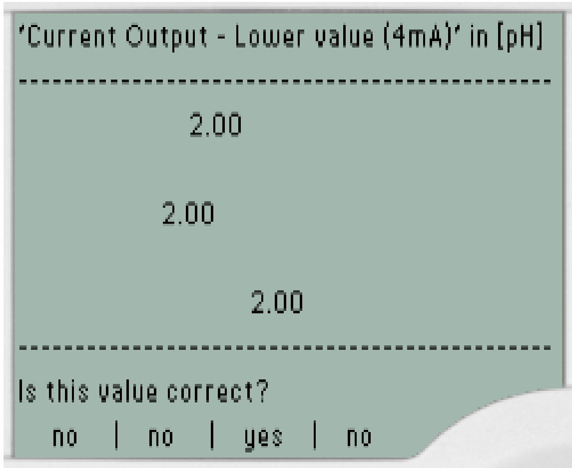


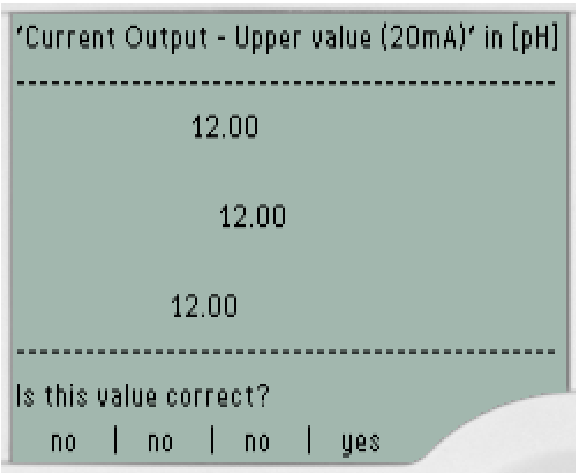
You get this screen, if you have not correctly set up all parameters for SIL mode:

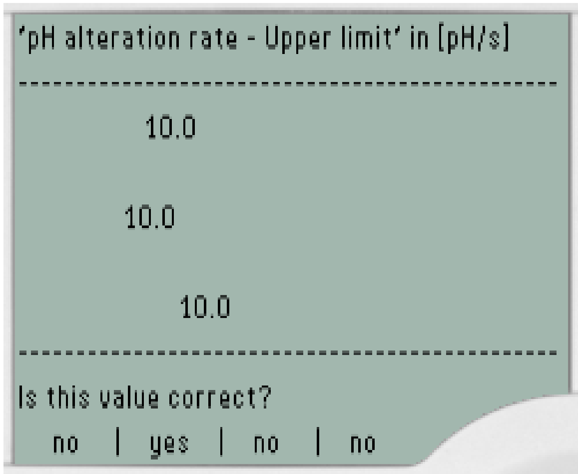


If all parameters are OK, you get the screen to input the expert's password.



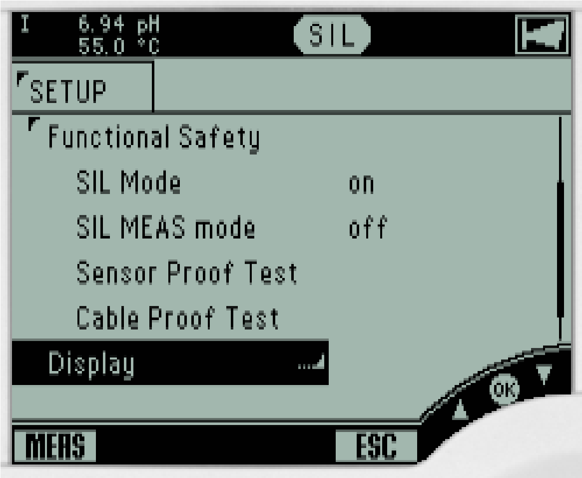






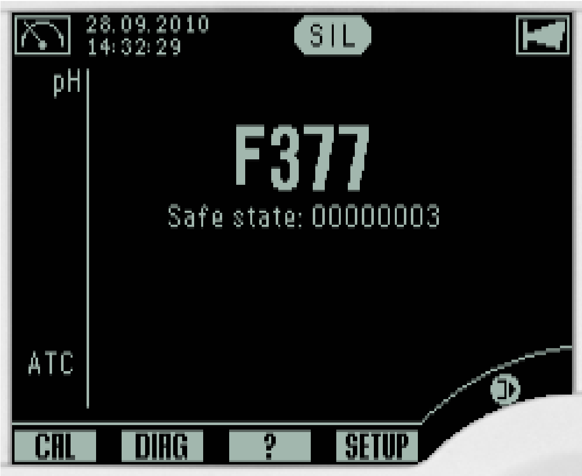
Please choose a pH alteration rate which suits fo your process! (SETUP – Sensor pH/ORP – Sensor diagnosis – Max pH alteration rate)

Now the menu looks like:



4.5 The SIL mode – Active safe state mode

This mode always displays the reason for its activation. It is given as a hexadecimal number and looks like



In this example the reason is 00000003, which means: "user has explicitly deactivated the SIL measurement mode (via safe adjustment)".

Here is the table of reasons for the activation of the active safe state and its meaning: (below each reason, there is short help on what to do if this diagnostic code appears)

Number decimal	Number hexadecimal as displayed on screen	Reason (→ proposed action)
0	00000000	No error. Maybe just switched to SIL mode.
2	00000002	User has explicitly deactivated the SIL measurement mode (via safe calibration)
3	00000003	User has explicitly deactivated the SIL measurement mode (via safe adjustment)
4	00000004	Physical sensor reported internal error. → disconnect and connect sensor, or change sensor
5	00000005	Sensor value ranges check violation. → change sensor
6	00000006	Sensor state error bits set. → change sensor

7	00000007	Sensor and transmitter pH value difference. → try changing sensor
8	00000008	Sensor sends measurement values too fast or often. → change sensor
9	00000009	Sensor sends measurement values too slow or seldom. → change sensor
10	0000000a	Sensor updates measurement values too fast or often. → try changing sensor
11	0000000b	Sensor updates measurement values too slow or seldom. → try changing sensor
12	0000000c	Sensor sequence counter jump detected. → try changing sensor
13	0000000d	pH alteration rate higher than physically possible. → try changing sensor
14	0000000e	pH alteration rate higher than user specified limit. → try changing sensor
15	0000000f	Timing control error: pH value to old. → try changing sensor
16	0000010	pH value exceeds pH limits. → try changing sensor
17	0000011	Current output detected an invalid request. → contact E+H service.
18	0000012	Responses to current output module came too slow/seldom. → contact E+H service.
19	0000013	SIL measurement mode aborted because classic error active (if user has configured some). → see DIAG information for further steps
20	0000014	DAT module detected in SIL mode. → remove DAT module from system

4.6 Switch to SIL measurement mode

After entering SIL mode, in the Functional Safety menu the "SIL measurement mode switch" appeared directly below the “SIL mode switch”. A SIL sensor has to be connected to do this switch.

Please switch on the SIL measurement mode and **check and confirm the values of the sensor’s latest calibration** (zero point, slope and sensor temperature adjustment). It is necessary to **document these values during calibration/adjustment and compare them with the values given here**. The software itself does not have the possibility to check the "correctness".

Now the SIL measurement mode is finally started. The measured value is (safely) delivered to the PCS and all safety diagnostics are running permanently in the background.

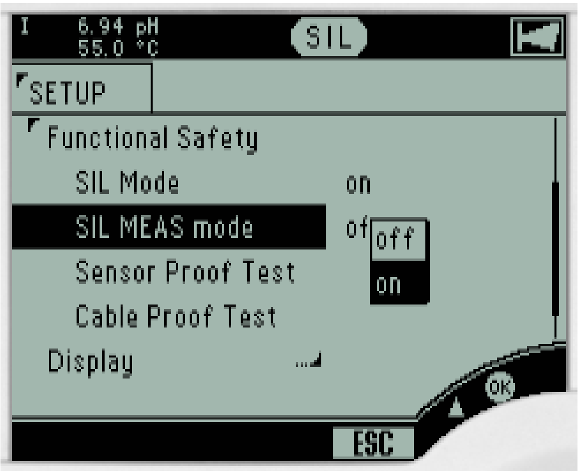
If an error is detected (e.g. sensor disconnected) the system leaves the SIL measuring mode and enters the "SIL mode – active safe state". The reason for the active safe state is given in the display as a hexadecimal number (see 4.5).

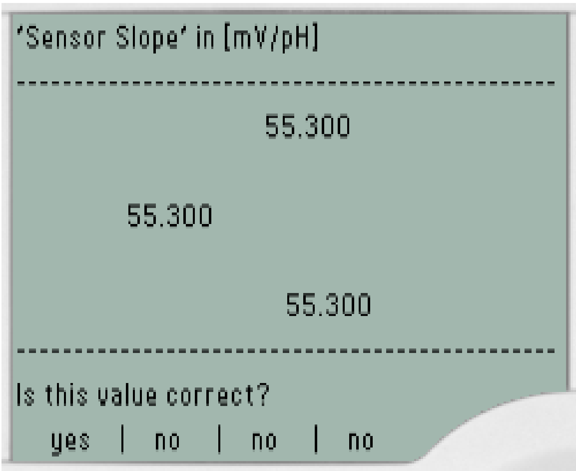
The SIL measurement mode requires for certain settings which have to be set in case the operator changed the default settings. If any for the SIL measurement mode relevant condition is not fulfilled, a pop-up window will indicate this.

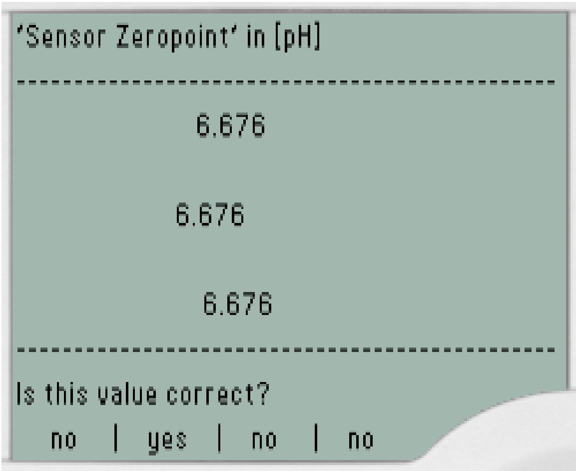
The conditions are the same as switching to SIL mode, but this time it is mandatory to have a sensor connected.

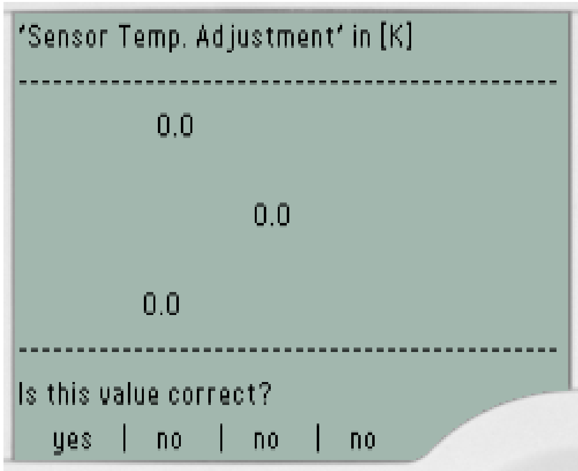
The fastest way to default settings required for SIL measuring mode: Use factory settings.

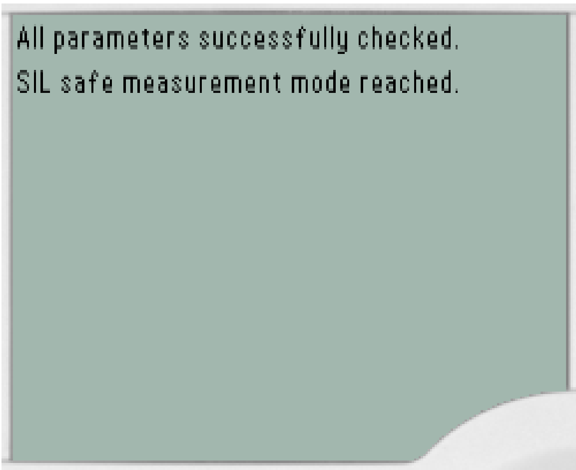
The following screenshots give an impression how it looks like on the display:



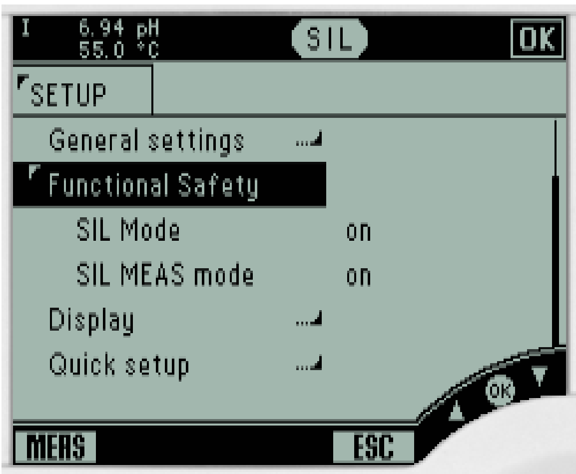




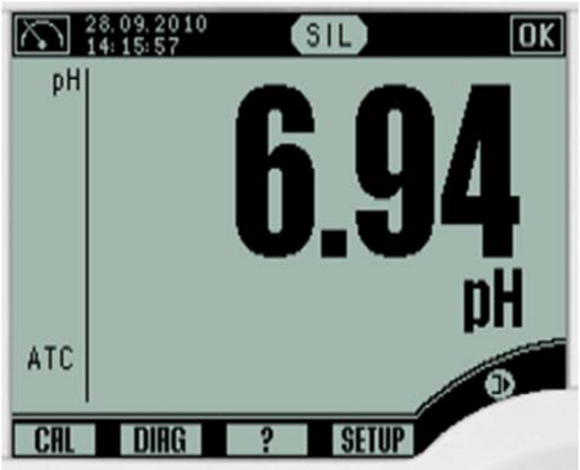




Now the Functional Safety menu looks like:



The measurement screen will now look like:



4.7 Using the safe sensor calibration and adjustment

Important remark!

You can also do the calibration in Classic mode (unsafe calibration/adjustment), this is not checked for when using a SIL sensor. It is up to the user to check, if a correct "safe" calibration is used. This can be looked up under DIAG – Logbooks – Calibration logbook

4.7.1 2-point pH calibration

The two point calibration uses the following formulas to compute the slope and the zero point of the sensor in the transmitter (the transmitter transforms the given equations internally to reduce computational errors):

Use two buffers (only E+H buffers with pH 7.00 and pH 4.00 and in this sequence are allowed), measure the two voltages U_1 and U_2 with their pH-values pH 1 and pH 2. Then we have:

Slope from the two measured values: $S_{Tk} = (U_1 - U_2) / (pH1 - pH2)$

Automatic temperature compensation (ATC) is done by using an adapted slope:

$$S'_{25°C} = S_{Tk} * ((273.15 + 25°C) / (273.15 + Tk\ [°C]))$$

Zero-Point (x=2 is used): $pH_{NP} = -(U_x / S_{Tk}) + pH_x$

U_x = voltage measured at electrode

S_{Tk} = slope at temperature Tk, $S'_{25°C}$ = slope at 25°C/77°F

pH_x = pH-value of the buffer solutions (x is 1 or 2) – the pH-values are taken from the E+H buffer tables with regard to the temperature of the buffers (T1 or T2)

T1: temperature of pH-buffer 1, T2: temperature of pH-buffer 2

Tk = (T1+T2)/2, mean temperature of calibration

$S'_{25°C}$ and pH_{NP} will be stored in the sensor, if the safe adjustment is used.

For the formulas of the pH calculation see chapter 2.1.

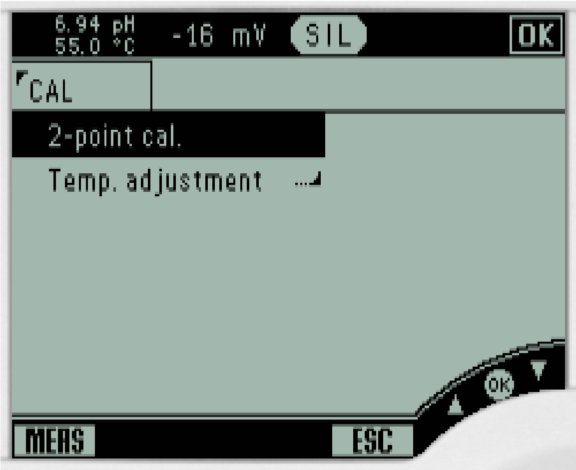
To start the calibration/adjustment use the menu "2-point calibration" from the CAL menu. Then follow the instructions given on the display. The sequence is the same as for the traditional unsafe calibration/adjustment in classic mode. Except that there are some safe screens in between.

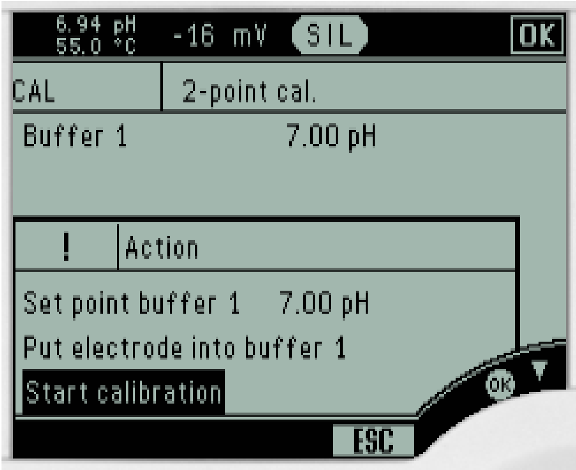
During the 2 point calibration in SIL mode the current outputs show the measured values of the calibration. Only after the calibration is finished or cancelled the error current is set on both current outputs, because you have entered the active safe state.

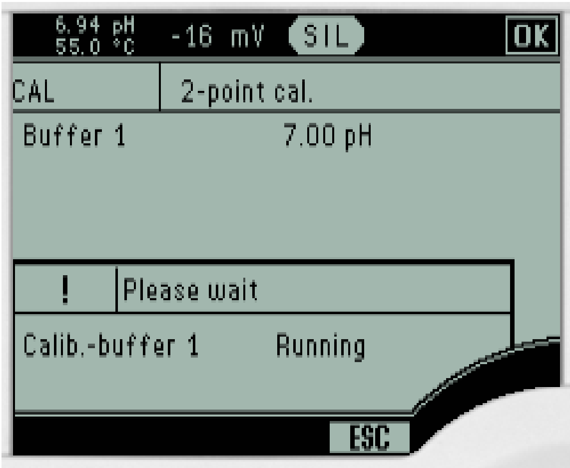
Important!

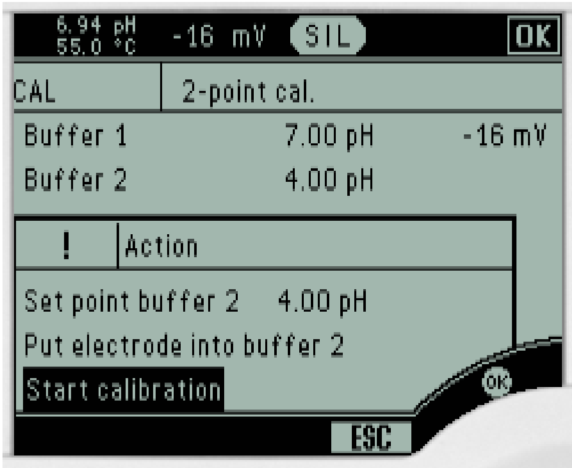
Use only the "safe screens" to document or check values. Safe screens are characterized by small, very basic font, the black status bar is not shown. Example: screen “SIL measurement mode reached”. All other screens are not safe and are just for controlling the sequence of the calibration/adjustment.
If any of the given screenshots here are not displayed or the sequence is not the same as given here, you have to stop the calibration/adjustment and start over again. If the "error" persists, you have to change the transmitter or the two modules and contact the E+H service.

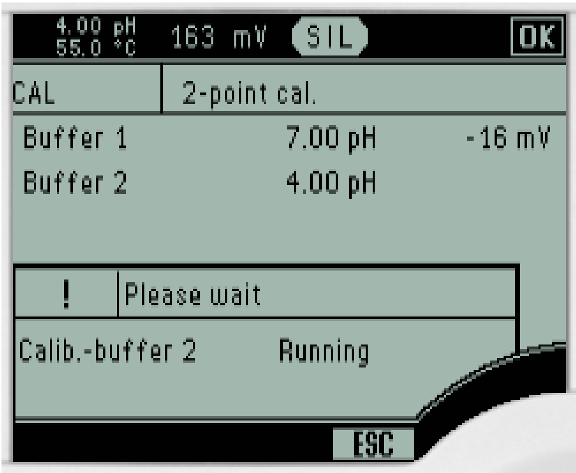
See the following screenshots for the sequence of screens:

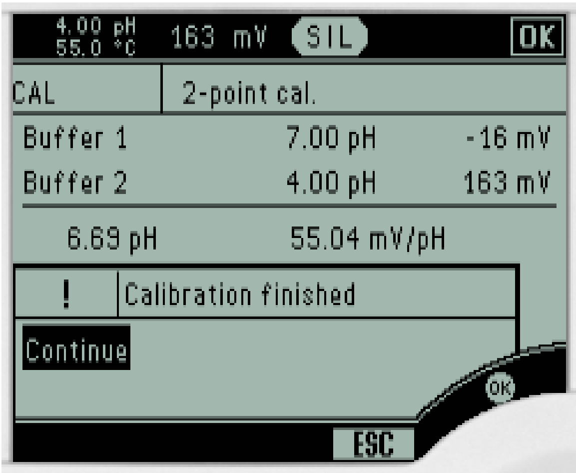




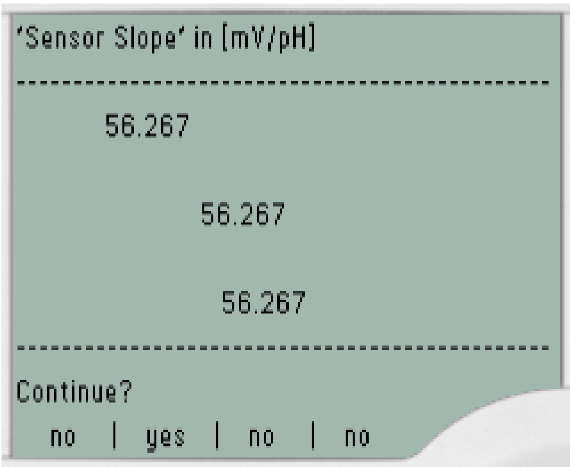


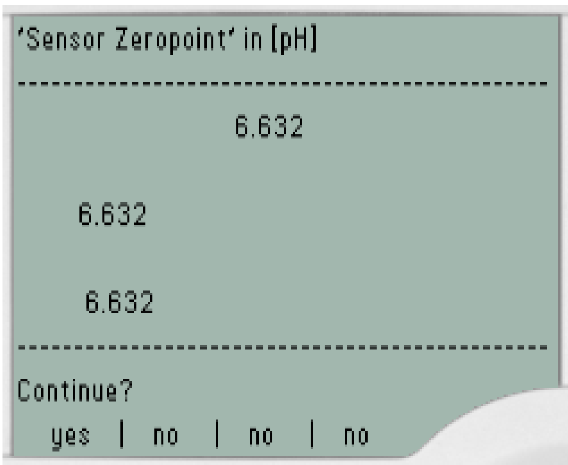




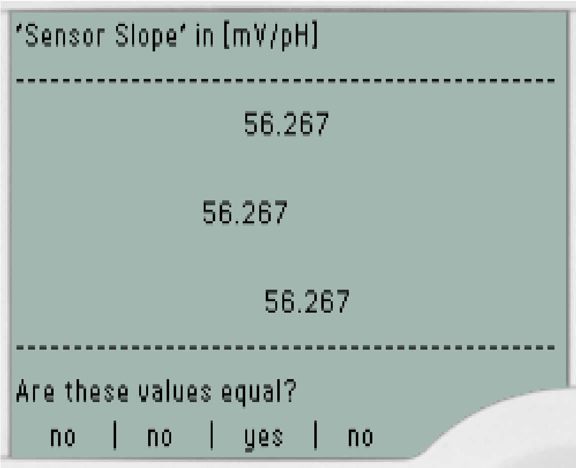


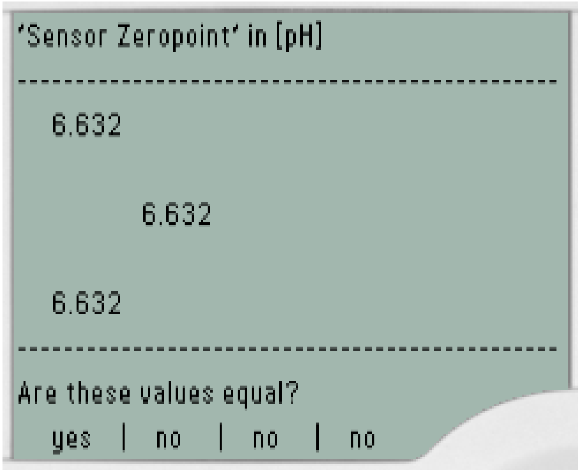
Now carefully check the next screen, if all values are the same and if the value displayed makes sense for you. Only if everything is OK, push the "yes" soft key, and otherwise push "no".

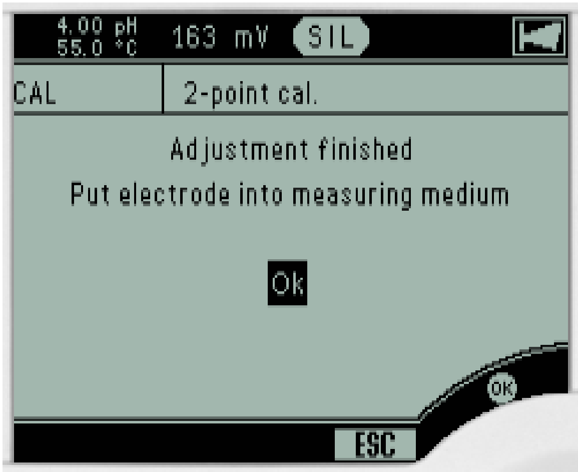




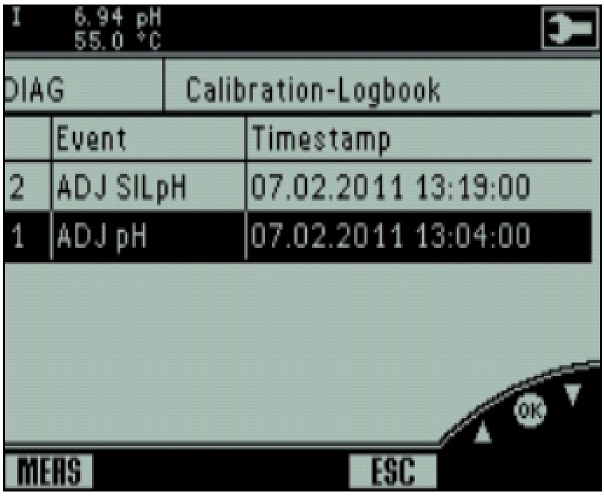
Now again very carefully check the three values. If they are all the same, you can be sure that these values have been written to the sensor correctly and will be used by this sensor now.



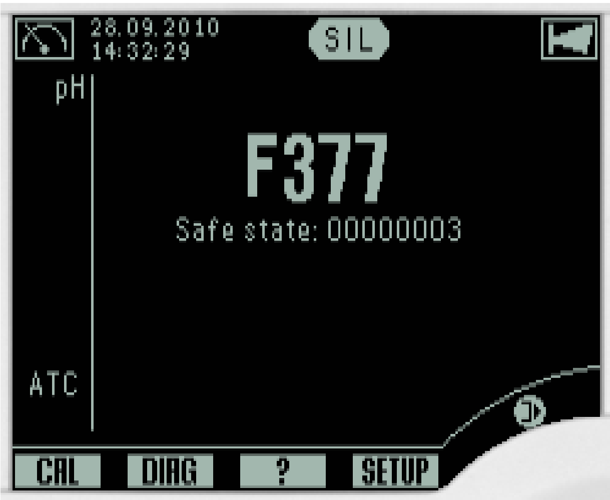




You can check if a safe calibration was done by entering the calibration logbook (DIAG – Logbooks – Calibration logbook):



A safe calibration is marked with “SIL”.

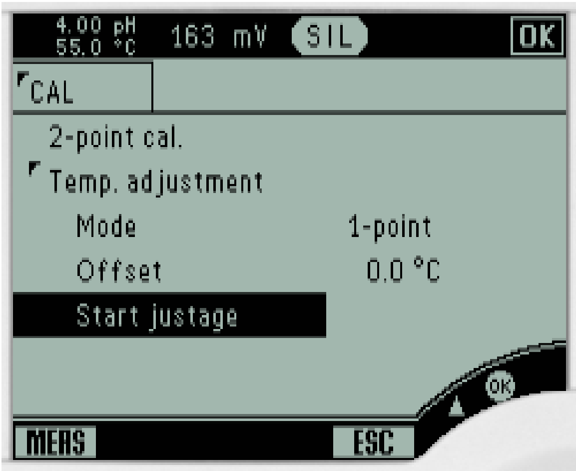


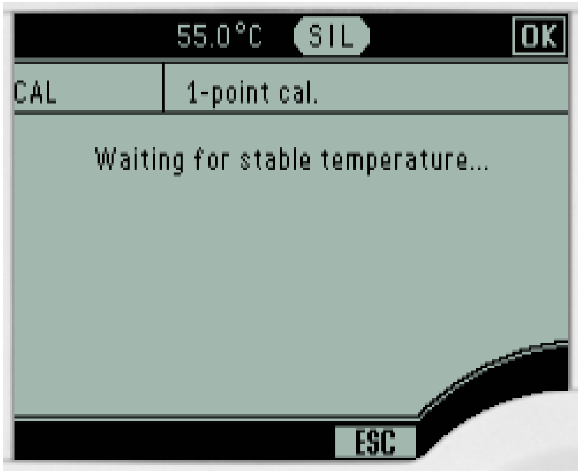
This picture above shows the result of the temperature calibration: the active safe state has been entered and the reason is 00000003, which means a safe calibration has taken place.

4.7.2 1-point temperature calibration

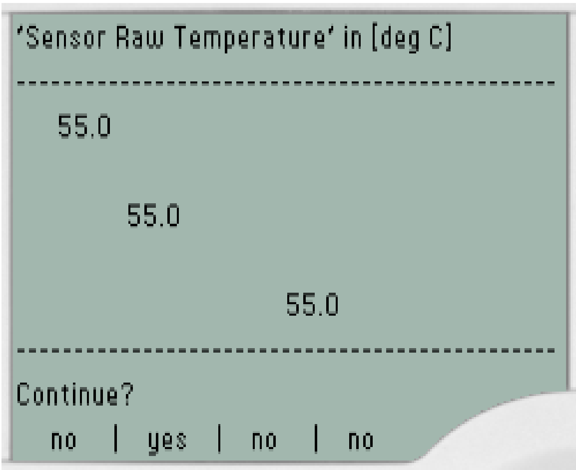
First enter the menu using the CAL menu in SIL measuring mode and follow the instructions given on the display carefully.

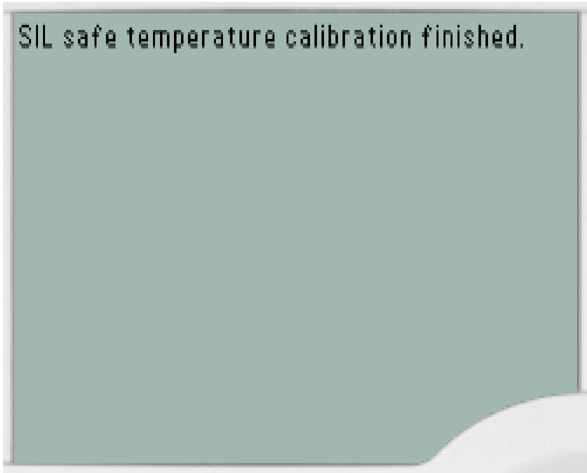
Again: Only the safe screens must be used to document values. See the remarks given with the 2-point pH calibration in chapter 4.7.1.

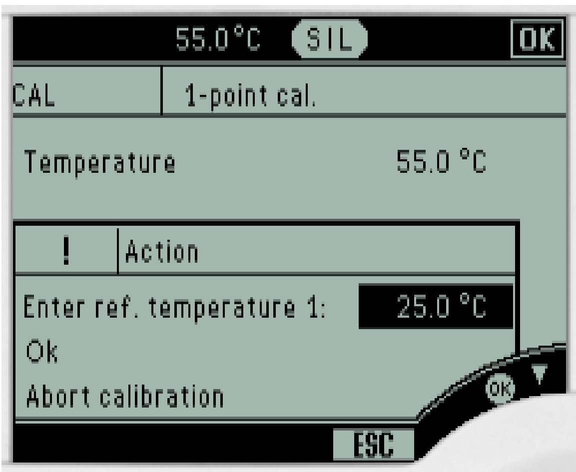


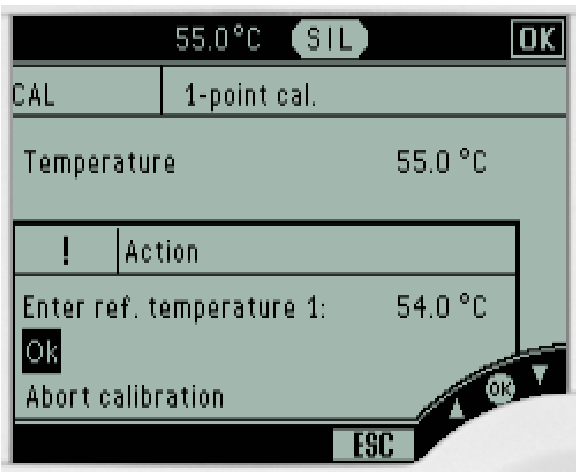


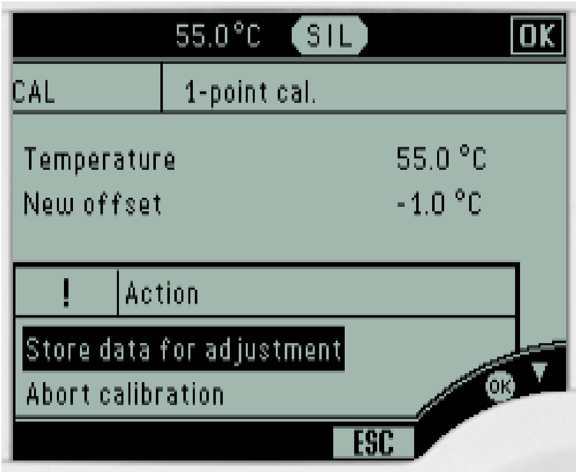
The next screen shows the raw temperature measured. Compare this to your reference measurement and document both measured temperatures.

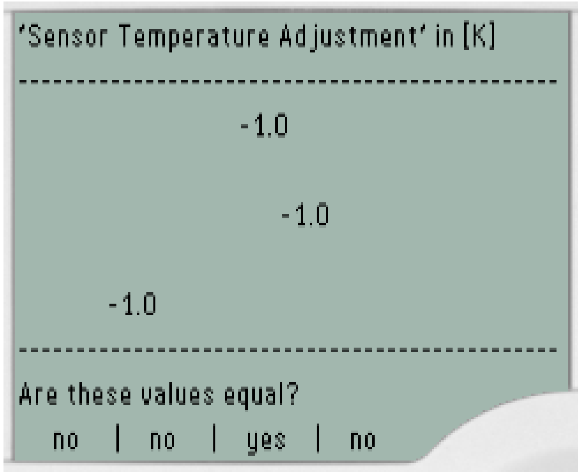


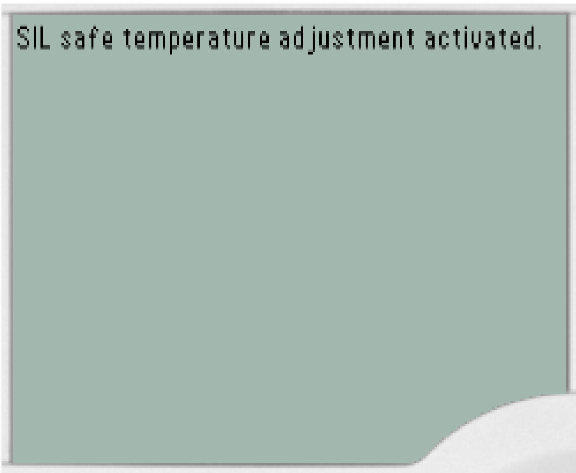




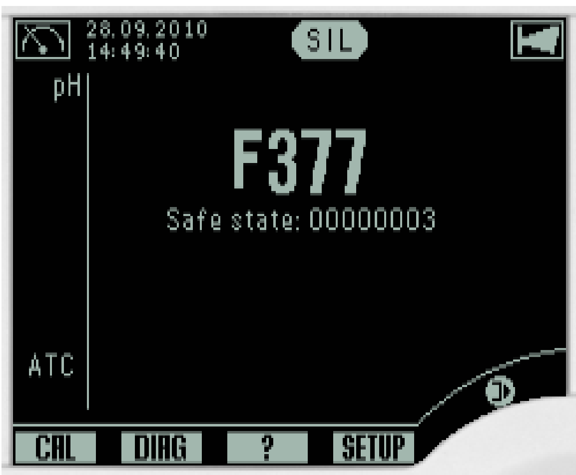



55.0°C SIL OK
CAL
1-point cal.
Temperature 55.0 °C
New offset -1.0 °C
! Action
Store data for adjustment
Abort calibration
OK
ESC


'Sensor Temperature Adjustment' in [K]
-1.0
-1.0
-1.0
Are these values equal?
no | no | yes | no


SIL safe temperature adjustment activated.


54.0°C SIL
CAL
1-point cal.
Adjustment finished
Put electrode into measuring medium
Ok
OK
ESC


28.09.2010
14:49:40
SIL
pH
F377
Safe state: 00000003
ATC
CAL
DIAG
?
SETUP

The last picture above shows the result of the temperature calibration: the active safe state has been entered and the reason is 00000003, which means a safe calibration has taken place.

5 Maintenance, recalibration

If necessary (depending on the application), it is recommended to clean the device acc. to the operation manual occasionally.

6 Proof test

6.1 Proof test

Safety functions must be tested at appropriate intervals to ensure that they are working correctly.

The time intervals must be defined by the operator (refer to chapter 2.3).

Proof testing must be carried out in accordance with the procedure given below.

If several devices are used in MooN ("M out of N") configurations, the proof test described here must be performed separately for each device.

In addition, checks must be carried out to ensure that all restrictions for the operation are still obeyed (see chapter 2.3).

6.2 Testing to ensure its safe functioning

Note!

Please see also the section "Maintenance, recalibration" in chapter 5.

Note!

If one of the described proof criteria is not satisfied, you are not allowed to use the device as a part of a safety related system anymore.

Note!

The proof test is used to detect random failures. The influence of systematic errors on the safety function is not covered by this test and has to be considered separately. Systematic errors can for example be forced by medium properties, environmental conditions, corrosion, etc.

6.2.1 Proof test of the Liquiline M CM42 transmitter

You need a transmitter, a Memosens cable and a Memosens sensor. All components must be certified according to IEC 61508. You need an already calibrated sensor. You also need two buffer solutions, one with pH 7.0 and the other with pH 9.0 or 9.2.
You need a reliable ampere meter to measure the current at both current outputs. The precision must be at least ±1mA.

Note!

The proof test can be done in the laboratory or "in process".

The procedure of the proof test is as follows:

(This is the procedure used, if you can use buffers. If you need to do this procedure "in process", you need a way of changing the pH value of at least 2.0 pH – e.g. pH 5.0 and pH 7.0. You must adapt the corresponding settings in the procedure below and document that.)

- Switch off the transmitter Liquiline M CM42. Now all connected devices (sensor, cable and transmitter) are switched off.
- Put the sensor into the buffer with pH 9.0 or pH 9.2.
- Wait for at least two minutes (to discharge almost all capacities of the electronic).
- Switch on the transmitter and wait until the system shows the pH value in the main screen of the transmitter display. Now (almost) all self tests of the device have been run successfully.
- Now run the “cable proof test in the menu” "SETUP – Functional safety". It must finish successfully.
- Set the safety function to SAF1 and set the current output spreading for the pH-value (SETUP – Current outputs – Current output 1/2) to 8.0 (minimum) und 10.0 (maximum). If you reference to process solutions, the pH values of the current output spread have to be 1 pH below the lowest and 1 pH above the highest reference value. All other settings should have reasonable values.
- Then switch to SIL mode and then to SIL measuring mode. The system must run in SIL measuring mode without any errors. Now start to measure both current outputs.
- Wait for at least two minutes. The current outputs must show a constant value between 4 and 20 mA. The value itself is not important, just that it stays constant and it is not an error current.
  Both values of the current outputs are each allowed to spread at a maximum of ±0.05mA at constant temperature.

- Now change the buffer and put the sensor into the pH 7.0 buffer or rather the process solution with the lower pH value. This pH value is outside the allowed pH interval for SAF1 and therefore the safety function must execute.
  The current outputs must change (because of the pH change) and as soon as the pH value is below pH 8.0 / below the lower value of the current output spread, the current outputs must show a high or low error current for at least four seconds.
  The (active) safe state has been reached.
- Reconfigure the system for your application, especially reset the current output spreading to the values you need.
- Done.

The proof test has to be documented with date, tester and the result (see example of protocol in chapter 9).

This test detects approx. 90 % (proof test coverage) of all possible dangerous undetected device failures.

6.2.2 Proof test of the Memosens cable CYK10

You need a transmitter, a Memosens cable and a Memosens sensor. All components must be certified according to IEC 61508.

Note!

The proof test can be done in the laboratory or "in process".

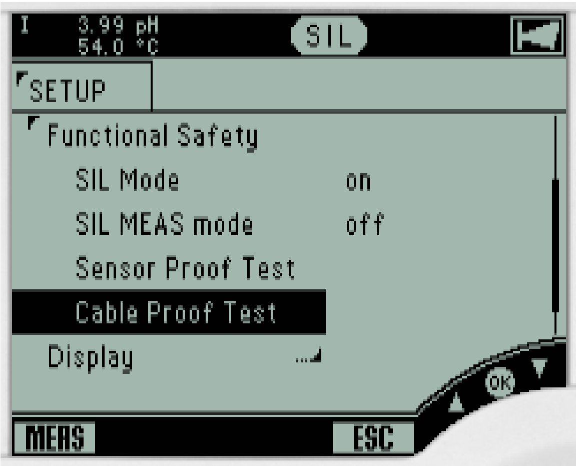
The procedure of the proof test is as follows:

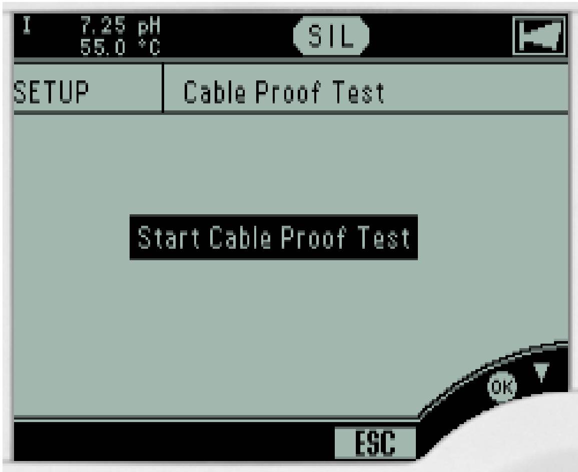
- Navigate to the menu Setup – Functional Safety and deactivate “SIL meas Mode” if switched on.
- Enter the menu item "Cable Proof Test".
- Push the jog shuttle to start the proof test. Make sure that you have connected the cable and the sensor correctly. The system is not able to distinguish between a disconnected sensor and a broken communication link.
- Wait until the proof test has been finished (about 30 seconds).
- The result is displayed. In case of an error, you can restart the test, but beforehand you should check the connections between cable and transmitter and cable and sensor.

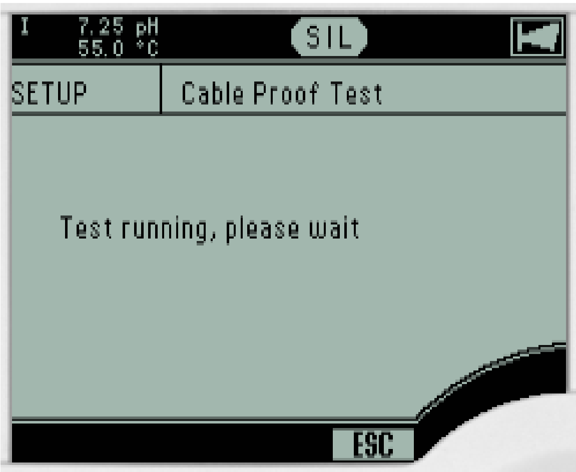
The proof test has to be documented with date, tester and the result (see example of protocol in the safety manual of the cable).

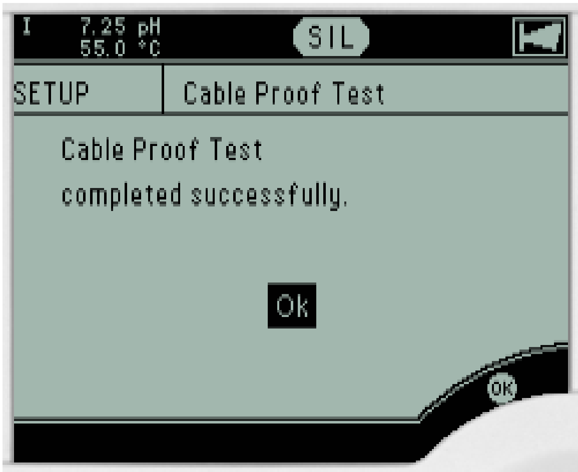
This test detects approx. 90 % (proof test coverage) of all possible dangerous undetected device failures.

The following screenshots give an impression how it looks like on the display:

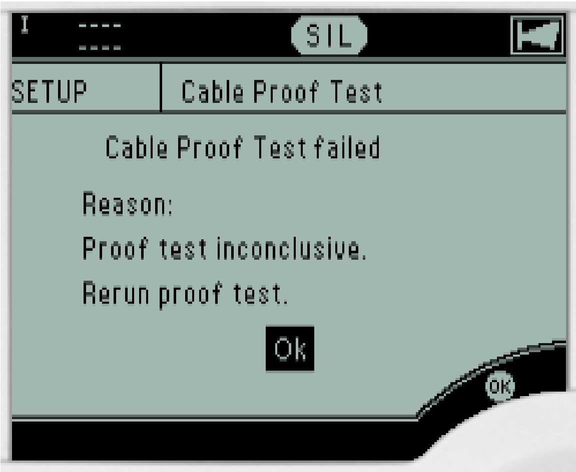


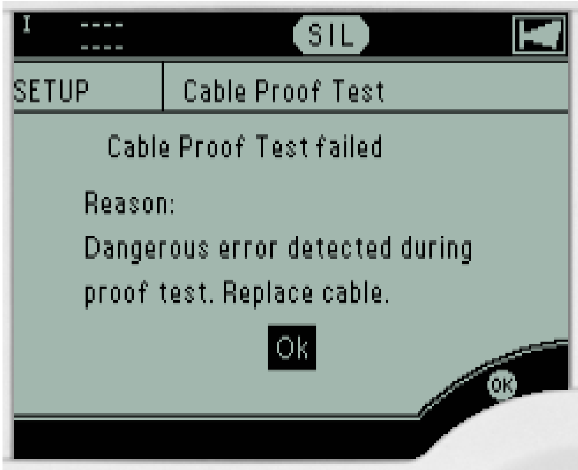


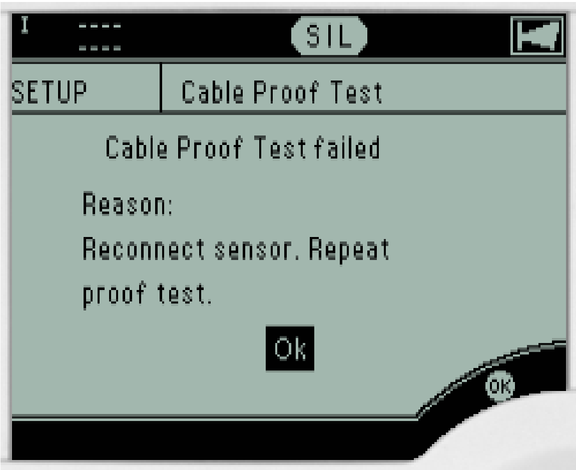




Possible error messages:







6.2.3 Proof test of the Memosens pH glass sensor

You need a transmitter, a Memosens cable and a Memosens sensor. All components must be certified according to IEC 61508. You also need two buffer solutions, one with pH 7.0 and the other with pH 4.0.

Note!

The proof test can be done in the laboratory or "in process".

The procedure of the proof test is as follows:

- Navigate to the menu Setup – Functional Safety and deactivate "SIL meas Mode" if switched on.
- Enter the menu "Sensor Proof Test".
- Read carefully the instructions given on the display and push the jog shuttle button as requested.

- After the proof test has been done, the result is displayed. If an error has been detected, you are not allowed to use this sensor for any safety related functions anymore.

The proof test has to be documented with date, tester and the result (see example of protocol in the safety manual of the sensor).

This test detects approx. 90 % (proof test coverage) of all possible dangerous undetected device failures.

Note!
The test forces the safety function of the sensor to execute.

Very important!

Very carefully read the display during the proof test and only continue, if you have finished exactly, what has been asked for on the display. If you for example put the sensor in pH 7.0 instead of pH 4.0, this will leave the sensor in an almost unusable configuration which cannot be undone!

The steps of the proof test are:

All of the steps below have to be done successfully. Only steps A) to C) are done by the proof test sequence. Step D) has to be done manually by you.

A) Put electrode into pH 4.0
   a. Adjust sensor with special slope/zero point 1
   b. Sensor into pH 7.0

B) Put electrode into pH 4.0
   a. Put electrode into pH 7.0
   b. Adjust sensor with special slope/zero point 2
   c. Sensor into pH 4.0

C) Put electrode into pH 7.0
   a. Adjust sensor with a default slope/zero point
   b. Start measuring again.

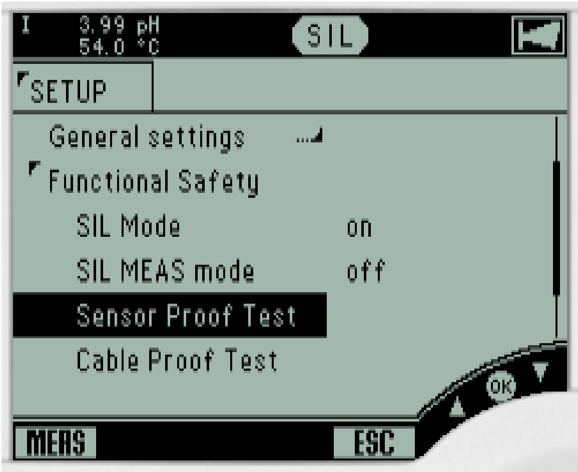
D) Do a safe calibration and adjustment with this sensor now.

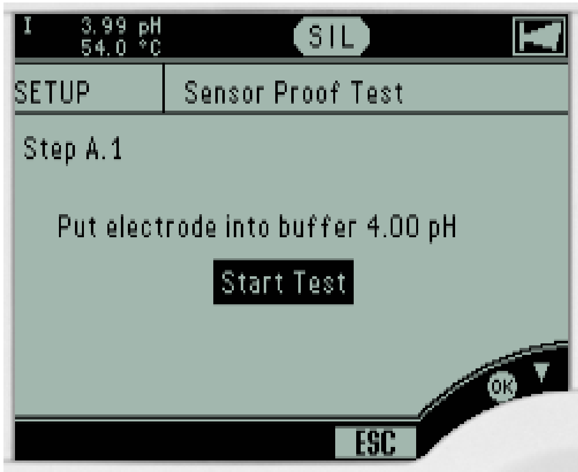
Note!

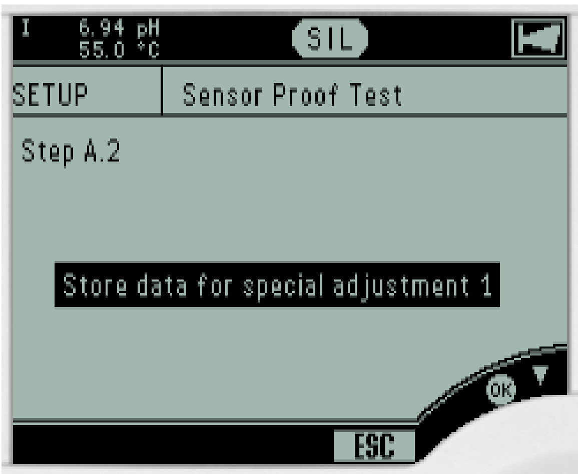
In case you have escaped the proof test sequence or the proof test failed, because of a "correctable error", the sensor is in an unusable state.

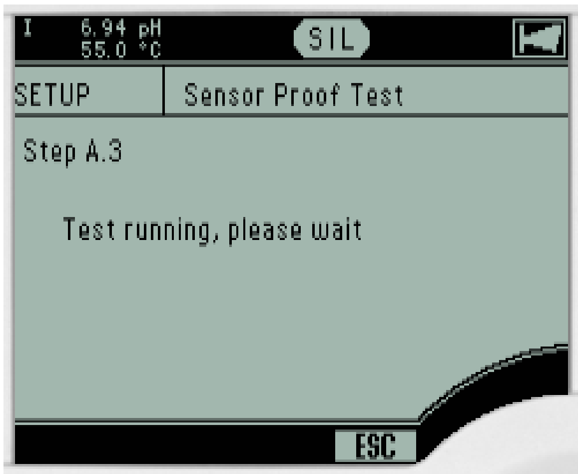
For safety reasons, to reset the sensor you have to do the complete proof test successfully. Therefore try to start the proof test by putting the sensor as described above in pH 4.0. If that does not work (you can stop the proof test by pushing the ESC soft key, if after 120 seconds nothing happens on the display), you start with pH 7.0, although the display says pH 4.0. If that worked, follow exactly the instructions given on the display. If it still does not work, you have to change the sensor.

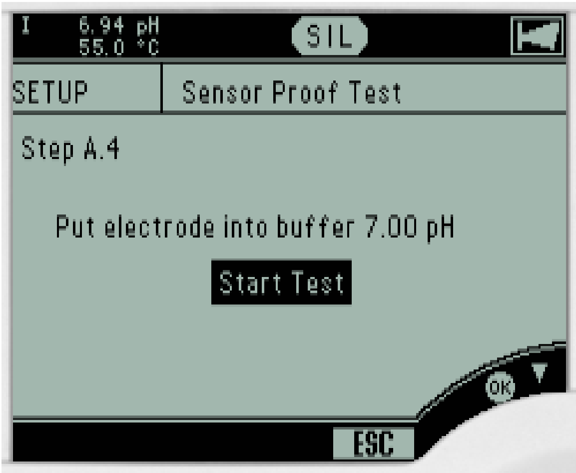
The following screenshots give an impression how it looks like on the display:

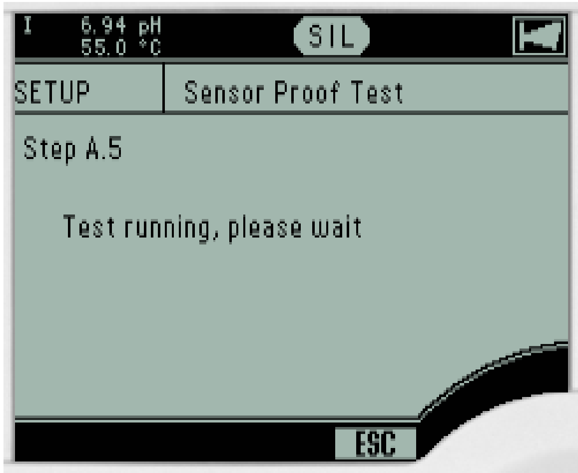


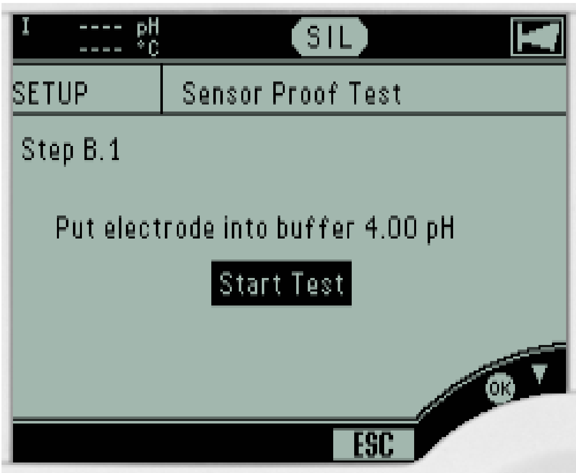


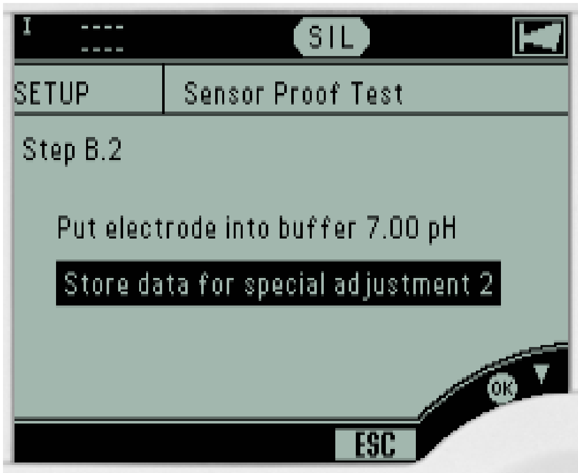


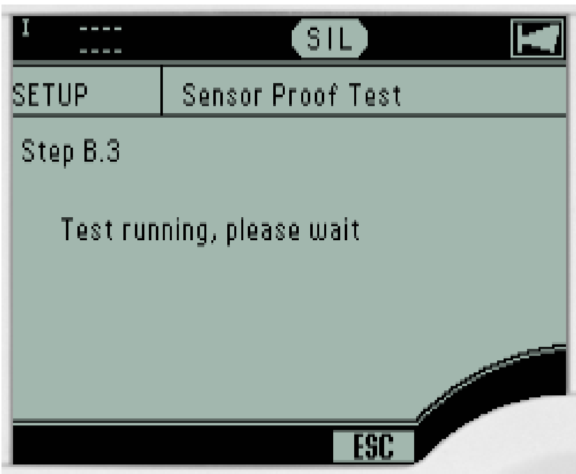


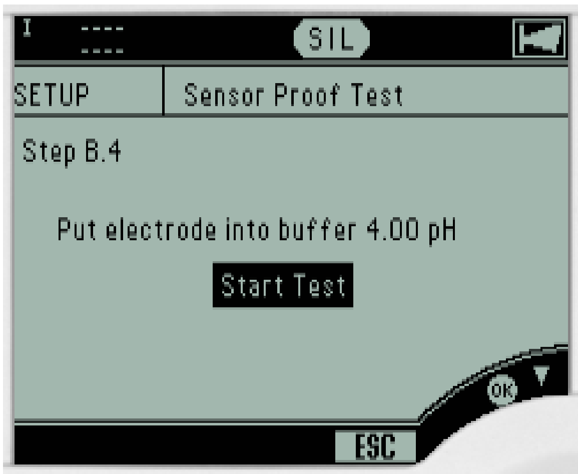

6.94 pH
55.0 °C
SIL
SETUP
Sensor Proof Test
Step A.4
Put electrode into buffer 7.00 pH
Start Test
OK
ESC

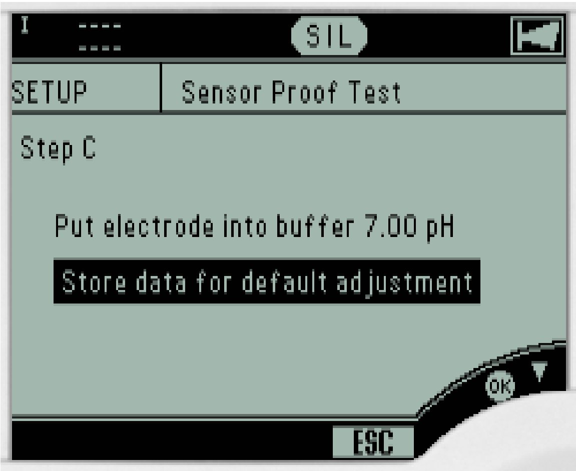

6.94 pH
55.0 °C
SIL
SETUP
Sensor Proof Test
Step A.5
Test running, please wait
ESC

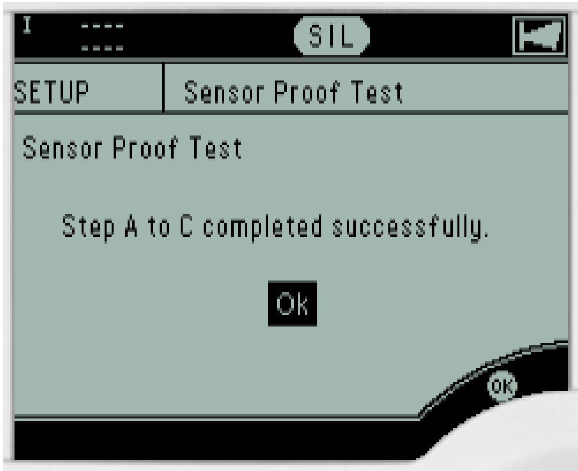

---- pH
---- °C
SIL
SETUP
Sensor Proof Test
Step B.1
Put electrode into buffer 4.00 pH
Start Test
OK
ESC


SIL
SETUP
Sensor Proof Test
Step B.2
Put electrode into buffer 7.00 pH
Store data for special adjustment 2
OK
ESC

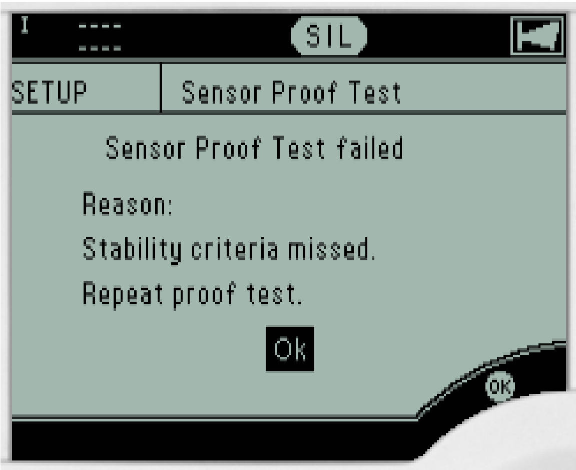

SIL
SETUP
Sensor Proof Test
Step B.3
Test running, please wait
ESC


SIL
SETUP
Sensor Proof Test
Step B.4
Put electrode into buffer 4.00 pH
Start Test
OK
ESC

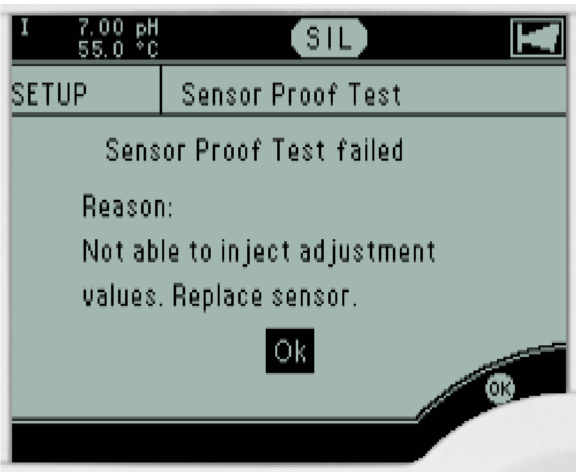


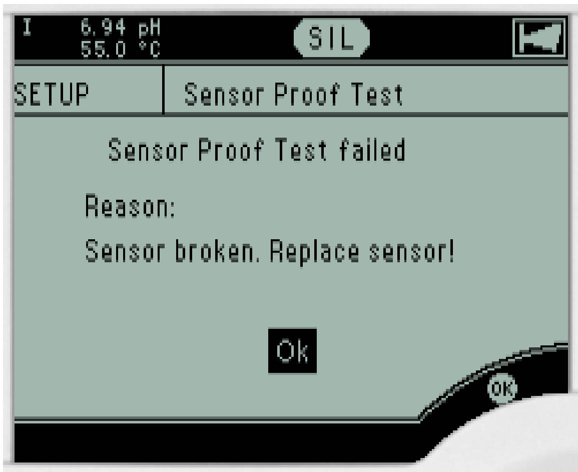


In case the system detects a "correctable error", you get for example:



In case of an unrecoverable error, you get for example:





7 Repair

In general Liquiline M CM42 SIL devices can be repaired like non SIL devices. But there are two things to take into account:

1. If only one of the Liquiline M CM42 modules is replaced, the complete system is NOT in an "almost new" state. Therefore you have to do a proof test of all not changed components and compute the current PFD_{avg} value for your specific system. To avoid this effort, a service **kit containing both hardware modules** (FMIH1, SIL and FSDG1, SIL) is offered, **order code 71123799**. These modules are not available separately.

Regarding PFD_{avg}, the exchange of both modules is comparable with a new device.

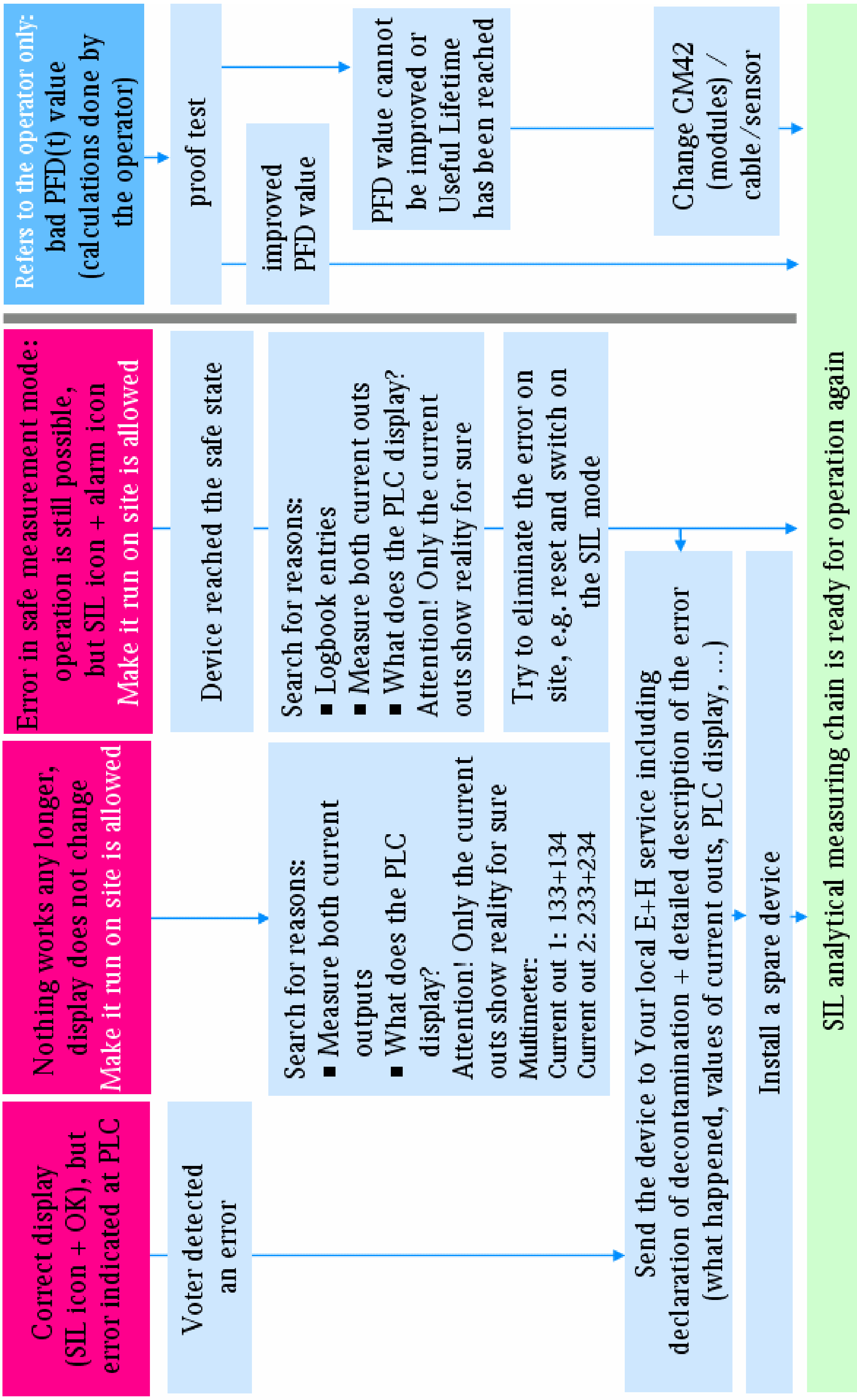
2. In case the **voter detected an λ_{du} error** (error displayed by PCS, but Liquiline M CM42 status seems to be ok) **please send the device back to E+H**. It is the responsibility of all of us to do everything possible to find out the reason which lead to this safety relevant λ_{du} error.

Please fill in the form “Declaration of de-contamination” on www.endress.com/service – support – returned material or copy the last but one side of this manual and send it together with the clean device back to your local E+H service.

Are you interested in a training especially regarding the SIL Memosens pH analytical measuring chain? Please send your request to

analysis-academy@conducta.endress.com.

The following scheme gives an overview of what to do in case the SIL measurement is interrupted:


Correct display (SIL icon + OK), but error indicated at PLC
Voter detected an error
Nothing works any longer, display does not change
Make it run on site is allowed
Search for reasons:
Measure both current outputs
What does the PLC display?
Attention! Only the current outs show reality for sure
Multimeter:
Current out 1: 133+134
Current out 2: 233+234
Error in safe measurement mode: operation is still possible, but SIL icon + alarm icon
Make it run on site is allowed
Device reached the safe state
Search for reasons:
Logbook entries
Measure both current outs
What does the PLC display?
Attention! Only the current outs show reality for sure
Try to eliminate the error on site, e.g. reset and switch on the SIL mode
Refers to the operator only: bad PFD(t) value (calculations done by the operator)
proof test
improved PFD value
PFD value cannot be improved or Useful Lifetime has been reached
Change CM42 (modules) / cable /sensor
Send the device to Your local E+H service including declaration of decontamination + detailed description of the error (what happened, values of current outs, PLC display, ...)
Install a spare device
SIL analytical measuring chain is ready for operation again

For a useful description of an error the following should be checked and described:

1. Which error occurred (error number and short text of the error message)?
2. Which entries are listed up in the logbook(s)?
3. In case of a system crash the parametrization of the data logbook is interesting.
4. Please describe the error (behaviour of the device, display, current output values at the transmitter display and at the PCS, ...)
5. In which situation did the error occur? (during a proof test, a standard check, a trial or during operation?
6. What did the control room show in the relevant period of time?
7. Could you observe the behaviour of the current outputs at the display? If yes, what did the current outputs and the voter show? Were there differences?
8. Which are the serial numbers of the transmitter, sensor and cable?
   Regarding Liquiline M CM42, the versions of the hardware modules FMIH1 and FSDG1 as well as the projecting versions (= Software version, please read via the display and not at the type plate) are good to know, if modules had been changed and/or a software update was done.
9. Boundary conditions:
   - Voltage at the device
   - Current output value or typical measuring range and expected pH value
   - Are ESD influences possible? (Motors, frequency converter, ...near by)?

8 Notes on the redundant use of the device for SIL 3

SIL3 can be reached either by homogenous redundancy or by inhomogeneous redundancy.

9 Proof test protocol example

Application Specific Data	
Company	
Measuring point	
Facility	
Device type	Liquiline M CM42, SIL
Serial number	
Checked again the restrictions for usage	O yes O no
Sensor calibration data used slope [pH/mV] zero point [pH]	
Partial stroke test for current out used	O yes O no
Temperature range check values minimum [°C/°F] maximum [°C/°F]	
PFDavg value before proof test	
PFDavg value after proof test	
Date of last proof test	
Date of next proof test (estimated)	
Name of tester	
Date	
Signature	

To store the settings (all parameters) of the used transmitter, you can use a CopyDAT CY42-C1 (see operating instructions).

10 Overview of modes and current output

Mode of CM42	Current output 1	Current output 2
Classic mode	as configured, see operating instructions	as configured, see operating instructions
SIL-Mode, active safe state mode	21.5 mA	21.5 mA
SIL-Mode, passive safe state mode	>21.5 mA	>21.5 mA
SIL-Mode, calibration running	Measured pH value (computed by transmitter)	Measured pH value (computed by sensor)
SIL-Mode, SIL measurement mode	Measured pH value (computed by transmitter)	Measured pH value (computed by sensor)
System startup, until classic mode reached	≥21.5 mA	≥21.5 mA

11 PFD_{avg} computation examples

In this chapter we provide some examples to compute the PFD_{avg} values of a measuring chain and the PFD_{avg} value after doing proof tests.

Remark: $PFD_{avg}(T) = 1/T \int_0^T (\lambda_{DU}\, t)\, dt = ½\, \lambda_{DU}\, T$ (for a1oo1D system, assuming constant and small failure rate λ_{DU}). Usually PFD_{avg} is given without a parameter T, which means this is the value of PFD_{avg} at time T of the mandatory proof test.

11.1 Example to calculate PFD_{avg} after a proof test

The aim of a proof test is to show, that the system does not have any dangerous undetected failures. The proof test coverage denotes the effectiveness of the proof test.

So after the proof test has been successfully finished, the systems PFD_{avg} value has been "improved" and you can determine when the next proof test has to be carried out.

Here we use the Memosens cable CYK10 in a 1oo1D setting for the example.

Assumptions for this example:

Proof test is done after two years of operation, because system is not allowed to have a higher PFD_{avg} than 1.80×10^{-4} at all times.

Initial PFD_{avg} of new cable: $PFD_{avg}(0) = 0$

PFD_{avg} of a two year old cable: PFD_{avg} (2 years) $= 1.80 \times 10^{-4}$

assuming $\lambda_{DU} = 2.05 \times 10^{-8}$ 1/h (= 20.5 FIT) and

where $PFD_{avg}(t) = 1/2 \times t \times \lambda_{DU}$, t in hrs.

Then you do the proof test (follow the CM42 menu guidance) successfully.

Proof test coverage is (see Memosens cable safety manual): 90%.

New values **after the proof test** has been successfully finished:

New PFD_{avg} value after two years and after a successful proof test

PFD_{avg} (2 years; proof test successful) $= 1.80 \times 10^{-4} \times (1.00 - 0.90) = 0.18 \times 10^{-4}$

PFD_{avg} value after two additional years (no additional proof test done yet):

PFD_{avg} (4 years) $= 0.18 \times 10^{-4} + 1.80 \times 10^{-4} = 1.98 \times 10^{-4}$

Further questions:

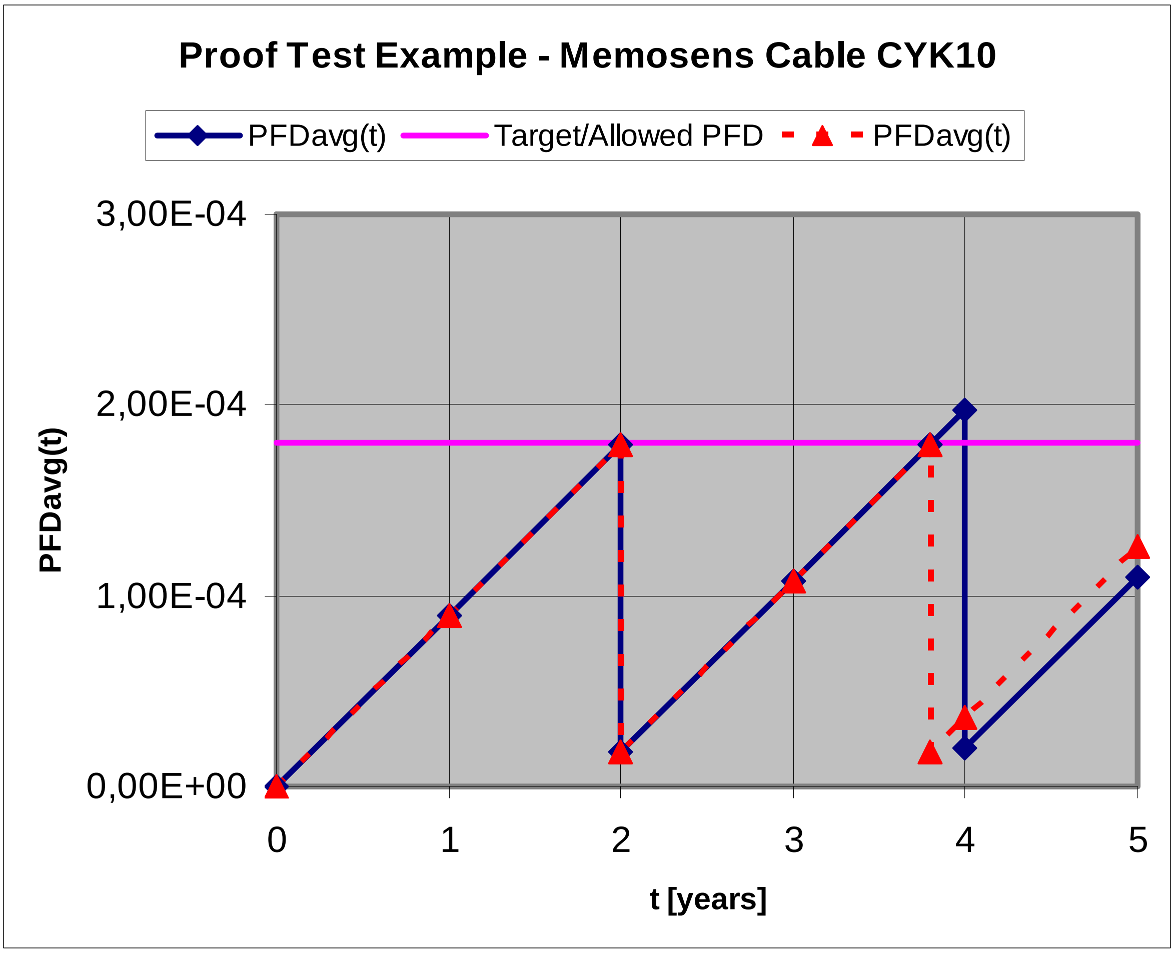
What is the time period t, after which the $PFD_{avg}(t)$ value of this once "proof tested system" reaches again 1.80×10^{-4}?

Find t, where $PFD_{avg}(t) = 1.80 \times 10^{-4}$

$\Rightarrow 1.80 \times 10^{-4} = 0.18 \times 10^{-4} + 0.50 \times \lambda_{DU} \times t$

=> T in years: T = 0.9 × 2.0 years = 1.8 years = 21.6 months

And therefore the proof test interval T after the first "incomplete" proof test with a proof test coverage of 90%, will be smaller than two years.



The dotted line is the $PFD_{avg}(t)$ value, if the proof test is done after 2 years and 21.6 months. The solid line, if the proof test is done after 2 years and 4 years. And the straight horizontal line denotes the limit of the PFD_{avg} value given by the customer.

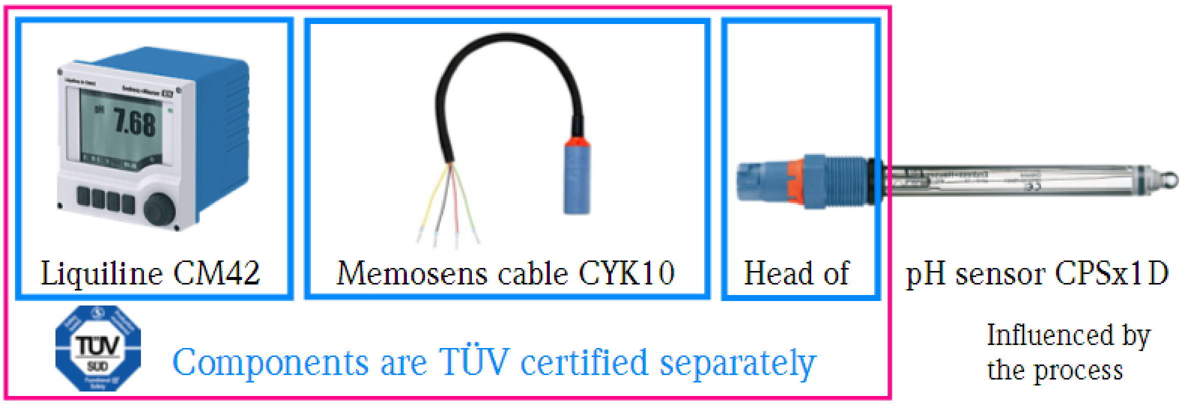
11.2 PFD_{avg} computation example for a pH measuring point

Note!

The following example can be used as the result for the safety parameters of the complete Endress+Hauser pH SIL measuring chain (see table at end of chapter).

Assume we have a measuring point consisting of the following components from Endress+Hauser:

1. Memosens pH glass sensor, SIL
2. Memosens cable CYK10, SIL
3. Memosens transmitter Liquiline M CM42, SIL



The measuring chain is connected to a PCS (e.g. a PLC), which is itself connected to some kind of actor to activate the safe state.

You can calculate the PFD value of the complete chain (PFD_{avg} mc; mc means measuring chain) by summing up the individual PFD values of all components in the chain, including the communication protocol (here the Memosens protocol):

$$PFD_{avg}\text{ mc} = PFD_{avg}\text{ sensor} + PFD_{avg}\text{ cable} + PFD_{avg}\text{ transmitter} + PFD_{avg}\text{ Memosens protocol}$$

Then for a complete safety instrumented system (SIS) you get:

$$PFD_{avg}\text{ sis} = PFD_{avg}\text{ mc} + PFD_{avg}\text{ PCS} + PFD_{avg}\text{ actor}$$

As an example, the value of the complete (non-redundant) Endress+Hauser pH measuring chain, described at the beginning of this section, we get (The Memosens protocol has been taken into account with 1% of the PFD SIL-2 value = 1.0 E-4):

$$\mathbf{PFD_{avg}\ mc} = 8.3\text{ E-4} + 0.9\text{ E-4} + 10.3\text{ E-4} + 1.0\text{ E-4} = \mathbf{20.5\text{ E-4}}$$

(Proof test intervals are chosen to be 1 year for all devices)

According to IEC 61508 a maximum PFD_{avg} of 1E-2 is allowed to realize a SIL-2 SIS. So the just calculated value accords to about 21% of the SIL-2 PFD_{avg} value. That means the PCS and actors can use the remaining 79% of the SIL-2 PFD_{avg} value.

Of course, you also have to calculate and use the SFF given in the IEC 61508 to fulfil all requirements of the standard.

For the SFF of this specific chain you get:

SFF_{mc} = **93.8%** with

SFF_{sensor} = 92.3%,

SFF_{cable} = 90.4% and

$SFF_{transmitter}$ = 94.8%.

The following table shows the specific functional safety parameters for a single-channel device operation:

Parameters according to IEC 61508	**E+H Memosens pH SIL Measuring chain**
Safety Function	1: pH limit monitoring 2: pH value measurement 3+4: safe calibration and adjustment
SIL	Hardware: 2, Software: 3 in homogenous redundancy: 3
HFT	0
Device Type	B
Mode of Operation	Low demand mode
SFF	93.8 %
MTTR (used for PFD calculation)	8 h
T_1 (Proof test interval)	Recommended: 1 / 1 / 1 year, (sensor / cable / transmitter)
λ_{SD}	688 FIT
λ_{SU}	1623 FIT
λ_{DD}	4473 FIT
λ_{DU}	447 FIT
λ_{Total} *1	7238 FIT
PFD_{avg} (for T_1 = 1 / 1 / 1 year) *4	19.6×10^{-4}
PFH	4.5×10^{-7}
MTBF *1	15 years
Diagnostic-Test-Interval *2	< 60 min
Error Reaction Time *3	< 10 seconds
DC_D (Diagnostic Coverage Dangerous)	91 %

*1 According to Siemens SN29500 at 60°/100° Celsius – 140°F/212°F. MTBF calculated as reciprocal of PFH/ λ_{Total}.

*2 During this time all diagnostic functions are completed at least once.

*3 Time between failure detection and failure reaction.

*4 Of course, you can choose different (e.g. longer) proof test intervals. Choose the one suited for your application.

Note!

These values do NOT include the PFD_{avg}/SFF values of the used voter and the sensor element in contact with the medium. Nor does it take into account any medium interactions with the sensor element.

History

Version	Changed by	Date of change	Change
2.0	Nentwich	21.02.2011	- Update of the graphics in chapters 2.3 + 7 - New: Graphic in chapter 4.4 - Text in chapter 7 - New: Declaration of Decontamination - LED deactivated in SIL device
2.1	Nentwich	18.06.2011 Not officially published	- SAP version number of FMIH1 added - Addition of TÜV certificate - Elinimnation of „Orbisint CPS11D“ - SIL3 for software, homogenous redundancy - Questions to describe an error
2.2	Nentwich	30.01.2012	- 1.3: valid device types updated - 2.2: “+/- 0,04” pH explained - 2.3: Reason for use of weather protection roof added
2.3	Nentwich	24.10.2012	-1.3: new: Projection of FMIH1 module Updated FBIH1 version

Endress+Hauser

People for Process Automation

Declaration of Hazardous Material and De-Contamination

RA No. ☐☐☐☐☐☐☐☐

Please reference the Return Authorization Number (RA#), obtained from Endress+Hauser, on all paperwork and mark the RA# clearly on the outside of the box. If this procedure is not followed, it may result in the refusal of the package at our facility.

Because of legal regulations and for the safety of our employees and operating equipment, we need the "Declaration of Hazardous Material and De-Contamination", with your signature, before your order can be handled. Please make absolutely sure to attach it to the outside of the packaging.

Type of instrument / sensor ________________________ **Serial number** ____________________

☐ **Used as SIL device in a Safety Instrumented System**

Process data

Temperature _____ [°F] _____ [°C] Pressure _____ [psi] _____ [Pa]

Conductivity ________ [µS/cm] Viscosity _____ [cp] _____ [mm²/s]

Medium and warnings

	Medium / concentration	Identification CAS No.	flammable	toxic	corrosive	harmful/ irritant	other *	harmless
Process medium								
Medium for process cleaning								
Returned part cleaned with								

* explosive; oxidising; dangerous for the environment; biological risk; radioactive

Please tick should one of the above be applicable, include safety data sheet and, if necessary, special handling instructions.

Description of failure ____

____

____

Company data

Company ______________________

____

Address ______________________

____

____

Phone number of contact person ______________________

Fax / E-Mail ______________________

Your order No. ______________________

"We hereby certify that this declaration is filled out truthfully and completely to the best of our knowledge. We further certify that the returned parts have been carefully cleaned. To the best of our knowledge they are free of any residues in dangerous quantities."

(place, date) ______________ Name, dept. (please print) ______________ Signature ______________

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