Safety Manual

VEGAPULS series 60

Two-wire 4 … 20 mA/HART

Four-wire 4 … 20 mA/HART

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Contents

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1 Functional safety

1.1 General information

Scope

This safety manual applies to measuring systems consisting of the VEGAPULS series 60 radar sensor in two-wire and four-wire versions 4 … 20 mA/HART:

VEGAPULS 61, 62, 63, 65, 66, 67, 68

Valid hardware and software versions:

	Serial number of the electronics	Sensor software
VEGAPULS 61, 62, 63, 65, 66	> 13978716	from version 3.22 up to version 3.90
VEGAPULS 61, 62, 63 with increased sensitivity	> 14165303	from version 3.25 up to version 3.90
VEGAPULS 67, 68	> 14165303	from version 3.25 up to version 3.90

Application area

The measuring system can be used for level measurement of liquids and solids that meets the special requirements of safety engineering.

Due to the service-proven reliability, implemention is possible in a single channel architecture up to SIL2 and in a multi-channel, diversitary redundant architecture up to SIL3.

The use of the measuring system in a multiple channel, homogeneous redundant architecture is excluded.

SIL conformity

The SIL conformity is confirmed by the verification documents in the appendix.

Abbreviations, terms

SIL	Safety Integrity Level
HFT	Hardware Fault Tolerance
SFF	Safe Failure Fraction
PFD_{avg}	Average Probability of dangerous Failure on Demand
PFH	Probability of a dangerous Failure per Hour
FMEDA	Failure Mode, Effects and Diagnostics Analysis
λ_{sd}	Rate for safe detected failure
λ_{su}	Rate for safe undetected failure
λ_{dd}	Rate for dangerous detected failure
λ_{du}	Rate for dangerous undetected failure
DC_S	Diagnostic Coverage of safe failures; $DC_S = \lambda_{sd}/(\lambda_{sd}+\lambda_{su})$
DC_D	Diagnostic Coverage of dangerous failures; $DC_D = \lambda_{dd}/(\lambda_{dd}+\lambda_{du})$
FIT	Failure In Time (1 FIT = 1 failure/10^9 h)
MTBF	Mean Time Between Failure
MTTF	Mean Time To Failure

MTTR	Mean Time To Repair

Further abbreviations and terms are stated in IEC 61508-4.

Relevant standards

- IEC 61508
  – Functional safety of electrical/electronic/programmable electronic safety-related systems
- IEC 61511-1
  – Functional safety - safety instrumented systems for the process industry sector - Part 1: Framework, definitions, system, hardware and software requirements

Safety requirements

Failure limit values for a safety function, depending on the SIL class (of IEC 61508-1, 7.6.2)

Safety integrity level	**Low demand mode**	**High demand mode**
SIL	**PFD_{avg}**	**PFH**
4	$\geq 10^{-5} \ldots < 10^{-4}$	$\geq 10^{-9} \ldots < 10^{-8}$
3	$\geq 10^{-4} \ldots < 10^{-3}$	$\geq 10^{-8} \ldots < 10^{-7}$
2	$\geq 10^{-3} \ldots < 10^{-2}$	$\geq 10^{-7} \ldots < 10^{-6}$
1	$\geq 10^{-2} \ldots < 10^{-1}$	$\geq 10^{-6} \ldots < 10^{-5}$

Safety integrity of hardware for safety-related subsystems of type B (IEC 61508-2, 7.4.3)

Safe failure fraction	Hardware fault tolerance		
SFF	**HFT = 0**	**HFT = 1 (0)**	**HFT = 2**
< 60 %	not permitted	SIL1	SIL2
60 % … < 90 %	SIL1	SIL2	SIL3
90 % … < 99 %	SIL2	SIL3	(SIL4)
≥ 99 %	SIL3	(SIL4)	(SIL4)

Service proven

According to IEC 61511-1, paragraph 11.4.4, the failure tolerance HFT can be reduced by one for service-proven subsystems if the following conditions are met:

- The instrument is service proven
- Only process-relevant parameters can be modified on the instrument (e. g. measuring range, current output in case of failure …)
- These process-relevant parameters are protected (e.g. password, …)
- The safety function requires less than SIL4

The assessment by change management staff was a part of the "service proven" verification.

1.2 Planning

Safety function

The measuring system generates on the current output a signal between 3.8 mA and 20.5 mA corresponding to the level.

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This analogue signal is transmitted to a connected processing unit to monitor the following conditions:

- Exceeding a preset level
- Falling below a preset level

When the switching point set on the processing unit is reached, a signal is output.

Safe state

The safe state depends on the mode:

	Monitoring upper level	**Monitoring lower level**
Safe state	Exceeding the switching point	Falling below the switching point
Output current in safe state	> Switching point (-1 %)	< Switching point (+1 %)
Failure current "fail low"	< 3.6 mA	< 3.6 mA
Failure current "fail high"	> 21.5 mA	> 21.5 mA

The current tolerance ±1 % refers to the full measuring range of 16 mA.

Fault description

A safe failure exists when the measuring system switches to the defined safe state or the fault mode without the process demanding it.

If the internal diagnostic system detects a failure, the measuring system goes into fault mode.

A dangerous undetected failure exists if the measuring system switches neither to the defined safe state nor to the failure mode when the process requires it.

Configuration of the processing unit

If the measuring system delivers output currents of "*fail low*" or "*fail high*", it can be assumed that there is a malfunction.

The processing unit must therefore interpret such currents as a malfunction and output a suitable fault signal.

If this is not the case, the corresponding portions of the failure rates must be assigned to the dangerous failures. The stated values in chapter "*Safety-relevant characteristics*" can thus worsen.

The processing unit must correspond to the SIL level of the measurement chain.

Low demand mode

If the demand rate is only once a year, then the measuring system can be used as safety-relevant subsystem in "*low demand mode*" (IEC 61508-4, 3.5.12).

If the ratio of the internal diagnostics test rate of the measuring system to the demand rate exceeds the value 100, the measuring system can be treated as if it is executing a safety function in the mode with low demand rate (IEC 61508-2, 7.4.3.2.5).

An associated characteristic is the value PFD_{avg} (average Probability of dangerous Failure on Demand). It is dependent on the test interval T_{Proof} between the function tests of the protective function.

Number values see chapter "*Safety-related characteristics*".

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High demand mode

If the "*low demand rate*" does not apply, the measuring system should be used as a safety-relevant subsystem in the mode "*high demand mode*" (IEC 61508-4, 3.5.12).

The fault tolerance time of the complete system must be higher than the sum of the reaction times or the diagnostics test periods of all components in the safety-related measurement chain.

An associated characteristic is the value PFH (failure rate).

Number values see chapter "*Safety-related characteristics*".

Assumptions

The following assumptions form the basis for the implementation of FMEDA:

- Failure rates are constant, wear of the mechanical parts is not taken into account
- Failure rates of external power supplies are not taken into account
- Multiple errors are not taken into account
- The average ambient temperature during the operating time is 40 °C (104 °F)
- The environmental conditions correspond to an average industrial environment
- The lifetime of the components is around 8 to 12 years (IEC 61508-2, 7.4.7.4, remark 3)
- The repair time (exchange of the measuring system) after an non-dangerous malfunction is eight hours (MTTR = 8 h)
- The processing unit can interpret "*fail low*" and "*fail high*" failures as a disruption and trigger a suitable error message
- Existing communication interfaces (e. g. HART, I^2C-Bus) are not used for transmission of safety-relevant information

General instructions and restrictions

The measuring system should be used appropriately taking pressure, temperature, density, dielectric value and chemical properties of the medium into account.

Instructions to critical process and vessel situations are described in the operating instructions manual.

The user-specific limits must be complied with. The specifications of the operating instructions manual must not be exceeded.

1.3 Instrument parameter adjustment

Adjustment tools

Since plant conditions influence the functional safety of the measuring system, the instrument parameters must be set in compliance with the application.

The following tools are allowed:

- The DTM suitable for VEGAPULS in conjunction with an adjustment software according to the FDT/DTM standard, e. g. PACTware
- Display and adjustment module

Note:
Make sure that DTM Collection 10/2005 or a newer version is used.

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Create a measurement loop

If the measuring system has not been ordered especially for applications in safety-instrumented systems (SIS), the parameter "*Sensor according to SIL*" must be selected in the adjustment sofware in the menu level "*Basic setting*". If the display and adjustment module is used, the parameter "*SIL*" must be activated in the menu level "*Service*".

Reaction when malfunctions occur

The parameter adjustment of the interference current influences the safety-related characteristics. For safety-relevant applications only the following interference currents are permitted:

- fail low = <3.6 mA (default value)
- fail high = 22 mA

Damping of the output signal

The damping of the output signal must be adapted to the process safety time.

Inadmissible modes

Measured value transmission via HART signal as well as HART multidrop mode is not permitted.

Inspection possibilities

The effectivity of the set parameters must be checked in a suitable way.

- After connecting the instrument, the output signal jumps to the set interference current (at the end of the switch-on phase)
- In mode "*Simulation*", the signal current can be simulated independently of the actual level

Access locking

To avoid unwanted or unauthorized modification, the set parameters must be protected against unintentional access:

- Activate the password protection in the adjustment software
- Activate the PIN on the display and adjustment module

Access by means of HART handheld or similar equipment is not permitted.

Protecting against unintentional or unauthorized adjustment can be done, e.g. by sealing the housing cover.

⚠ **Caution:**
After a reset of the values, all parameters must be checked or readjusted.

1.4 Setup

Mounting and installation

Take note of the mounting and installation instructions in the operating instructions manual.

In the setup procedure, a check of the safety function by means of an initial filling is recommended.

1.5 Reaction during operation and in case of failure

Operation and interference

The adjustment elements or device parameters must not be modified during operation.

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If modifications have to be made during operation, carefully observe the safety functions.

Fault signals that may appear are described in the appropriate operating instructions manual.

If faults or error messages are detected, the entire measuring system must be shut down and the process held in a safe state by other measures.

The exchange of the electronics is simple and described in the operating instructions manual. Note the instructions for parameter adjustment and setup.

If due to a detected failure the electronics or the complete sensor is exchanged, the manufacturer must be informed (incl. a fault description).

1.6 Recurring function test

Reason

The recurring function test is testing the safety function and to find out possible undetected, dangerous failuress. The functional capability of the measuring system has to be tested in adequate time intervals. It is up to the user's responsibility to selct the kind of testing. The time intervals are subject to the PFD_{avg}-value according to the chart and diagram in section "*Safety-relevant characteristics*".

With high demand rate, a recurring function test is not requested in IEC 61508. The functional efficiency of the measuring system is demonstrated by the frequent use of the system. In double channel architectures it is a good idea to verify the effect of the redundancy through recurring function tests at appropriate intervals.

Implementation

Please carry out the test in such a way, that the correct safety function in combination with all components is granted. This is granted by the control of the response height during a filling process. If a filling up to the response height is not practicable, the measuring system has to be responded by an appropriate simulation of the level or the physical measuring effect.

The methods and procedures used during the tests must be stated and their suitability must be specified. The tests must be documented.

If the function test proves negative, the entire measuring system must be switched out of service and the process held in a safe state by means of other measures.

In a multiple channel architecture this applies separately to each channel.

Function test without interrupting the process

As an alternative to the above procedure, the VEGAPULS sensor can also be subjected to the recurring function test without interrupting the process. A detailed test instruction with test protocol is available in Appendix A of this safety manual.

1.7 Safety-related characteristics

Basics

The failure rates of the electronics, the mechanical parts of the transmitter as well as the process fitting are determined by an FMEDA according to IEC 61508. The calculations are based on component failure rates according to SN 29500. All values refer to an average ambient temperature during the operating time of 40 °C (104 °F).

For a higher average temperature of 60 °C (140 °F), the failure rates should be multiplied by a factor of 2.5. A similar factor applies if frequent temperature fluctuations are expected.

The calculations are also based on the specifications stated in chapter "*Planning*".

Service life

After 8 to 12 years, the failure rates of the electronic components will increase, whereby the derived PFD and PFH values will deteriorate (IEC 61508-2, 7.4.7.4, note 3).

Failure rates

Applies to overfill and dry run protection:

λ_{sd}	0 FIT
λ_{su}	461 FIT
λ_{dd}	1129 FIT
λ_{du}	358 FIT
DC_S	0 %
DC_D	75 %
MTBF = MTTF + MTTR	0.45×10^6 h

Fault reaction time

VEGAPULS 61, 62, 63

E013 (no measured value available)	2 … 20 min depending on the application
E042/E043 (hardware error)	< 2 min
E036/E037 (no executable sensor software)	< 25 h

VEGAPULS 65, 66

E013 (no measured value available)	2 … 8 min depending on the application
E042/E043 (hardware error)	< 2 min
E036/E037 (no executable sensor software)	< 15 h

VEGAPULS 68 and VEGAPULS 61, 62, 63 with increased sensitivity

E013 (no measured value available)	2 … 36 min depending on the application
E042/E043 (hardware error)	< 4 min
E036/E037 (no executable sensor software)	< 80 h

Single channel architecture

Specific characteristics

SIL	SIL2
HFT	0
Instrument type	Type B

Applies to overfill and dry run protection:

SFF	81 %
PFD_{avg} T_{Proof} = 1 year T_{Proof} = 5 years	 < 0.157×10^{-2} < 0.779×10^{-2}
PFH	< 0.358×10^{-6}/h

Time-dependent process of PFD_{avg}

The chronological sequence of PFD_{avg} is nearly linear to the operating time over a period up to 10 years. The above values apply only to the T_{Proof} interval after which a recurring function test must be carried out.

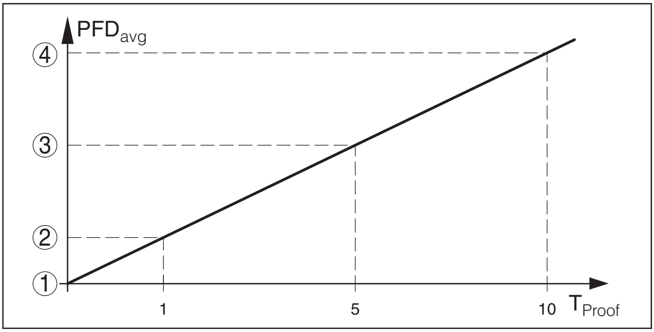

Fig. 1: Chronological sequence of PFD_{avg} (figures see above charts)

1 *PFD_{avg} = 0*
2 *PFD_{avg} after 1 year*
3 *PFD_{avg} after 5 years*
4 *PFD_{avg} after 10 years*

Multiple channel architecture

Specific characteristics

If the measuring system is used in a multiple channel architecture, the safety-relevant characteristics of the selected structure of the meas. chain must be calculated specifically for the selected application according to the above failure rates.

A suitable Common Cause Factor must be taken into account.

The measuring system must only be used in a diversitary redundant architecture!

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2 Appendix A: Recurring function test

2.1 Prerequisites

With the procedure described here you can carry out a recurring function test without dismounting the instrument or moving the product level to the switching point.

With this procedure, 88 % or 96 % of all dangerous undetected instrument failures (λ_{du}) are detected.

Fault detection rate λ_{du} 96 %

If you have already created a sensor documentation during setup, you can check the sensor at a detection rate of 96 % of all dangerous undetected failures.

The remaining dangerous undetected failures are 11 FIT.

FIT = Failure In Time (1 FIT = 1 failure/10^9 h)

Note:
Make sure that also a later sensor documentation is possible. This sensor documentation of a recurring function test must be at least 6 months old.

Fault detection rate λ_{du} 88 %

If you did not create a sensor documentation during setup, you can check the sensor only at a detection rate of 88 % of all dangerous undetected failures.

The remaining dangerous undetected failures are in this case 32 FIT.

FIT = Failure In Time (1 FIT = 1 failure/10^9 h)

Please note the Ex-specific safety information for installation and operation in Ex areas. These safety instructions are part of the scope of delivery and come with the Ex-approved instruments.

Warning:
The recurring function test influences connected devices. Take note that downstream devices may be activated during the test.

Information:
Proceed according to the specified, recommended sequence of these instructions to isolate possible device failures systematically.

Information:
Document the recurring function test, for example, in the test protocol in the Appendix. To facilitate the recording and for further function tests, we recommend to copy the empty test protocol before completing it.

This supplementary information manual can be downloaded from our download section.

Information:
The recurring function test cannot replace the prescribed test according to WHG (Water Resources Act).

2.2 Authorised personnel

All operations described in this operating instructions manual must be carried out only by trained qualified personnel authorised by the plant operator.

During work on and with the device, the required personal protective equipment must always be worn.

2.3 Required tools

- This test instruction
- PACTware
- Actual VEGA DTM Collection
- Device-DTM of the corresponding sensor (part of the VEGA DTM Collection)
- Communication-DTM (part of the VEGA DTM Collection)
- Interface adapter VEGACONNECT
- Ammeter or PLC or process control system (accuracy ≤ ±0.2 %)
- Operating instructions of the sensor
- Safety Manual

2.4 Required comparative data

The setup data should be used for verification of the settings.

The following setup data are required:

- Sensor documentation of the setup with all parameters or a sensor documentation created at least 6 months ago
- Documentation of all parameter changes since the setup

Note:
If the sensor documentation of the setup or a sensor documentation created at least 6 months ago is not available, then the described recurring function test (λ_{du} 96 %) cannot be carried out completely. In this case, only the test at a detection rate of 88 % of all dangerous, undetected failures is possible.

2.5 Required plant situation

Caution:
Make sure that there are no considerable process-relating changes in your plant during the recurring function test. This means also that the level in the vessel should not change significantly by filling or emptying during the test. Make sure that also temperature changes, stirrers, current reactions in the vessel, etc. can cause level changes.

Information:
Document the recurring function test, for example, in the test protocol in the appendix.

The following conditions must be fulfilled for performance of the recurring function test:

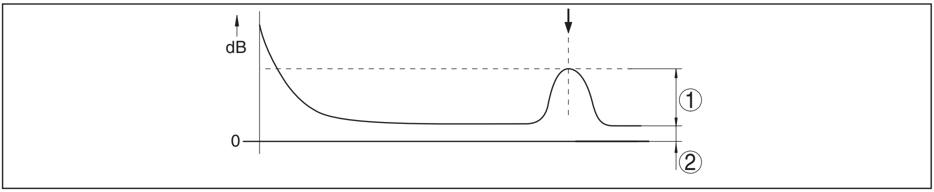

Fig. 2: Level echo - VEGAPULS

1 Amplitude of the useful echo above the noise level (signal/noise ratio)
2 Noise level

- The level must be in the following areas:
  - Min. distance to the level: Lower antenna edge +200 mm
  - Level above the vessel bottom ≥ 250 mm
  - Measurement reliability at least 20 dB (amplitude of the useful logarithmic echo above the noise level). The measurement reliability can be verified during the test.
- The process conditions must be nearly constant (level, process pressure, process temperature).
- The medium must be the same as during setup or the medium must at least belong to the same product group
  - Solvents/Liquid gases/Hydrocarbons/Oils (DK value < 3)
  - Chemical mixtures (DK value 3 … 10)
  - Water/Acids/Bases (DK value > 10 or conductive)

2.6 Sequence of the recurring function test

Carry out the recurring function test in the following sequence:

- 2.7 Restart the sensor
- 2.8 Verification of the current output
- 2.9 Verification of the instrument parameters (only with sensor documentation)
- 2.10 Verification of the echo data (only with sensor documentation)
- 2.11 Sensor reaction to a level change

Information:
Document the recurring function test, for example, in the test protocol in the appendix.

Function test not successful

If one of the test points was not terminated successfully, there is probably an undetected dangerous failure. The recurring function test has failed.

In this case, proof of functional safety can only be provided by moving the level to the switching point.

2.7 Function test - Restart of the sensor

With this test point, it is possible to check of the sensor ouputs the same value within the prescribed min. accuravy after a restart.

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Warning:
The recurring function test influences connected devices. Take note that downstream devices may be activated during the test.

Carry out a restart of the sensor. Proceed as follows:

Before the restart

1. Start PACTware and the corresponding sensor DTM.

   Make sure that the conditions to the plant situation are maintained. See "*Required plant situation*".

   (range of the actual level or the measurement reliability at least 20 dB)
2. Set the indication to "Current".
3. The level is subject to plant or process-relevant fluctuations. Control the indicated current values over an adequate period.

   Make sure that a damping is probably adjusted on the sensor.
4. Note the upper and lower limit values of the measured value.
5. Measure the output current of the sensor.

   Preferrably use the indication of the input current value in the processing system.

   If you do not have this possibility, connect an mA-meter according to the following illustration.

   You require the mA-meter for the verification of the current output in the next test point. The accuracy of the mA-meter should be better than 0.2 %. Select the smallest measuring range covering 4 … 20 mA.

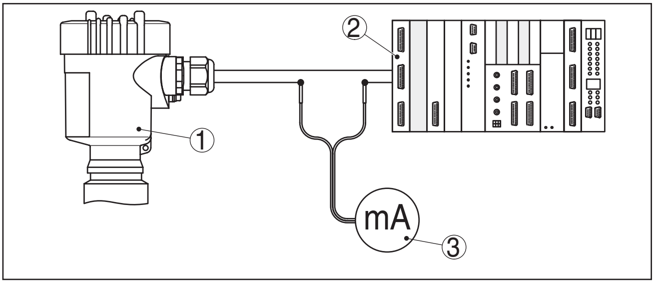

Fig. 3: Connection of the mA-meter

1 Level sensor
2 Processing system
3 mA-meter

6. Switch off the voltage supply.
7. Switch the voltage supply on again after approx. 10 s.

   If the software signals a communication error during or after switching off the power supply, you have to acknowledge it.

After connecting the sensor to voltage supply or after a voltage recurrence, the instrument carries out a self-check for approx. 30 seconds:

- Internal check of the electronics
- The output signal jumps to the set fault current

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Then the current corresponding to the level is output to the cable.

After switching on again

1. The level is subject to plant or process-relevant fluctuations. Control the indicated current values over an adequate period.
2. Note the upper and lower limit values of the measured value.
3. Compare the actually noted current values with the previously noted values.

The two values must correspond within the safety tolerance of 2 % (±0.32 mA).

If the two differential values are within the safety tolerance, then the test of the restart was successful.

Continue with the next test point.

2.8 Function test - Verification of the current output

In this test point you simulate certain level values via the current output. With this you can test the reaction of the sensor with different current output values and the switching behaviour.

Warning:
The recurring function test influences connected devices. Take note that downstream devices may be activated during the test.

Simulation 4 mA

1. Select in the DTM under the menu "*Service*" the menu item "*Simulation*".
2. Select "Current" as measured variable for the simulation.
3. Activate the simulation.
4. Set the simulation value to 4 mA.

   Take note that downstream devices may be activated.
5. Accept the simulation value.

   Wait approx. 30 s.

   The simulation is running and a corresponding current is being output.
6. Note the value (4 mA simulation) displayed on the ammeter.

   The value must correspond with the simulated value within the safety tolerance of 2 % (±0.32 mA).

Continue with the simulation if the two values correspond.

Simulation 20 mA

1. Set the simulation value of the current simulation to 20 mA.

   Take note that downstream devices may be activated.
2. Accept the simulation value.

   Wait approx. 30 s.

   The simulation is running and a corresponding current is being output.
3. Note the value (20 mA simulation) displayed on the ammeter.

   The value must correspond with the simulated value within the safety tolerance of 2 % (±0.32 mA).

The verification of the current output was successful if the two values correspond.

Caution:
Deactivate the simulation.

Continue with the next test point.

2.9 Function test - Verification of the instrument parameters

Note:
For this test point, the sensor documentation of the setup or the last sensor documentation (at least 6 months old) is required. If a parameter was changed since then, you also require the protocol or the sensor documentation of this parameter change.

If this sensor documentation is not available, then the described recurring function test cannot be carried out completely. In this case, only the test with a detection rate of 88 % of all dangerous, undetected failures is possible.

In this case, you continue with the test point "*Sensor reaction on level change*" or create an actual sensor documentation and carry out the function test after at least 6 months. The actual parameter adjustment must be checked for correctness in the respect.

A sensor documentation was created directly after the setup or at least 6 months ago. For assessment of the instrument parameters, the sensor documentation at setup, the current sensor documentation of the last parameter change or the sensor documentation created and checked 6 months ago must be taken into consideration.

Create a current sensor documentation

Create now a sensor documentation with the current instrument parameters. Proceed as follows:

1. Select the function "Print" in the DTM.
2. For complete sensor documentation, you have to select all instrument parameters (except special parameters).

   A multiple-page pdf documentation containing all relevant sensor data is then generated.
3. Save this documentation as pdf document and, where appropriate, print out the documentation to be on the safe side.
4. Compare the instrument parameters of this actual sensor documentation with the sensor documentation of the setup or the last parameter change.

   Deviating parameters must be documented, justified and checked on correctness.

If the actual sensor documentation corresponds to the stored sensor documentation or if the modified parameters are correct, then the verification of the instrument parameters was successful.

Continue with the next test point.

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2.10 Verification of echo data

Note:
For this test point, you require the sensor documentation of the setup or a sensor documentation created at least 6 months ago.

If none of these sensor documentations is available, the described recurring function test (λ_{du} 96 %) cannot be carried out.

Only the test at a detection rate of 88 % of all dangerous undetected failures is possible. In this case, just skip this test point.

In this case, continue with the test point "*Sensor reaction on level change*".

Use the two pdf files of the sensor documentation again for assessment of the level echo.

Under chapter "Echo curve" you will find a short table containing the "Echo data". The data of this table are relevant for the assessment.

Compare the values of the two echo data charts. The echo curve itself cannot be compared.

Calculation of the correction factor

Please proceed as follows:

1. Compare the distance [m] of the two level echoes (actual/setup).
2. Divide the distance [m] of the current level through the distance [m] of the level echo during setup.

   Round this ratio "V" mathematically to one decimal point.
3. Search in the following table the correction value (dB) belonging to the calculated ration "V".
4. Calculate with the correction value the corrected value of the amplitude.

   This corrected value of the amplitude [dB] of the actual level echo can be higher, but only max. 6 dB lower than the amplitude of the level echo during setup.

Ratio "V"	**Correction value (dB)**
0.5	-6
0.6	-4.5
0.7	-3
0.8	-2
0.9	-1
1.0	-0
1.1	+0.8
1.2	+1.5
1.3	+2.3
1.4	+3
1.5	+3.5
1.6	+4

Ratio "V"	Correction value (dB)
1.7	+4.6
1.8	+5
1.9	+5.6
2.0	+6

Example

During setup, the level echo had 32 dB. The distance [m] to the medium was 12.9 m.

The current level echo has 25 dB. The distance [m] to the medium is 15.8 m.

Division of the current distance [m] by the distance [m] during setup: 15.8 m : 12.9 m = 1.224

Round mathematically to one position after the decimal point: 1.224 --> 1.2

Correction value for the ratio (1.2): + 1.5

Calculation of the corrected value of the amplitude:
25 dB + 1.5 = 26.5 dB

The result of the example (26.5 dB) is thus within the permissible tolerance range of - 6 dB (32 dB - 6 dB = 26 dB)

In this example, the test point would be successfully fulfilled.

The following criteria must correspond when comparing the echo data:

- If there are false echoes in front of the level echo (highest useful echo probability), they must have a useful echo probability of 0 %.
- The amplitude [dB] (with correction factor) of the current level echo (highest useful echo probability) corresponds to the respective value of the level echo during setup (tolerance max. -6 dB). This means that the current level echo can be higher, but only max. 6 dB lower than the level echo during setup.

If all the above conditions are fulfilled, the measurement works correctly and the verification of the echo data was successful.

Continue with the next test point.

2.11 Function test - Sensor reaction to a level change

With this test point, you monitor the reaction of the sensor during a level change.

1. Set the indication of the sensor DTM to "Distance".
2. Change the filling of your vessel.

   It doesn't matter if you fill or empty the vessel.

   The filling speed is also not relevant.

   The level change must be at least 50 mm.
3. Take note of the sensor reaction.

Does the measured value [m(d)] move in the correct direction during emptying/filling?

The displayed measured value (distance) is the distance between seal surface of the sensor and the medium surface.

- The measured value will decrease during filling.
- The measured value will increase during emptying.

When the level value changes analogue to the level change, the measurement works correctly and the assessment of the sensor reaction was successful.

If all function tests were successful, the recurring function test is finished.

Note:
If you used an mA-meter for the recurring function test, switch off the sensor and remove the mA-meter from the sensor cable after finishing the recurring function test.

2.12 Result of the recurring function test

Function test successful

If all test points could be terminated successfully, then the recurring function test was successful.

Fulfilled test points	
2.7 / 2.8 / 2.9 / 2.10 / 2.11	Fault detection rate λ_{du} 96 %
2.7 / 2.8 / 2.11 (sensor documentation of the setup or a sensor documentation which is at least 6 months old is not available)	Fault detection rate λ_{du} 88 %

The test must be repeated in regular intervals. The time periods depend on the PFD_{avg} value according to the sepcifications in the Safety Manual (SIL).

Function test not successful

If one of the test points (2.7 / 2.8 / 2.11) could not be terminated successfully, there is probably an undetected dangerous failure. The recurring function test has failed.

In this case, proof of functional safety can only be provided by moving the level to the switching point.

2.13 Test protocol - Recurring function test

If you copy this protocol, please note the date of the function test, the measurement loop and the sensor serial number on each page.

Specifications VEGAPULS	
Tester	
Measurement loop name (sensor-TAG)	
Sensor type	
Serial number of the sensor	
Software version	

Specifications VEGAPULS	
Required plant situation (according to chapter 2.5)	☐ maintained
Safety-instrumented system (SIS)	☐ yes
SIL activated	☐ yes
Medium or process assembly	
Date of the setup (sensor documentation)	
Date of the last function test (if carried out)	

Test 2.7 - Restart of the sensor		
Measured value before switching off	Current value min. in mA	Current value max. in mA
Measured value after switching on again	Current value min. in mA	Current value max. in mA
Difference of the current values	Current value min. in mA	Current value max. in mA
Duration of the inspection in s		
Test result Min. and max. values	☐ Deviation ≤ 2 % (test point successful)	☐ Deviation > 2 % (test point not successful)

Test 2.8 - Verification of the current output		
Lower simulation value (4 mA)	Indication mA-meter in mA	
Intermediate result ≤ 2 % (≤ 0.32 mA)	☐ Corresponds	☐ Does not correspond
Upper simulation value (20 mA)	Indication mA-meter in mA	
Intermediate result ≤ 2 % (≤ 0.32 mA)	☐ Corresponds	☐ Does not correspond
Test result - Total	☐ Corresponds	☐ Does not correspond

Test 2.9 - Verification of the instrument parameters		
☐ Sensor documentation at setup available or ☐ Sensor documentation (at least 6 months old) is available	File name:	
	☐ Parameters correspond	
	☐ Parameters do not correspond - however checked on correctness	File name:
	☐ Parameters do not correspond - deviation not acceptable	File name:
☐ Sensor documentation at setup not available	☐ Parameters checked on correctness and saved (recheck after 6 months necessary)	File name:
Test result	☐ All parameters correct or checked on correctness	☐ Parameters not correct
	Tester:	

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Test 2.10 - Verification of the echo data		
No false echoes or echoes with useful echo probability 0 %	☐ Corresponds	☐ Does not correspond
Corresponding amplitude	☐ In the tolerance range	☐ Not in the tolerance range
Test result	☐ Corresponds	☐ Does not correspond

Test 2.11 - Verification of the sensor reaction		
Reduction of the level	☐ Distance value [m] increases	☐ Other reaction
Increase of the level	☐ Distance value [m] decreases	☐ Other reaction
Test result	☐ Corresponding sensor reaction	☐ Sensor reaction does not correspond

● Summary 96 % (λ_{du})		
	Date	Signature
Test 2.7 / 2.8 / 2.9 / 2.10 / 2.11	☐ All five test points passed	☐ One or several test points did not pass

● Summary 88 % (λ_{du})		
	Date	Signature
Test 2.7 / 2.8 / 2.11	☐ All three test points passed	☐ One or several test points did not pass

Date ______________________________________

Signature ______________________________________

3 Appendix B: Test report

FMEDA and Proven-in-use Assessment

Project:
Radar Transmitters VEGAPULS 60
for level measurement of liquids and solids

Customer:
VEGA Grieshaber KG
Schiltach
Germany

Contract No.: VEGA 04/08-03
Report No.: VEGA 04/08-03 R008
Version V3, Revision R1.0, June 2006
Stephan Aschenbrenner

Management summary

This report summarizes the results of the hardware assessment with proven-in-use consideration according to IEC 61508 / IEC 61511 carried out on the radar transmitters VEGAPULS 60 with 4..20 mA HART® output and software version Rev. 3.32. The devices manufactured in the USA by the Ohmart / VEGA Corporation carry the same name and are identically constructed under comparable quality aspects. Table 1 gives an overview of the different types that belong to the considered radar transmitters VEGAPULS 60.

The hardware assessment consists of a Failure Modes, Effects and Diagnostics Analysis (FMEDA). A FMEDA is one of the steps taken to achieve functional safety assessment of a device per IEC 61508. From the FMEDA, failure rates are determined and consequently the Safe Failure Fraction (SFF) is calculated for the device. For full assessment purposes all requirements of IEC 61508 must be considered.

Table 1: Version overview

(K-Band ~26GHz)		(C-Band ~6,3GHz)	
VEGAPULS 61	horn antenna – PVDF - enclosed	VEGAPULS 65	rod antenna
VEGAPULS 62	horn antenna / parabolic antenna	VEGAPULS 66	with or without horn antenna
VEGAPULS 62	standpipe	VEGAPULS 66 (HT)	with or without horn antenna (high temperature version)
VEGAPULS 63	horn antenna – PTFE - enclosed (flush mounted with flange)		
VEGAPULS 68	horn antenna / parabolic antenna – for bulk solids		

For safety applications only the 4..20 mA output was considered. All other possible output variants or electronics are not covered by this report. The different devices can be equipped with or without display.

The failure rates used in this analysis are the basic failure rates from the Siemens standard SN 29500.

According to table 2 of IEC 61508-1 the average PFD for systems operating in low demand mode has to be $\geq 10^{-3}$ to < 10^{-2} for SIL 2 safety functions. A generally accepted distribution of PFD_{AVG} values of a SIF over the sensor part, logic solver part, and final element part assumes that 35% of the total SIF PFD_{AVG} value is caused by the sensor part.

For a SIL 2 application operating in low demand mode the total PFD_{AVG} value of the SIF should be smaller than 1,00E-02, hence the maximum allowable PFD_{AVG} value for the sensor part would then be 3,50E-03.

The radar transmitters VEGAPULS 60 are considered to be Type B[1] components with a hardware fault tolerance of 0.

Type B components with a SFF of 60% to < 90% must have a hardware fault tolerance of 1 according to table 3 of IEC 61508-2 for SIL 2 (sub-) systems.

[1] Type B component: "Complex" component (using micro controllers or programmable logic); for details see 7.4.3.1.3 of IEC 61508-2.

As the radar transmitters VEGAPULS 60 are supposed to be proven-in-use devices, an assessment of the hardware with additional proven-in-use demonstration for the radar transmitters and their software was carried out. Therefore according to the requirements of IEC 61511-1 First Edition 2003-01 section 11.4.4 and the assessment described in section 5.6 a hardware fault tolerance of 0 is sufficient for SIL 2 (sub-) systems being Type B components and having a SFF of 60% to < 90%.

VEGA did a qualitative analysis of the mechanical parts of the radar transmitters VEGAPULS 60 (see [D11]). This analysis was used by *exida* to calculate the failure rates of the sensor elements using different failure rate databases ([N6], [N7], [N8] and *exida*'s experienced-based data compilation) for the different components of the sensor elements (see [R2] to [R9]). The results of the quantitative analysis were used for the calculations described in sections 5.2 to 5.7.

Assuming that the application program in the safety logic solver is configured to detect under-range and over-range failures and does not automatically trip on these failures, these failures have been classified as dangerous detected failures. The following tables show how the above stated requirements are fulfilled.

Table 2: Summary for the worst case version – Failure rates

Failure category	**Failure rates (in FIT)**
Fail Dangerous Detected	**1129**
Fail detected (internal diagnostics or indirectly) = $\lambda_{su} + \lambda_{dd}$	462
Fail low (detectable by the logic solver)	639
Fail High (detectable by the logic solver)	28
Fail Dangerous Undetected	**358**
No Effect	**409**
Annunciation Undetected	**52**
Not part	**295**
MTBF = MTTF + MTTR	51 years

Table 3: Summary for the worst case version – IEC 61508 Failure rates

λ_{SD}	λ_{SU} [2]	λ_{DD}	λ_{DU}	**SFF**	**DC$_S$** [3]	**DC$_D$** [3]
0 FIT	461 FIT	1129 FIT	358 FIT	81%	0%	75%

Table 4: Summary for the worst case version – PFD$_{AVG}$ values

T[Proof] = 1 year	**T[Proof] = 5 years**	**T[Proof] = 10 years**
PFD$_{AVG}$ = 1,57E-03	**PFD$_{AVG}$ = 7,79E-03**	**PFD$_{AVG}$ = 1,55E-02**

[2] Note that the SU category includes failures that do not cause a spurious trip

[3] DC means the diagnostic coverage (safe or dangerous) for the radar transmitters VEGAPULS 60 by the safety logic solver.

The boxes marked in yellow ( ) mean that the calculated PFD_{AVG} values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 but do not fulfill the requirement to not claim more than 35% of this range, i.e. to be better than or equal to 3,50E-03. The boxes marked in green ( ) mean that the calculated PFD_{AVG} values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 and do fulfill the requirement to not claim more than 35% of this range, i.e. to be better than or equal to 3,50E-03. The boxes marked in red ( ) mean that the calculated PFD_{AVG} values do not fulfill the requirements for SIL 2 according to table 2 of IEC 61508-1.

The failure rates listed above do not include failures resulting from incorrect use of the radar transmitters VEGAPULS 60, in particular humidity entering through incompletely closed housings or inadequate cable feeding through the inlets.

The listed failure rates are valid for operating stress conditions typical of an industrial field environment similar to IEC 60654-1 class C (sheltered location) with an average temperature over a long period of time of 40ºC. For a higher average temperature of 60°C, the failure rates should be multiplied with an experience based factor of 2,5. A similar multiplier should be used if frequent temperature fluctuation must be assumed.

A user of the radar transmitters VEGAPULS 60 can utilize these failure rates in a probabilistic model of a safety instrumented function (SIF) to determine suitability in part for safety instrumented system (SIS) usage in a particular safety integrity level (SIL). A full table of failure rates for different operating conditions is presented in sections 5.2 to 5.7 along with all assumptions.

It is important to realize that the “no effect” failures and the “annunciation” failures are included in the “safe undetected” failure category according to IEC 61508. Note that these failures on its own will not affect system reliability or safety, and should not be included in spurious trip calculations.

The failure rates are valid for the useful life of the radar transmitters VEGAPULS 60 (see Appendix 3).

Printing date:

All statements concerning scope of delivery, application, practical use and operating conditions of the sensors and processing systems correspond to the information available at the time of printing.
Subject to change without prior notice

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