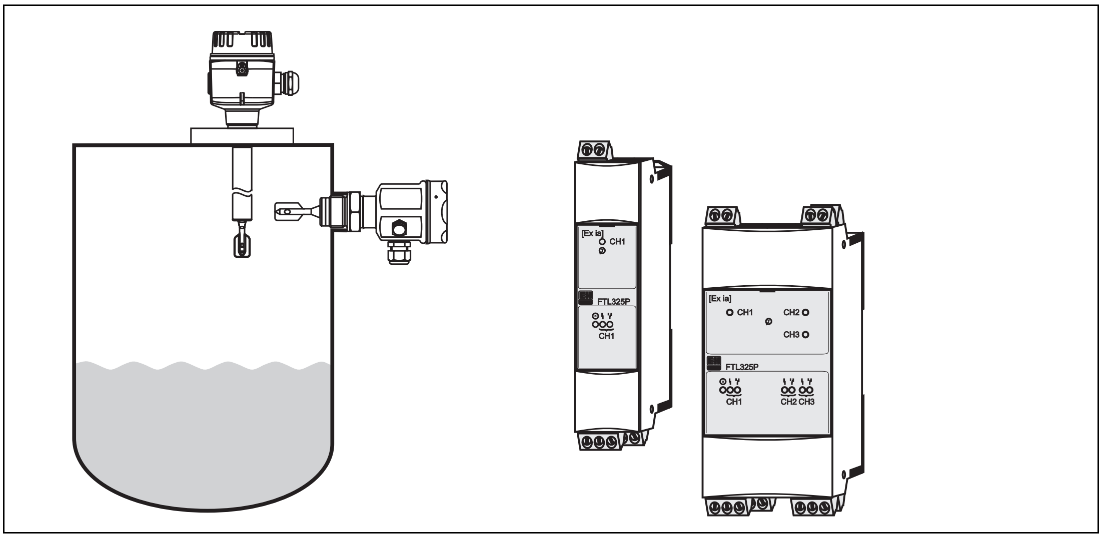
Level Pressure Flow Temperature Liquid Analysis Registration Systems Components Services Solutions

Functional safety manual

Liquiphant M/S with electronic insert FEL57 + Nivotester FTL325P

Level Limit Measuring System



Application

Overfill protection or operating maximum detection of all types of liquids in tanks to satisfy particular safety systems requirements as per IEC 61508.

The measuring device fulfills the requirements concerning

- Safety functions up to SIL 3
- Explosion protection by means of intrinsic safety
- EMC to EN 61326 and NAMUR Recommendation NE 21.

Content

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  Functional safety manual
  – Certified by TUEV Rheinland/Berlin Brandenburg TUEV Anlagentechnik GmbH Automation, software and IT to IEC 61508
- Page 19 to 40
  Functional safety manual
  – Independently assessed (Functional Assessment) by *exida* as per IEC 61508

SD111F/00/en
52010553

Endress+Hauser
People for Process Automation

TÜV certificate

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Berlin-Brandenburg

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TÜV Anlagentechnik GmbH
Automation, Software und Informationstechnologie

ZERTIFIKAT
CERTIFICATE

Nr./No. 968/EL 133.01/01

Prüfgegenstand **Product tested**	Level Limit Measuring System Nivotester FTL325P with Liquiphant M/S + FEL57	**Hersteller** **Manufacturer**	Endress + Hauser GmbH + Co. Hauptstraße 1 D-79689 Maulburg Germany
Typbezeichnung **Type designation**	Vibration limit switch Liquiphant M/S + FEL57 with Nivotester FTL325P. Instrument types and settings acc. to Safety Manual	**Verwendungs-zweck** **Intended application**	Maximum detection of liquids in applications of safety related *shut-down systems* up to SIL 2/ AK 4, SIL 3/AK 5 - 6 resp.
Prüfgrundlagen **Codes and standards forming the basis of testing**	IEC 61508, part 1 - 7/2000 DIN V 19250/1994 DIN V VDE 0801/1990 + A1/1994 EN 61131-2/1994 EN 50178/1998 EN 61326/1997 + A1/1998		
Prüfungsergebnis **Test results**	Suitable for safety related applications up to SIL 3/AK 6 according to the results of the test report no. 968/EL 133.00/01 dated 2001-04-30. Considering the instructions of the Safety Manual SD 111F/00/../09.01 the requirements of the codes and standards forming the basis of the testing are fulfilled.		
Besondere Bedingungen **Specific requirements**	The instructions for installation, operating and maintenance of the Safety Manual SD 111F/00/../09.01 must be considered.		

Die Prüfberichte Nr. 968/EL 133.00/01 vom 2001-04-30 und Nr. 968/EL 133.01/01 vom 2001-11-28 sind Bestandteile dieses Zertifikates.
Dieses Zertifikat ist nur gültig für Erzeugnisse, die mit dem Prüfgegenstand übereinstimmen. Es wird ungültig bei jeglicher Änderung der Prüfgrundlagen für den angegebenen Verwendungszweck.

The test reports No. 968/EL 133.00/01 dated 2001-04-30 and No. 968/EL 133.01/01 dated 2001-11-28 are integral parts of this certificate.
This certificate is valid only for products which are identical with the product tested. It becomes invalid at any change of the codes and standards forming the basis of testing for the intended application.

TÜV Anlagentechnik GmbH
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2001-11-28		H. Gull
Datum/Date	Firmenstempel/Company seal	Unterschrift/Signature

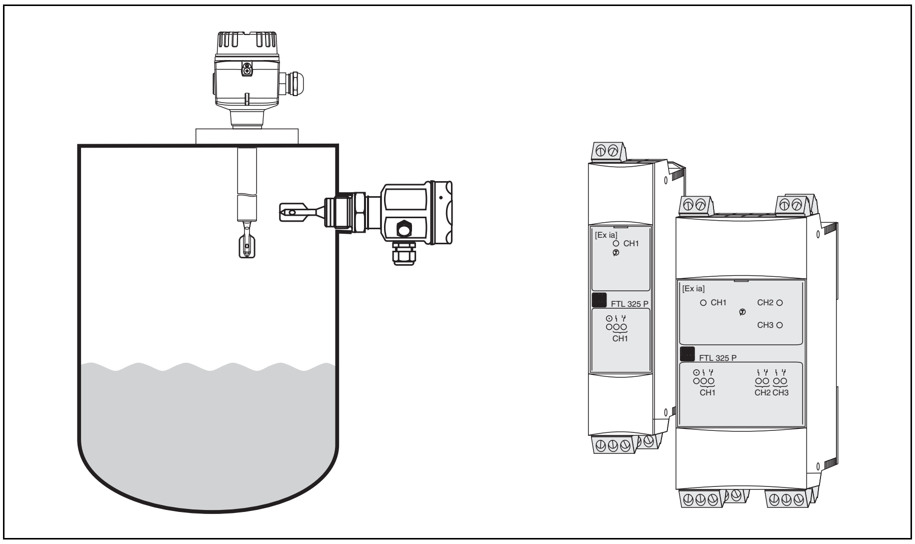
10/102 BB neutral 4.98

SIL05006a

Safety Manual
SD 111F/00/en/09.01
52010553

Limit Level Measuring System liquiphant M/S + nivotester FTL 325 P

Functional safety manual



Areas of application:
Overfill prevention device or operating maximum detection of all types of liquids in tanks or piping to satisfy particular safety systems requirements to IEC 61508 or DIN V 19250.

The measuring system fulfils the requirements concerning
- Functional safety according to IEC 61508 and DIN V 19250
- Explosion protection by intrinsic safety
- EMC to NAMUR Recommendations

Benefits at a glance
- For overfill prevention up to SIL 2/AK 4, in redundant versions up to SIL 3/AK 5&6
  - Certified by TUEV Rheinland/ Berlin Brandenburg TUEV Anlagentechnik GmbH Automation, software and IT to IEC 61508
- Permanent self-monitoring
- No calibration
- Protected against outside vibration by optimised drive
- Space-saving switching unit
- Measuring system test by pressing a test-button
- Fail-safe by PFM technology

Endress + Hauser
The Power of Know How

Contents

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Introduction

Terms and standards

Abbreviations

PFD	Probability of dangerous Failure on Demand	
PFD_{av}	Probability (average) of a dangerous Failure on Demand	
SIL	Safety Integrity Level *Discrete level (one out of possible four) for specifying the safety integrity requirements of the safety functions to be allocated to the E/E/PE safety related systems where safety integrity level 4 has the highest level of safety integrity and safety integrity level 1 has the lowest*	
HFT	Hardware Fault Tolerance *Ability of a functional unit (hardware) to continue to perform a required function in the presence of faults or errors*	
SFF	Safe Failure Fraction *Fraction of failure which do not have the potential to put the safety-related system in a hazardous or fail-to-function state*	
CCF, CC	Common Cause Failure *Failure which is the result of one or more events causing coincident failures of two or more separate channels in a multiple channel system, leading to system failure*	
E/E/PE	Electrical / Electronic / Programmable Electronic System	
XooY	"x out of y“ Voting (e.g. 2003)	
MTTR	Mean Time To Repair	
MTBF	Mean Time Between Failure	
TI	Test Interval between life testing of the protection function (in years)	

Tab. 1: Definitions from IEC 61508 Part 4

Relevant standards

IEC 61508 Part 1-7	Functional safety of programmable electronic safety-related systems (Target group: Manufacturers & Suppliers of Devices)	
IEC 61511 Part 1-3 Draft	Functional safety instrumented systems for the process industry sector. (Target group: Safety Instrumented Systems Designers, Integrators & Users)	
DIN V VDE 0801 A1	Principles for computers in safety-related systems (including Amendment A1)	
DIN V 19250	Fundamental safety aspects for measurement and control equipment	

Tab. 2: Relevant standards

Terms

Safety system	Complete safety-related measuring chain (protection function)
Safety function	Defined function performed by the system on demand

Tab. 3: Terms

General display of a safety system (protection function)

Version tables for determining Safety Integrity Level (SIL)

The following tables are used to define the reachable SIL or the requirements pertaining to the "Average Probability of a Dangerous Failure On Demand" (PFD_{av}), "Hardware Fault Tolerance" (HFT) and the "Safe Failure Fraction" (SFF) of the safety system. Refer to the tables in the Appendix for the specific values of the measuring system Liquiphant M/S (FEL 57) and Nivotester FTL 325 P.

The relationship between AK-classes according to DIN V 19250 and the Safety Integrity Level (SIL) according to IEC 61508:

AK-classes (DIN V 19250)		Safety Integrity Level SIL (IEC 61508)
1		–
2 & 3	⇒	1
4	⇒	2
5 & 6	⇒	3
7 & 8	⇒	4

Tab. 4: Relationship between AK and SIL

Permitted failure probability of the complete safety system as a function of SIL for systems which must react on demand (e.g. sensor signal when covered).

SIL	PFD_{av}
4	$\geq 10^{-5} ... < 10^{-4}$
3	$\geq 10^{-4} ... < 10^{-3}$
2	$\geq 10^{-3} ... < 10^{-2}$
1	$\geq 10^{-2} ... < 10^{-1}$

Tab. 5: Permitted failure probabilities (Source: IEC 61508, Part 1)

The ranges of PFD_{av} are generally distributed as follows for the whole safety system:

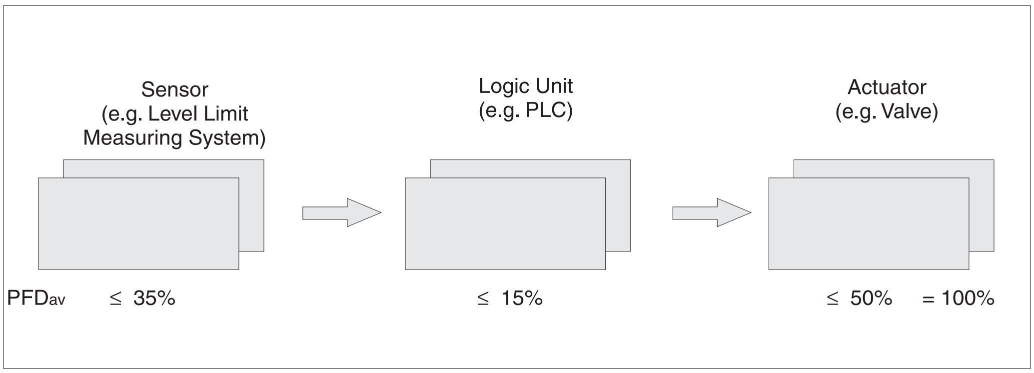


Fig. 1: General distribution of PFD_{av}

The following table shows the achievable Safety Integrity Level (SIL) as a function of the amount of safety-oriented errors and the hardware fault tolerance of the complete safety system for type B systems (complex components, for definition see IEC 61508, Part 2):

SFF		HFT		
		0	1	2
none:	< 60 %	not allowed	SIL 1	SIL 2
low:	60 % ...< 90 %	SIL 1	SIL 2	SIL 3
medium:	90 % ...< 99 %	SIL 2	SIL 3	SIL 4
high:	≥ 99 %	SIL 3	SIL 4	SIL 4

Tab. 6: Attainable SIL (Source: IEC 61508, Part 2)

Sensors in the measuring system with Liquiphant M/S (FEL 57) and Nivotester FTL 325 P

Limit level measuring system

Fig. 2 shows the instruments in the measuring system.

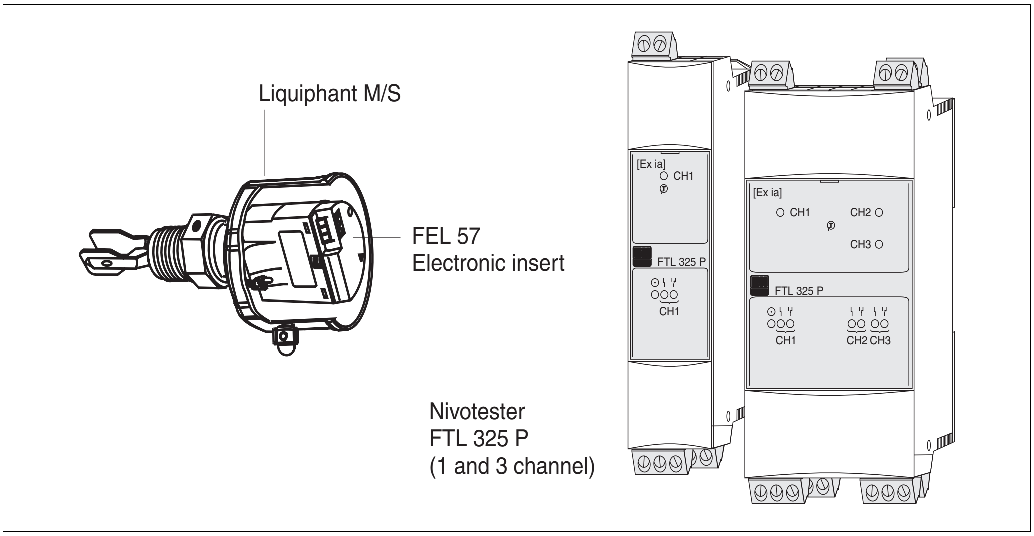


Fig. 2: Measuring system instruments (example)

Safety function

The safety function applies to all settings in MAX safety (monitoring of the covered state) and use of the NO contacts of the level relays.
The following settings are permitted for the safety function:

Instrument	Setting	As-delivered state
Liquiphant	Density switch setting: 0.5 Density switch setting: 0.7	Density switch setting: 0.7
	Test mode "STD" Test mode "EXT"	Test mode "STD"
Nivotester FTL325P-#3#3	MAX safety	MAX safety
	All settings **except** "ΔS function" (see chapter "Settings and installation instructions")	Three-channel operation
Nivotester FTL325P-#1#1	MAX safety	MAX safety
		One-channel operation

Tab. 7: Settings

The MAX safety setting has the effect that the level relay always works in quiescent current safety, i.e. the relay releases when:
- the switch point is exceeded (level exceeds response height)
- a fault occurs
- mains voltage fails

In addition to the level relay, the alarm relay works in quiescent current safety and releases when
- one of the following faults occurs:
  - the sensor connection is interrupted
  - the sensor connection short circuits
  - the sensor identifies corrosion at the vibration system
- mains voltage fails

Note!
- When the alarm relay releases, the level relay also releases.

Permitted combination of Nivotester with Liquiphant M/S for the safety function

The following combinations are permitted for the measuring system:

Nivotester		Liquiphant M + (FEL 57)	Liquiphant S + (FEL 57)
Three-channel instrument	Three-channel instrument		
FTL 325 P-H### FTL 325 P-P### FTL 325 P-T###	FTL 325 P-H### FTL 325 P-P### FTL 325 P-T###	FTL 50-######7###* FTL 51-######7###* FTL 50 H-######7###* FTL 51 H-######7###* FTL 51 C-######7####*	FTL 70-######7####* FTL 71-######7####*

*Tab. 8: Permitted instrument types (# = all instrument versions permitted); ** 7 = FEL 57 insert

Safety function data

The **mandatory settings** and data for the safety function can be found in the **Appendix**.
The measuring system reacts in ≤ 0.9 seconds.

Note!
- MTTR is set at eight hours.

Safety systems without a self-locking function must be monitored or set to an otherwise safe state after carrying out the safety function within MTTR.

Supplementary device documentation

The following must be available for the measuring system:

	Technical Information	Operating Instructions
Nivotester FTL 325 P	*For all instrument types:* TI 350F	*One channel instrument FTL 325 P-#1#1:* KA 167F
		Three channel instrument FTL 325 P-#3#3: KA 168F
Liquiphant M	*Types: FTL 50, FTL 51, FTL 50 H, FTL 51 H:* TI 328F	*Types: FTL 50, FTL 51:* KA 143F
		Types: FTL 50, FTL 51: KA 163F *(with aluminium housing/separate terminal compartment)*
		Types: FTL 50 H, FTL 51 H: KA 144F
		Types: FTL 50 H, FTL 51 H: KA 164F *(with aluminium housing/separate terminal compartment)*
	Type: FTL 51 C TI 354F	*Type: FTL 51 C:* KA 162F
		Type: FTL 51 C: KA 165F *(with aluminium housing/separate terminal compartment)*
Liquiphant S	*For all instrument types:* TI 354F	*Types FTL 70, FTL 71:* KA 172F
		Types: FTL 70, FTL 71: KA 173F *(with aluminium housing/separate terminal compartment)*
Relevant contend	Connection data Installation instructions	Setting, configuration, remarks, function tests

Tab. 9: Supplementary documentation

Settings and installation instructions

The ambient conditions for the Nivotester FTL 325 P must correspond to IP54 (as per EN 60529).

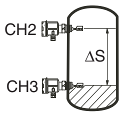
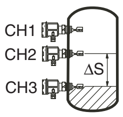
Refer to the following documentation for instructions on setting the instruments:

Instrument	Setting description in documentation:
Liquiphant M/S (FEL 57)	KA 143F, KA 163F, KA 144F, KA 164F, KA 162F, KA 165F, KA 172F, KA 173F, *
Nivotester FTL 325 P-#1#1	KA 167F
Nivotester FTL 325 P-#3#3	KA 168F

Tab. 10: Instrument documentation (type-dependent, see Tab. 9)*

Settings for Liquiphant M/S (FEL 57):
- The **density switch setting** has an influence on probability of failure and function test type (refer to the Appendix for details).
- The **test mode** setting has influence on the function test (refer to the Tab. 13 for details).

Settings for Nivotester FTL 325 P-#3#3 (three-channel version):

Setting	Description	Caution!
	Channels 2+3 in Delta-S function	THIS SETTING IS NOT PERMITTED FOR THE SAFETY FUNCTION
	Channel 1 independent	Channel 1 is permitted for the safety function
	Channels 2+3 in Delta-S function	CHANNELS 2 AND 3 IN THIS SETTING ARE NOT PERMITTED FOR THE SAFETY FUNCTION

Tab. 11: Settings of the Nivotester

Caution!
Observe the following for the Nivotester FTL 325 P-####:
The operator must use suitable measures (e.g. current limiter, fuses) to ensure the relay contact characteristics are not exceeded:

- $U \leq 253$ V AC 50/60 Hz, $I \leq 2$ A, $P \leq 500$ VA at $\cos \varphi \geq 0.7$ or
- $U \leq 40$ V DC, $I \leq 2$ A, $P \leq 80$ W

Caution!
Changes to the measuring system and settings after start-up can impair the protection function!

Response in operation and failure

Response in operation and failure is described in the following documentation:

Instrument	Description in documentation:
Liquiphant M/S (FEL 57)	KA 143F, KA 163F, KA 144F, KA 164F, KA 162F, KA 165F, KA 172F, KA 173F, *
Nivotester FTL 325 P-#1#1	KA 167F
Nivotester FTL 325 P-#3#3	KA 168F

Tab. 12: Instrument documentation (type-dependent, see Tab. 9)*

Recurrent function tests of the measuring system

The measuring system should be checked as follows:

Liquiphant M/S		**Nivotester**	**Test**	
Setting density switch	Test mode setting	Setting	Test interval	Description of test procedure
Setting 0.7	STD or EXT	Any permitted setting and Alarm signal CH1 -> ON, if channel 1 connected to a sensor	Annual function test	KA 167F KA 168F
Setting 0.5	STD or EXT	Any permitted setting and Alarm signal CH1 -> ON, if channel 1 connected to a sensor	Annual function test and complete test: Covered signal monitoring, e.g. by approaching the level, at least every 5 years	

Tab. 13: Recurrent functional test

Caution!
Note the following points for the function test:

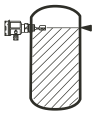
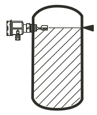
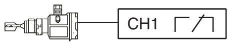
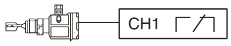
- Test each channel individually by pressing the associated test key.
- Check the electrical switching of relay contacts, e.g. using a hand multimeter connected to the terminals.
- In multi-channel instruments, all channels which do not carry out a safety function must be included in the recurrent function tests if faulty functioning cannot be detected by any other means - e.g. by means of independent protective measures or changing the response of the measuring point.
- A positive test result is obtained when the system reaction corresponds to the description.
- **If the system reaction does not correspond to the described procedure, the monitored process must be kept in a safe state by additional or different measures until the safety system is repaired.**

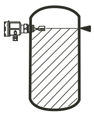
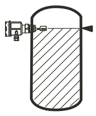
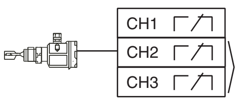
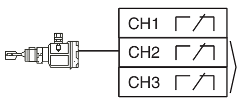
Appendix

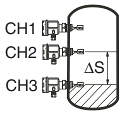
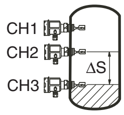
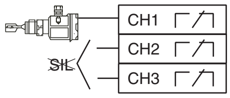
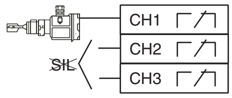
Specific values and wiring options for the measuring system Liquiphant M/S (FEL 57) and Nivotester FTL 325 P

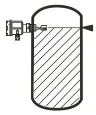
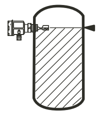
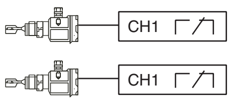
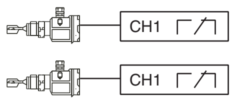
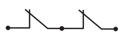
The tables show the specific values and wiring options for the measuring system.

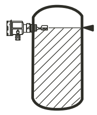
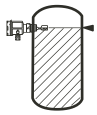
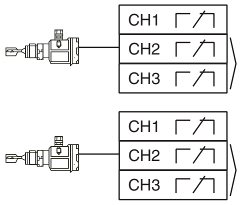
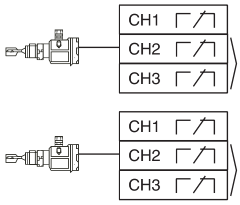
Note!
Note the following points on the tables below:
- The PFD_{av} values for multichannel systems already contain common cause errors for the associated wiring scheme.
- The PFD_{av} values are only valid for associated wiring scheme. They are not suitable for deriving calculations for other wiring schemes.
  Using NC contacts instead of NO contacts requires further consideration of the installation means.
- The wiring scheme shows the number of instruments (Liquiphant and Nivotester) and the limit relay contact circuits (open, when the sensor signals covering).
- With several instruments in a wiring scheme, they all indicated the same displayed settings.

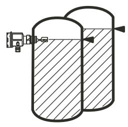
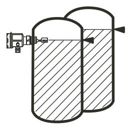
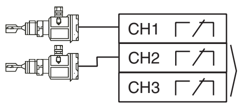
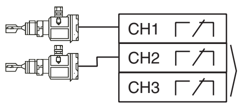
1oo1 architecture		
Liquiphant setting	Density 0.7	Density 0.5
Nivotester FTL 325 P-#1#1- Setting (one-channel instrument)	 MAX	 MAX
SIL / AK	SIL 2 / AK 4	SIL 2 / AK 4
HFT	0	0
SFF	> 90 %	> 90 %
PFDav	< 0.15 x 10^{-2}	< 0.20 x 10^{-2}
Wiring scheme	 CH1: 	 CH1: 
Function test with test key	Annual	Annual
Complete function test, e.g. by approaching level	Not required within normal life	at least every 5 years

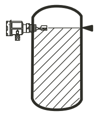
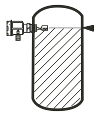
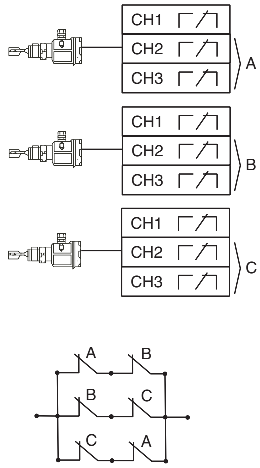
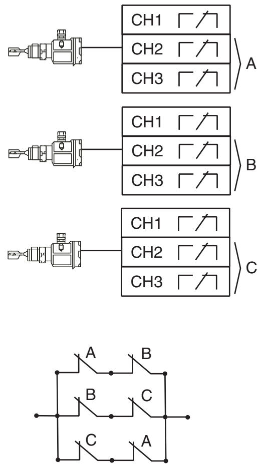
1oo1 architecture		
Liquiphant setting	Density 0.7	Density 0.5
Nivotester FTL 325 P-#3#3- Setting (three-channel instrument)	 MAX	 MAX
SIL / AK	SIL 2 / AK 4	SIL 2 / AK 4
HFT	0	0
SFF	> 90 %	> 90 %
PFDav	< 0.15 x 10^{-2}	< 0.20 x 10^{-2}
Wiring scheme	 CH2 or CH3: 	 CH2 or CH3: 
Function test with test key	Annual	Annual
Complete function test, e.g. by approaching level	Not required within normal life	at least every 5 years

1oo1 architecture		
Liquiphant setting	Density 0.7	Density 0.5
Nivotester FTL 325 P-#3#3- Setting (three-channel instrument)	 MAX	 MAX
SIL / AK	SIL 2 / AK 4	SIL 2 / AK 4
HFT	0	0
SFF	> 90 %	> 90 %
PFDav	< 0.15 x 10^{-2}	< 0.20 x 10^{-2}
Wiring scheme	 CH1: 	 CH1: 
Function test with test key	Annual	Annual
Complete function test, e.g. by approaching level	Not required within normal life	at least every 5 years

1oo2 architecture		
Liquiphant setting	Density 0.7	Density 0.5
Nivotester FTL 325 P-#1#1- Setting (one-channel instrument)	 MAX	 MAX
SIL / AK	SIL 3 / AK 5&6	SIL 3 / AK 5&6
HFT	1	1
SFF	> 90 %	> 90 %
PFDav	< 0.10 x 10^{-3}	< 0.15 x 10^{-3}
Wiring scheme	 CH1 + CH1: 	 CH1 + CH1: 
Function test with test key	Annual	Annual
Complete function test, e.g. by approaching level	Not required within normal life	at least every 5 years

1oo2 architecture		
Liquiphant setting	Density 0.7	Density 0.5
Nivotester FTL 325 P-#3#3- Setting (three-channel instrument)	 MAX	 MAX
SIL / AK	SIL 3 / AK 5&6	SIL 3 / AK 5&6
HFT	1	1
SFF	> 90 %	> 90 %
PFDav	< 0.10 x 10^{-3}	< 0.15 x 10^{-3}
Wiring scheme	 CH2 + CH2 or CH3 + CH3: 	 CH2 + CH2 or CH3 + CH3: 
Function test with test key	Annual	Annual
Complete function test, e.g. by approaching level	Not required within normal life	at least every 5 years

1oo2 architecture		
Liquiphant setting	Density 0.7	Density 0.5
Nivotester FTL 325 P-#3#3- Setting (three-channel instrument)	 MAX	 MAX
SIL / AK	SIL 3 / AK 5&6	SIL 3 / AK 5&6
HFT	1	1
SFF	> 90 %	> 90 %
PFDav	< 0.10 x 10^{-3}	< 0.15 x 10^{-3}
Selection circuit	 CH1 + CH2 or CH1 + CH3: 	 CH1 + CH2 or CH1 + CH3: 
Function test with test key	Annual	Annual
Complete function test, e.g. by approaching level	Not required within normal life	at least every 5 years

2oo3 architecture		
Liquiphant setting	Density 0.7	Density 0.5
Nivotester FTL 325 P-#3#3-Setting (three-channel instrument)	 MAX	 MAX
SIL / AK	SIL 3 / AK 5&6	SIL 3 / AK 5&6
HFT	1	1
SFF	> 90 %	> 90 %
PFDav	$< 0.10 \times 10^{-3}$	$< 0.15 \times 10^{-3}$
Wiring scheme		
Function test with test key	Annual	Annual
Complete function test, e.g. by approaching level	Not required within normal life	at least every 5 years

Notes

Subject to modification

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Gmbh+Co.
Instruments International
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Germany

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Endress + Hauser
The Power of Know How

SD 111F/00/en/09.01
52010553
CCS/FM 6

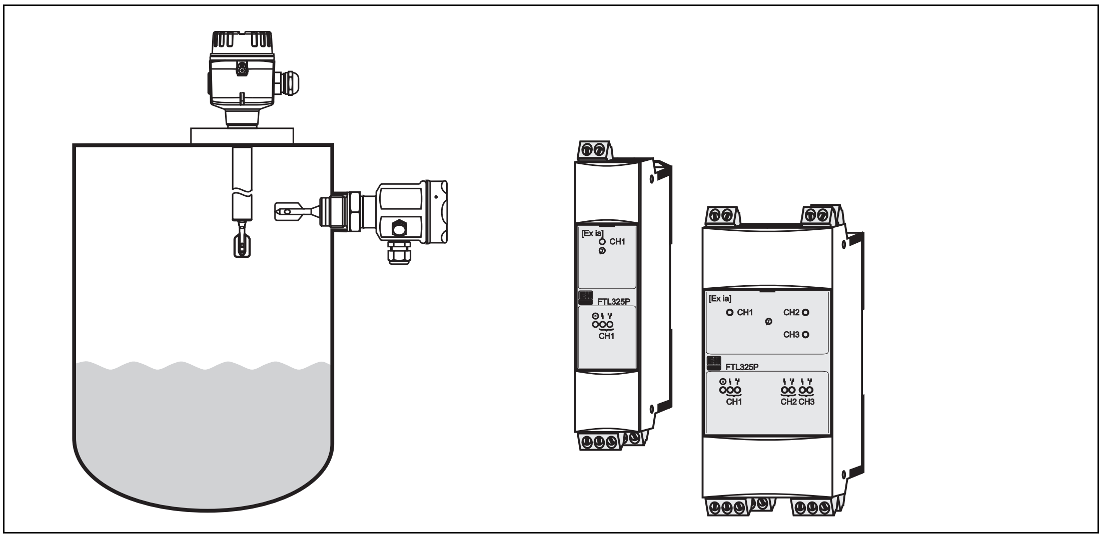
52010553

Level Pressure Flow Temperature Liquid Analysis Registration Systems Components Services Solutions

Functional safety manual

Liquiphant M/S with electronic insert FEL57 + Nivotester FTL325P

Level Limit Measuring System



Application
Overfill protection or operating maximum detection of all types of liquids in tanks to satisfy particular safety systems requirements as per IEC 61508.

The measuring device fulfills the requirements concerning
- Safety functions up to SIL 3
- Explosion protection by means of intrinsic safety
- EMC to EN 61326 and NAMUR Recommendation NE 21.

Your benefits
- For overfill protections up to SIL 2, in redundant version up to SIL 3
  - Independently assessed (Functional Assessment) by *exida* as per IEC 61508
- Permanent automatic monitoring
- No calibration
- Insensitive to external vibration
- Easy commissioning
- Space-saving switching unit
- Testing of the measuring system at the push of a button
- Fail-safety by means of PFM technology

SD111F/00/en
52010553

Endress+Hauser
People for Process Automation

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SIL declaration of conformity

SIL-06002a/00/a2

SIL-Konformitätserklärung
Funktionale Sicherheit nach IEC 61508

SIL Declaration of Conformity
Functional safety according to IEC 61508

Endress+Hauser GmbH+Co. KG, Hauptstraße 1, 79689 Maulburg

Level
Pressure
Flow
Temperature
Liquid Analysis
Registration
Systems Components
Services
Solutions

erklärt als Hersteller, dass der Füllstandgrenzschalter für Flüssigkeiten
declares as manufacturer, that the level limit switch for liquids

Liquiphant M FTL5x or Liquiphant S FTL7x
+ Electronic insert FEL57 and Nivotester FTL325P

für den Einsatz in Schutzeinrichtungen entsprechend der IEC 61508 geeignet ist, wenn das Handbuch zur Funktionalen Sicherheit SD111F/00 und nachfolgende Kenngrößen beachtet werden:
is suitable for the use in safety-instrumented systems according to IEC 61508, if the functional safety manual SD111F/00 and following characteristics are observed:

Gerät/Product	Liquiphant M or Liquiphant S +FEL57	Liquiphant M or Liquiphant S +FEL57 and FTL325P [3]
Schutzfunktion/Safety Function	Überfüllsicherung/overfill protection	Überfüllsicherung/overfill protection
SIL	2	2
Prüfintervall/Proof test interval	≤ 1 Jahr/year	≤ 1 Jahr/year
Gerätetyp/Device type	B	B
HFT	0	0 (einkanalige Verwendung/single channel use)
SFF	94 %	95%
PFD_{avg} [1]	0,01x10-2	0,02x10-2
λ_{du}	30 FIT	45 FIT
λ_{dd}	1,3 FIT	1,3 FIT
λ_{su}	426 FIT	822 FIT
λ_{sd}	138 FIT	153 FIT
$MTBF_{tot}$ [2]	190 Jahre/years	106 Jahre/years

[1] Die Werte entsprechen SIL 2 nach ISA S84.01 / The values comply with SIL 2 according to ISA S84.01
[2] gemäß Siemens SN29500, einschließlich Fehlern, die außerhalb der Sicherheitsfunktion liegen/ according to Siemens SN29500, including faults outside the safety function
[3] Die Kenngrößen beziehen sich auf alle im Anhang der SD111F/00 dargestellten Konfigurationen und zeigen je Kenngröße den ungünstigsten Wert. This characteristics are referring to all configurations shown in the appendix of SD111F/00 and are showing the worst value of each characteristic.

Maulburg, 03.03.2006

Endress+Hauser GmbH+Co. KG

i.V.
Leitung Zertifizierungsstelle
Management Certification Department

i.V.
Leitung Entwicklungsprojekt
Management R&D Project

Endress+Hauser
People for Process Automation

SIL05006a

Introduction

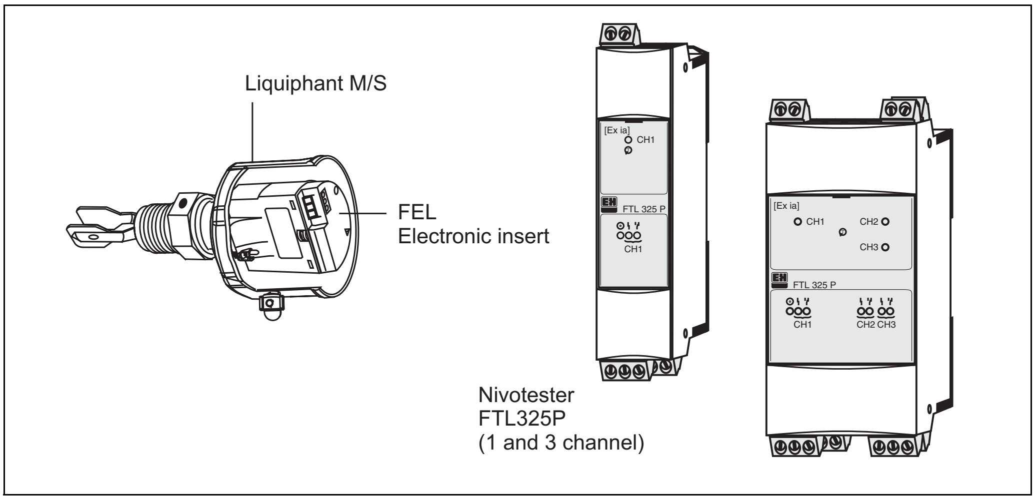
Note!
General information about Functional Safety (SIL) can be obtained at: www.de.endress.com/SIL

and in the competence brochure CP002Z "Functional safety in the Process Industry – risk reduction with Safety Instrumented Systems"

Structure of the measuring system with Liquiphant M/S with FEL57 + Nivotester FTL325P

Level limit measuring system

The following diagram displays the measuring system (example).



L00-FTL325Px-16-06-xx-de-000

Safety function

The safety-related signal of the measuring system is the level relay of the Nivotester. All safety functions refer exclusively to this signal.
The safety function applies to settings in MAX safety (monitoring of the covered state) and use of the NO contacts of the level relays.

The MAX safety setting causes the level relay to always work in quiescent current safety;
i.e. the relay opens if:

- The switch point is exceeded (level exceeds response height)
- A fault occurs
- The power supply voltage fails

In addition to the level relay, the alarm relay works in operating current safety and closes the contact if:

- One of the following faults occurs:
  – the sensor connection is interrupted
  – the sensor connection short circuits
  – the corrosion alarm of the sensor is triggered
- Detection of internal errors
- The power supply voltage fails

The measuring range of the Liquiphant M/S is dependent on the installation site and fork length.

The detection range is located within the fork length and is dependent on the density of the medium.

Alternative measures must be taken during device configuration and maintenance work on the Liquiphant M/S + Nivotester FTL325P to guarantee process safety.

The following settings are permitted for the safety function:

Instrument	Setting for the safety function	As-delivered state
Liquiphant	– Density switch setting: 0.5 – Density switch setting: 0.7	– Density switch setting: 0.7
	– Test mode "STD" – Test mode "EXT"	– Test mode "STD"
Nivotester FTL325P-#3#3	– MAX safety	– MAX safety
	– All settings **except for** "ΔS function" (see "Settings and installation instructions" Section)	– 3-channel operation
Nivotester FTL325P-#1#1	– MAX safety	– MAX safety
	– 1-channel operation	– 1-channel operation

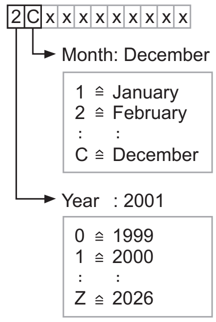
✎ Note!
- When the alarm relay releases, the level relay also releases.
- The alarm relay is not part of the safety function!

Permitted versions of the Nivotester with the Liquiphant M/S with FEL57 for the safety function

The following combinations are permitted for the measuring system:

- Nivotester FTL325P-H1#1, FTL325P-H3#3
- Nivotester FTL325P-P1#1, FTL325P-P3#3
- Nivotester FTL325P-T1#1, FTL325P-T3#3

HW version (Hardware): as of V01.00; valid as of serial no.



- Liquiphant M FTL50-######7###
- Liquiphant M FTL51-######7###
- Liquiphant M FTL50H-######7###
- Liquiphant M FTL51H-######7###
- Liquiphant M FTL51C-######7###
- Liquiphant S FTL70-######7####
- Liquiphant S FTL71-######7####

- Valid FW version (Firmware): as of V01.00.01
- Valid HW version (Hardware): as of V01.00

Permitted device types (# = all device versions permitted except for 9 and Y)

Safety function data

The **mandatory settings** and data for the safety function can be found in the Appendix (Page 27).

The reaction time of the measuring system is ≤ 0.9 s.

✎ Note!
MTTR is set at 8 hours.
Safety systems **without a self-locking function** must be monitored or set to an otherwise safe state after carrying out the safety function within MTTR.

Supplementary device documentation

Warning!
The technical limit values, safety, installation and configuration instructions must be observed in accordance with the documentation associated with the device. The following table displays an overview of the associated documentation and its contents for Liquiphant M/S + Nivotester FTL325P.

The following must be available for the measuring system:

Instrument	Technical Information	Operating Instructions
Nivotester	FTL325P: TI350F/00	For 1-channel device FTL325P-#1#1: KA167F/00
		For 3-channel device FTL325P-#3#3: KA168F/00
Liquiphant M	FTL50, FTL51, FTL50H, FTL51H: TI328F/00	FTL50, FTL51: KA143F/00 FTL50, FTL51 with aluminum housing/ separate connection compartment: KA163F/00 FTL50H, FTL51H: KA144F/00 FTL50H, FTL51H with aluminum housing/ separate connection compartment: KA164F/00
	FTL51C: TI347F/00	FTL51C: KA162F/00
Liquiphant S	FTL70, FTL71: TI354F/00	FTL70, FTL71: KA172F/00 FTL70, FTL71 with aluminum housing/ separate connection compartment: KA173F/00
Relevant contents	Connection data, Installation instructions	Setting, configuration, remarks, function tests

Settings and installation instructions

Installation instructions

The ambient conditions for the Nivotester FTL325P must correspond to IP54 (in accordance with EN 60529).

Please refer to the Operating Instructions (KA) for information regarding the correct installation of the Liquiphant M/S with FEL57. Since the application conditions have an effect on the safety of the measurement, pay attention to the notes in the Technical Information (TI) and Operating Instructions (KA).

Refer to the following documentation for instructions on setting the instruments:

Instrument	Setting description in documentation
Nivotester	1-channel device FTL325P-#1#1: KA167F/00
	3-channel device FTL325P-#3#3: KA168F/00
Liquiphant M/S with FEL57	KA143F/00, KA144F/00, KA162F/00, KA163F/00, KA164F/00, KA165F/00, KA172F/00, KA173F/00

Settings for Liquiphant M/S with FEL57

The setting of the density switch has an effect on the probability of failure and the type of function test (see "Appendix" Section).

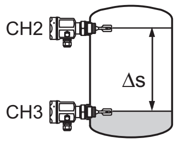
The setting of the test mode has an effect on the function test (see "Recurrent function tests of the measuring system" Section).

The SIL evaluation of the Liquiphant M/S comprises the entire device including electronic insert, tuning fork with drive, process connection and internal wiring.

Caution!
After commissioning the measuring system, changes to the settings at the electronic insert FEL57 can impair the safety function!

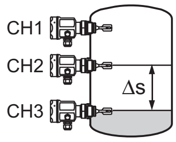
Settings for Nivotester FTL325P-#3#3 (3-channel)

It is recommended that the shift elements following the overfill protection be left in a safe state after responding until the alarm signal has been acknowledged.



Channel 2+3 in ΔS function (e.g. pump control)

This setting is **not** permitted for the safety function!



Channel 1, independent,
Channel 2+3 in ΔS function (e.g. pump control)

Channel 1 is permitted for the safety function!
Channels 2 and 3 in this setting are **not** permitted for the safety function!

Caution!
Observe the following for the Nivotester FTL325P:
The operator must use suitable measures (e.g. current limiter, fuse) to ensure the relay contact characteristics are not exceeded:

- $U \leq 253$ V AC 50/60 Hz , $I \leq 2$ A, $P \leq 500$ VA at $\cos \varphi \geq 0.7$ or
- $U \leq 40$ V DC, $I \leq 2$ A, $P \leq 80$ W

Caution!
Changes to the measuring system and settings after commissioning can impair the safety function!

Response in operation and failure

The response in operation and failure is described in the following documentation.

Instrument	Setting description in documentation
Nivotester	1-channel device FTL325P-#1#1: KA167F/00
	3-channel device FTL325P-#3#3: KA168F/00
Liquiphant M	FTL50, FTL51: KA143F/00 FTL50, FTL51 with aluminum housing/separate connection compartment: KA163F/00 FTL50H, FTL51H: KA144F/00 FTL50H, FTL51H with aluminum housing/separate connection compartment: KA164F/00 FTL51C: KA162F/00
Liquiphant S	FTL70, FTL71: KA172F/00 FTL70, FTL71 with aluminum housing/separate connection compartment: KA173F/00

Repair

In the event of failure of a SIL-labeled E+H device, which has been operated in a protection function, the "Declaration of Contamination and Cleaning" with the corresponding note "Used as SIL device in protection system" must be enclosed when the defective device is returned.

Recurrent function tests of the measuring system

Liquiphant M/S		Nivotester	Test	
Setting for density switch	Setting for test mode	Setting	Test interval	Description of the test procedure
Setting 0.7	STD or EXT	Every permitted setting and fault message CH1 -> ON when channel 1 is connected to a sensor	Annual function test	KA167F/00 KA168F/00
Setting 0.5	STD or EXT	Every permitted setting and fault message CH1 -> ON when channel 1 is connected to a sensor	Annual function test and complete test: checking the covered message, e.g. by approaching the level, after 5 years at the latest	

The operativeness of the overfill protection must be checked periodically if the PFD_{avg} values given in the Appendix are used.
The check must be carried out in such a way that it is proven that the overfill protection functions perfectly in interaction with all components. This is guaranteed when the response height is approached in a filling process. If it is not practical to fill to the response height, suitable simulation of the level or of the physical measuring effect must be used to make the level sensor respond. If the operativeness of the level sensor/transmitter can be determined otherwise (exclusion of faults that impair function), the check can also be completed by simulating the corresponding output signal.

Caution!
Note the following points for the function test:
- Every channel must be tested individually by pressing the respective test key.
- Relay contact switching must be checked electrically, e.g. using a hand multimeter at the terminals.
- In multi-channel instruments, all channels which do not carry out a safety function must be included in the recurrent function tests if faulty functioning cannot be detected by any other means, e.g. using independent protection measures or by changing the response of the measuring point.
- As a positive test result, the system reaction must correspond to the specified description.
- **If the system reaction does not correspond to the described procedure, the monitored process must be set to a safe state by means of additional or other measures and/or kept in the safe state until the safety system is repaired.**

Failure rates of electrical components

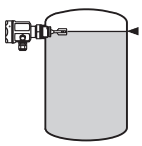
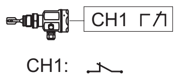
The underlying failure rates of electrical components apply within the usable service life IEC 61508-2 Section 7.4.7.4 Note 3

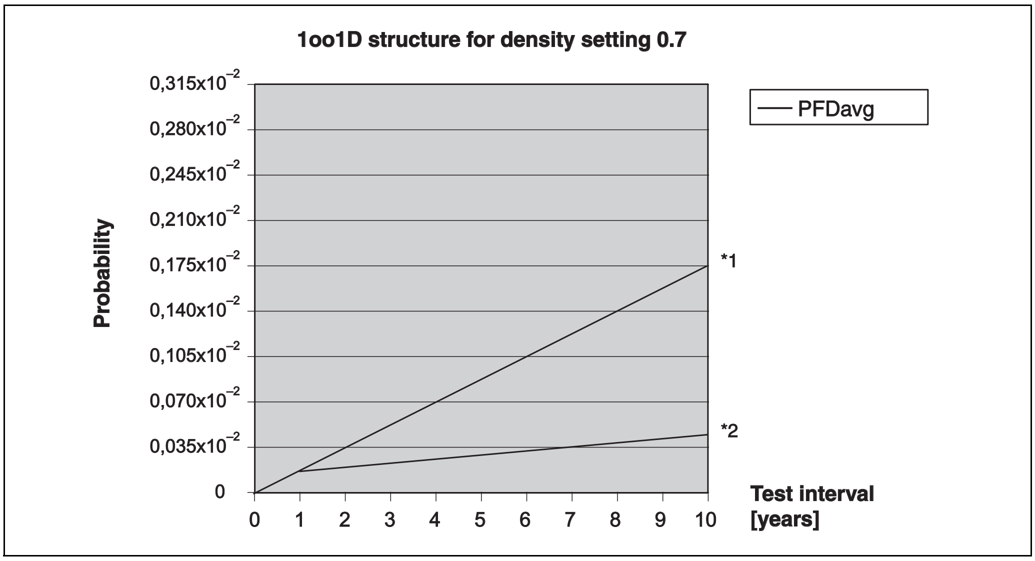
Appendix

Specific values and wiring options for the measuring system Liquiphant M/S with FEL57 and Nivotester FTL325P

The tables show the specific values and wiring options for the measuring system.

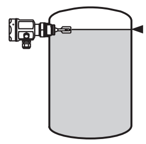
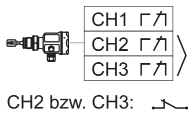
Note!
Note the following points on the tables below:
- A common cause factor β = 5 % has been assumed for the calculations specified below.
- The PFD_{avg} values for multi-channel systems already contain common cause failures for the associated wiring scheme.
- The PFD_{avg} values are only valid for the associated wiring scheme. They are not suitable for deducing calculations for other wiring schemes.
  Using NC contacts instead of NO contacts requires further consideration of the installation means.
- The wiring scheme shows the number of instruments (Liquiphant and Nivotester) and the limit relay contact circuits (open, when the sensor signals covering).
- With several instruments in a wiring scheme, they all indicate the same displayed settings.
- The tables show safety-relevant values and wiring options for the measuring system.
- The following safety-relevant values have been taken from the exida report
  (Report No.: E+H 02/6-16 R015).
- FIT = Failure in Time, 1 FIT = 10^{-9} 1/h

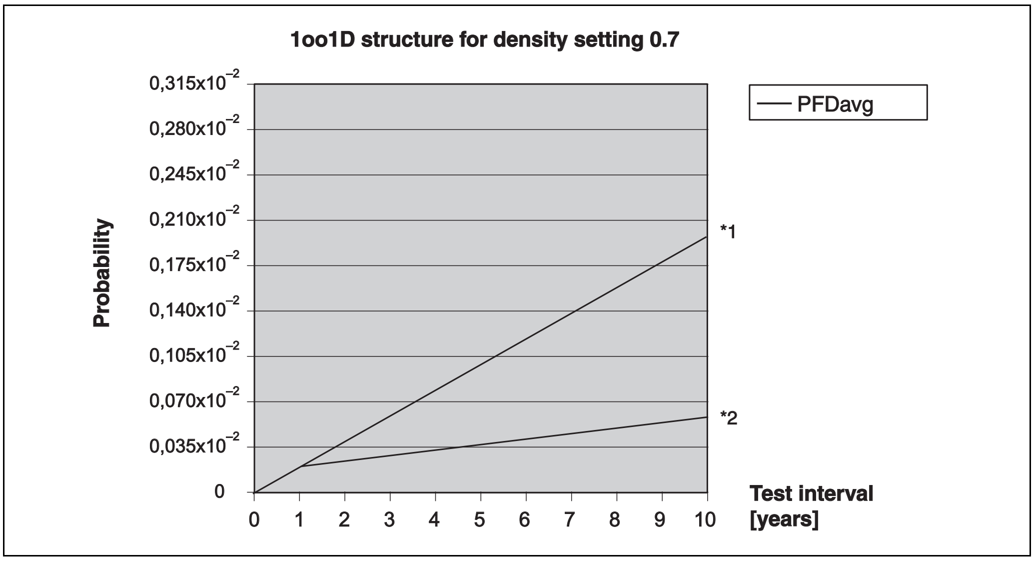
1oo1 architecture D [CONF 6]		
Liquiphant M/S - Setting	Density 0.7	Density 0.5
Nivotester FTL325P-#1#1 Setting (1-channel device)	MAX safety  L00-FTL3x5Px-14-06-xx-xx-001	
SIL	SIL 2	SIL 2
HFT	0	0
SFF[1)]	95 %	95 %
PFD_{avg}[1)] (low demand mode of operation)	1.75×10^{-4}	1.82×10^{-4}
λ_{sd}[1)]	156 FIT	156 FIT
λ_{su}[1)]	768 FIT	766 FIT
λ_{dd}[1)]	1.3 FIT	1.3 FIT
λ_{du}[1)]	40 FIT	42 FIT
MTBF	113 years	
Wiring scheme	 L00-FTL3x5Px-04-06-xx-xx-001	
Function test with test button	annually	annually
Complete function test, e.g. approaching the level	not required within the normal service life	at least every 5 years
[1)] Source: Management summary of the exida.com test report (see Appendix)		



L00-FTL325Px-05-06-xx-en-001

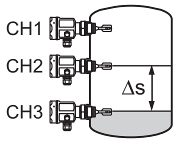
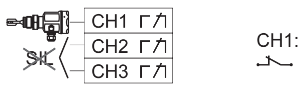
**1 without annual function test with test button / *2 with annual function test with test button*

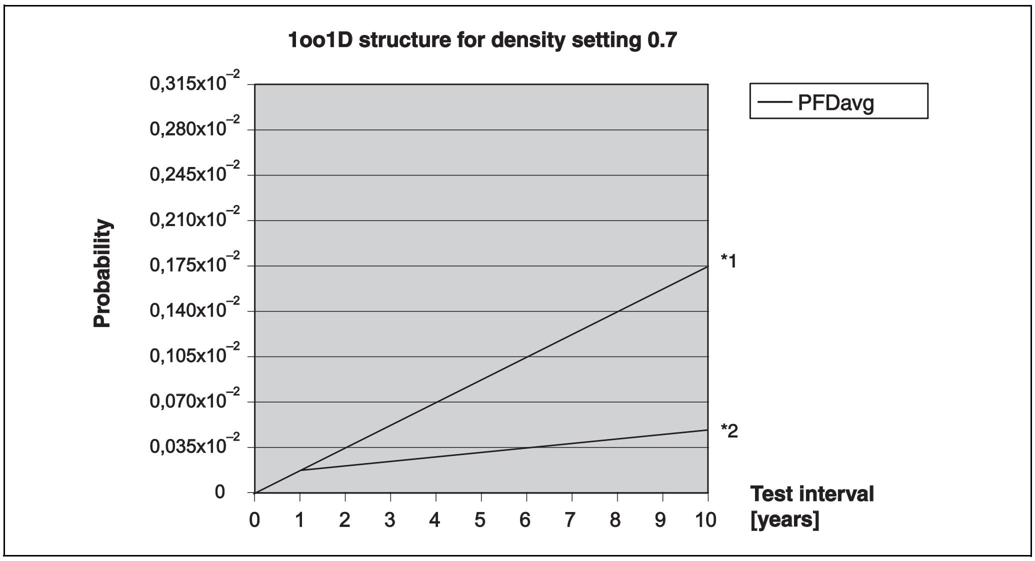
1oo1 architecture D [CONF 7]		
Liquiphant M/S - Setting	Density 0.7	Density 0.5
Nivotester FTL325P-#3#3 Setting (3-channel device)	MAX safety  L00-FTL3x5Px-14-06-xx-xx-001	
SIL	SIL 2	SIL 2
HFT	0	0
SFF 1)	95 %	95 %
PFD_{avg} 1) (low demand mode of operation)	1.97×10^{-4}	2.05×10^{-4}
λ_{sd} 1)	156 FIT	156 FIT
λ_{su} 1)	822 FIT	820 FIT
λ_{dd} 1)	1.3 FIT	1.3 FIT
λ_{du} 1)	45 FIT	47 FIT
MTBF	123 years	
Wiring scheme	 L00-FTL3x5Px-04-06-xx-de-002	
Function test with test button	annually	annually
Complete function test, e.g. approaching the level	not required within the normal service life	at least every 5 years
1) Source: Management summary of the exida.com test report (see Appendix)		



L00-FTL325Px-05-06-xx-en-002

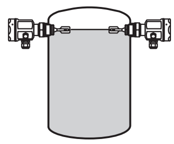
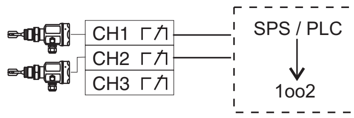
**1 without annual function test with test button / *2 with annual function test with test button*

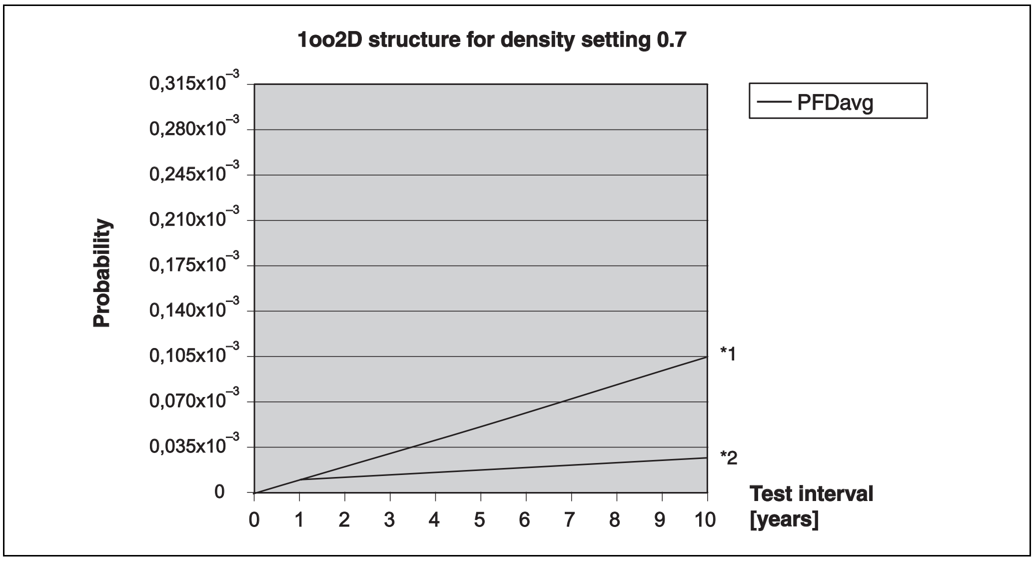
1oo1 architecture D [CONF 10]		
Liquiphant M/S - Setting	Density 0.7	Density 0.5
Nivotester FTL325P-#3#3 Setting (3-channel device)	MAX safety  L00-FEL5xxxx-14-06-06-xx-001	
SIL	SIL 2	SIL 2
HFT	0	0
SFF[1)]	95 %	95 %
PFD_{avg}[1)] (low demand mode of operation)	1.75 x 10^{-4}	1.82 x 10^{-4}
λ_{sd}[1)]	156 FIT	156 FIT
λ_{su}[1)]	768 FIT	766 FIT
λ_{dd}[1)]	1.3 FIT	1.3 FIT
λ_{du}[1)]	40 FIT	42 FIT
MTBF	118 years	
Wiring scheme	 L00-FTL5xxxx-04-06-xx-xx-006	
Function test with test button	annually	annually
Complete function test, e.g. approaching the level	not required within the normal service life	at least every 5 years
1) Source: Management summary of the exida.com test report (see Appendix)		



L00-FTL325Px-05-06-xx-en-003

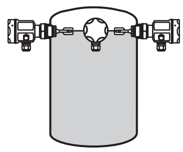
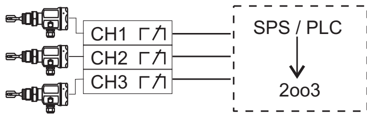
**1 without annual function test with test button / *2 with annual function test with test button*

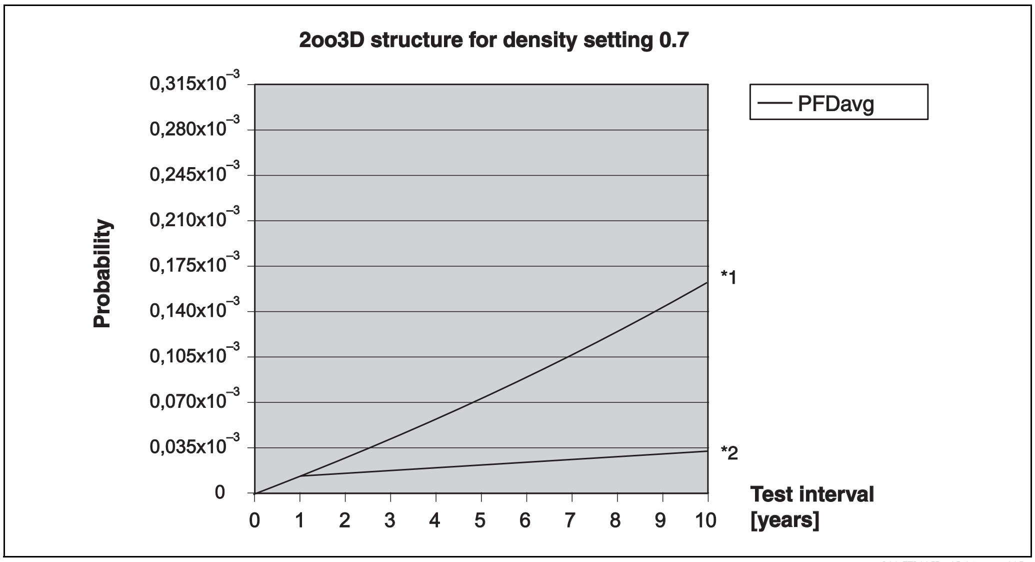
1oo2 architecture D [CONF 8]		
Liquiphant M/S - Setting	Density 0.7	Density 0.5
Nivotester FTL325P-#3#3 Setting (3-channel device)	MAX safety  L00-FEL5xxxx-14-06-06-xx-001	
SIL	SIL 3	SIL 3
HFT	1	1
SFF[1)]	95 %	95 %
PFD_{avg}[1)] (low demand mode of operation)	9.92 x 10^{-6}	1.03 x 10^{-5}
λ_{sd}[1)]	156 FIT	156 FIT
λ_{su}[1)]	822 FIT	820 FIT
λ_{dd}[1)]	1.3 FIT	1.3 FIT
λ_{du}[1)]	45 FIT	47 FIT
MTBF	123 years	
Wiring scheme	 L00-FTL57xxx-04-06-xx-xx-000	
Function test with test button	annually	annually
Complete function test, e.g. approaching the level	not required within the normal service life	at least every 5 years
[1)] Source: Management summary of the exida.com test report (see Appendix)		



L00-FTL325Px-05-06-xx-en-004

**1 without annual function test with test button / *2 with annual function test with test button*

2oo3 architecture D [CONF 9]		
Liquiphant M/S - Setting	Density 0.7	Density 0.5
Nivotester FTL 325 P-#3#3 Setting (3-channel device)	MAX safety  L00-FEL5xxxx-14-06-06-xx-001	
SIL	SIL 3	SIL 3
HFT	1	1
SFF[1)]	94 %	94 %
PFD_{avg}[1)] (low demand mode of operation)	1.29×10^{-5}	1.33×10^{-5}
λ_{sd}[1)]	155 FIT	155 FIT
λ_{su}[1)]	849 FIT	847 FIT
λ_{dd}[1)]	1.3 FIT	1.3 FIT
λ_{du}[1)]	57 FIT	59 FIT
MTBF	101 years	
Wiring scheme	 L00-FTL5xxxx-04-06-xx-xx-001	
Function test with test button	annually	annually
Complete function test, e.g. approaching the level	not required within the normal service life	at least every 5 years
[1)] Source: Management summary of the exida.com test report (see Appendix)		



L00-FTL325Px-05-06-xx-en-005

**1 without annual function test with test button / *2 with annual function test with test button*

FMEDA Report

FMEDA including SFF determination and PFD_{AVG} calculation

Project:
Level limit switch Liquiphant M/S
with PFM output FEL 57 and Nivotester FTL325P or FTL375P
Applications with level limit detection in liquids (MAX detection)

Customer:
Endress+Hauser GmbH+Co.KG
Maulburg
Germany

Contract No.: E+H 02/6-16
Report No.: E+H 02/6-16 R015
Version V0, Revision R1.0, August 2003
Stephan Aschenbrenner

L00-FTL325Px-01-06-xx-en-001

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 Liquiphant M/S with PFM output FEL 57 with software version V01.00.01 and hardware version V01.00 and Nivotester FTL325P or FTL375P for applications with MAX detection. Table 1 gives an overview of the different configurations which have been assessed.

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: Configuration overview

	Configurations
[CONF 1]	FEL 57
[CONF 2]	FEL 57 with Nivotester FTL375P as single channel device with two output relays in parallel
[CONF 3]	FEL 57 with Nivotester FTL375P as dual channel device
[CONF 4]	FEL 57 with Nivotester FTL375P as three channel device in three channel mode
[CONF 5]	FEL 57 with Nivotester FTL375P as three channel device in single channel mode
[CONF 6]	FEL 57 with Nivotester FTL325P as single channel device in single channel mode
[CONF 7]	FEL 57 with Nivotester FTL325P as three channel device in single channel mode with two output relays in parallel
[CONF 8]	FEL 57 with Nivotester FTL325P as three channel device in dual channel mode with one channel having two output relays in parallel
[CONF 9]	FEL 57 with Nivotester FTL325P as three channel device in three channel mode
[CONF 10]	FEL 57 with Nivotester FTL325P as three channel device in single channel mode

The failure rates used in this analysis are based on the Siemens standard SN 29500.

According to table 2 of IEC 61508-1 the PFD_{AVG} for systems operating in low demand mode has to be $\geq 10^{-3}$ to $< 10^{-2}$ for SIL 2 and $\geq 10^{-4}$ to $< 10^{-3}$ for SIL 3 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 the total PFD_{AVG} value of the SIF shall be smaller than 1,00E-02, hence the maximum allowable PFD_{AVG} value for the sensor part would then be 3,50E-03. For a SIL 3 application the total PFD_{AVG} value of the SIF shall be smaller than 1,00E-03, hence the maximum allowable PFD_{AVG} value for the sensor part would then be 3,50E-04.

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Liquiphant M/S with PFM output FEL 57 is considered to be a Type B[1] component. Nivotester FTL325P and FTL375P are considered to be Type A[2] components. In the following both sub-systems are considered to be Type B components for simplification reasons and as a worst-case assumption.

For Type A components with a SFF of 60% to < 90% a hardware fault tolerance of 0 according to table 2 of IEC 61508-2 is sufficient for SIL 2 (sub-) systems and a hardware fault tolerance of 1 is sufficient for SIL 3 (sub-) systems.

For Type B components with a SFF of 90% to < 99% a hardware fault tolerance of 0 according to table 2 of IEC 61508-2 is sufficient for SIL 2 (sub-) systems and a hardware fault tolerance of 1 is sufficient for SIL 3 (sub-) systems.

As Liquiphant M/S with PFM output FEL 57 and Nivotester FTL325P or FTL375P are supposed to be proven-in-use devices, an assessment of the hardware with additional proven-in-use demonstration for the device and its 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 5.1 the hardware fault tolerance could even be reduced.

Table 2: Summary for [CONF 1] with density 0,5 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 1,39E-04	PFD_{AVG} = 2,95E-04	PFD_{AVG} = 4,90E-04
Without annual manual test	PFD_{AVG} = 1,39E-04	PFD_{AVG} = 6,96E-04	PFD_{AVG} = 1,39E-03

λ_{sd} = 1,38E-07 1/h

λ_{su} = 4,24E-07 1/h

λ_{dd} = 1,30E-09 1/h

λ_{du} = 3,18E-08 1/h

SFF = 94%; HFT = 0; architecture suitable for SIL 2

Table 3: Summary for [CONF 1] with density 0,7 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 1,32E-04	PFD_{AVG} = 2,57E-04	PFD_{AVG} = 4,13E-04
Without annual manual test	PFD_{AVG} = 1,32E-04	PFD_{AVG} = 6,58E-04	PFD_{AVG} = 1,32E-03

λ_{sd} = 1,38E-07 1/h

λ_{su} = 4,26E-07 1/h

λ_{dd} = 1,30E-09 1/h

λ_{du} = 3,01E-08 1/h

SFF = 94%; HFT = 0; architecture suitable for SIL 2

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

[2] Type A component: "Non-complex" component (all failure modes are well defined); for details see 7.4.3.1.2 of IEC 61508-2.

Table 4: Summary for [CONF 2] with density 0,5 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 2,85E-04	PFD_{AVG} = 4,41E-04	PFD_{AVG} = 6,36E-04
Without annual manual test	PFD_{AVG} = 2,85E-04	PFD_{AVG} = 1,43E-03	PFD_{AVG} = 2,85E-03

λ_{sd} = 1,69E-07 1/h

λ_{su} = 6,81E-07 1/h

λ_{dd} = 1,32E-09 1/h

λ_{du} = 6,51E-08 1/h

SFF = 92%; HFT = 0; architecture suitable for SIL 2

Table 5: Summary for [CONF 2] with density 0,7 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 2,83E-04	PFD_{AVG} = 4,08E-04	PFD_{AVG} = 5,64E-04
Without annual manual test	PFD_{AVG} = 2,83E-04	PFD_{AVG} = 1,41E-03	PFD_{AVG} = 2,83E-03

λ_{sd} = 1,69E-07 1/h

λ_{su} = 6,83E-07 1/h

λ_{dd} = 1,33E-09 1/h

λ_{du} = 6,45E-08 1/h

SFF = 92%; HFT = 0; architecture suitable for SIL 2

Table 6: Summary for [CONF 3] with density 0,5 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 2,26E-05	PFD_{AVG} = 3,04E-05	PFD_{AVG} = 4,03E-05
Without annual manual test	PFD_{AVG} = 2,26E-05	PFD_{AVG} = 1,20E-04	PFD_{AVG} = 2,58E-04

λ_{sd} = 1,69E-07 1/h

λ_{su} = 7,54E-07 1/h

λ_{dd} = 1,32E-09 1/h

λ_{du} = 1,01E-07 1/h

SFF = 90%; HFT = 1; architecture suitable for SIL 3

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Table 7: Summary for [CONF 3] with density 0,7 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 2,22E-05	PFD_{AVG} = 2,85E-05	PFD_{AVG} = 3,64E-05
Without annual manual test	PFD_{AVG} = 2,22E-05	PFD_{AVG} = 1,18E-04	PFD_{AVG} = 2,53E-04

λ_{sd} = 1,69E-07 1/h

λ_{su} = 7,56E-07 1/h

λ_{dd} = 1,32E-09 1/h

λ_{du} = 9,96E-08 1/h

SFF = 90%; HFT = 1; architecture suitable for SIL 3

Table 8: Summary for [CONF 4] with density 0,5 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 2,43E-05	PFD_{AVG} = 3,22E-05	PFD_{AVG} = 4,27E-05
Without annual manual test	PFD_{AVG} = 2,43E-05	PFD_{AVG} = 1,46E-04	PFD_{AVG} = 3,52E-04

λ_{sd} = 1,69E-07 1/h

λ_{su} = 7,61E-07 1/h

λ_{dd} = 1,32E-09 1/h

λ_{du} = 1,06E-07 1/h

SFF = 89% [3]; HFT = 1; architecture suitable for SIL 3

Table 9: Summary for [CONF 4] with density 0,7 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 2,39E-05	PFD_{AVG} = 3,03E-05	PFD_{AVG} = 3,86E-05
Without annual manual test	PFD_{AVG} = 2,39E-05	PFD_{AVG} = 1,43E-04	PFD_{AVG} = 3,44E-04

λ_{sd} = 1,69E-07 1/h

λ_{su} = 7,63E-07 1/h

λ_{dd} = 1,32E-09 1/h

λ_{du} = 1,04E-07 1/h

SFF = 89% [3]; HFT = 1; architecture suitable for SIL 3

[3] The SFF < 90% is the result of the combination of the Type A and Type B sub-systems. The Type B sub-system, however, has a SFF > 90%.

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Table 10: Summary for [CONF 5] with density 0,5 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 4,65E-04	PFD_{AVG} = 6,20E-04	PFD_{AVG} = 8,15E-04
Without annual manual test	PFD_{AVG} = 4,65E-04	PFD_{AVG} = 2,32E-03	PFD_{AVG} = 4,65E-03

λ_{sd} = 1,69E-07 1/h

λ_{su} = 7,59E-07 1/h

λ_{dd} = 1,32E-09 1/h

λ_{du} = 1,06E-07 1/h

SFF = 89% [4]; HFT = 0; architecture suitable for SIL 2

Table 11: Summary for [CONF 5] with density 0,7 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 4,57E-04	PFD_{AVG} = 5,82E-04	PFD_{AVG} = 7,39E-04
Without annual manual test	PFD_{AVG} = 4,57E-04	PFD_{AVG} = 2,29E-03	PFD_{AVG} = 4,57E-03

λ_{sd} = 1,69E-07 1/h

λ_{su} = 7,61E-07 1/h

λ_{dd} = 1,32E-09 1/h

λ_{du} = 1,04E-07 1/h

SFF = 89% [4]; HFT = 0; architecture suitable for SIL 2

Table 12: Summary for [CONF 6] with density 0,5 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 1,82E-04	PFD_{AVG} = 3,38E-04	PFD_{AVG} = 5,33E-04
Without annual manual test	PFD_{AVG} = 1,82E-04	PFD_{AVG} = 9,11E-04	PFD_{AVG} = 1,82E-03

λ_{sd} = 1,56E-07 1/h

λ_{su} = 7,66E-07 1/h

λ_{dd} = 1,30E-09 1/h

λ_{du} = 4,16E-08 1/h

SFF = 95%; HFT = 0; architecture suitable for SIL 2

[4] The SFF < 90% is the result of the combination of the Type A and Type B sub-systems. The Type B sub-system, however, has a SFF > 90%.

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Table 13: Summary for [CONF 6] with density 0,7 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 1,75E-04	PFD_{AVG} = 3,00E-04	PFD_{AVG} = 4,56E-04
Without annual manual test	PFD_{AVG} = 1,75E-04	PFD_{AVG} = 8,73E-04	PFD_{AVG} = 1,75E-03

λ_{sd} = 1,56E-07 1/h

λ_{su} = 7,68E-07 1/h

λ_{dd} = 1,30E-09 1/h

λ_{du} = 3,99E-08 1/h

SFF = 95%; HFT = 0; architecture suitable for SIL 2

Table 14: Summary for [CONF 7] with density 0,5 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 2,05E-04	PFD_{AVG} = 3,96E-04	PFD_{AVG} = 6,34E-04
Without annual manual test	PFD_{AVG} = 2,05E-04	PFD_{AVG} = 1,02E-03	PFD_{AVG} = 2,05E-03

λ_{sd} = 1,56E-07 1/h

λ_{su} = 8,20E-07 1/h

λ_{dd} = 1,30E-09 1/h

λ_{du} = 4,67E-08 1/h

SFF = 95%; HFT = 0; architecture suitable for SIL 2

Table 15: Summary for [CONF 7] with density 0,7 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 1,97E-04	PFD_{AVG} = 3,57E-04	PFD_{AVG} = 5,58E-04
Without annual manual test	PFD_{AVG} = 1,97E-04	PFD_{AVG} = 9,84E-04	PFD_{AVG} = 1,97E-03

λ_{sd} = 1,56E-07 1/h

λ_{su} = 8,22E-07 1/h

λ_{dd} = 1,30E-09 1/h

λ_{du} = 4,50E-08 1/h

SFF = 95%; HFT = 0; architecture suitable for SIL 2

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Table 16: Summary for [CONF 8] with density 0,5 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 1,03E-05	PFD_{AVG} = 1,99E-05	PFD_{AVG} = 3,21E-05
Without annual manual test	PFD_{AVG} = 1,03E-05	PFD_{AVG} = 5,30E-05	PFD_{AVG} = 1,10E-04

λ_{sd} = 1,56E-07 1/h

λ_{su} = 8,20E-07 1/h

λ_{dd} = 1,30E-09 1/h

λ_{du} = 4,67E-08 1/h

SFF = 95%; HFT = 1; architecture suitable for SIL 3

Table 17: Summary for [CONF 8] with density 0,7 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 9,92E-06	PFD_{AVG} = 1,80E-05	PFD_{AVG} = 2,82E-05
Without annual manual test	PFD_{AVG} = 9,92E-06	PFD_{AVG} = 5,10E-05	PFD_{AVG} = 1,05E-04

λ_{sd} = 1,56E-07 1/h

λ_{su} = 8,22E-07 1/h

λ_{dd} = 1,30E-09 1/h

λ_{du} = 4,50E-08 1/h

SFF = 95%; HFT = 1; architecture suitable for SIL 3

Table 18: Summary for [CONF 9] with density 0,5 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 1,33E-05	PFD_{AVG} = 2,32E-05	PFD_{AVG} = 3,61E-05
Without annual manual test	PFD_{AVG} = 1,33E-05	PFD_{AVG} = 7,43E-05	PFD_{AVG} = 1,68E-04

λ_{sd} = 1,55E-07 1/h

λ_{su} = 8,47E-07 1/h

λ_{dd} = 1,30E-09 1/h

λ_{du} = 5,91E-08 1/h

SFF = 94%; HFT = 1; architecture suitable for SIL 3

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Table 19: Summary for [CONF 9] with density 0,7 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 1,29E-05	PFD_{AVG} = 2,11E-05	PFD_{AVG} = 3,19E-05
Without annual manual test	PFD_{AVG} = 1,29E-05	PFD_{AVG} = 7,18E-05	PFD_{AVG} = 1,62E-04

λ_{sd} = 1,55E-07 1/h

λ_{su} = 8,49E-07 1/h

λ_{dd} = 1,30E-09 1/h

λ_{du} = 5,74E-08 1/h

SFF = 94%; HFT = 1; architecture suitable for SIL 3

Table 20: Summary for [CONF 10] with density 0,5 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 1,82E-04	PFD_{AVG} = 3,38E-04	PFD_{AVG} = 5,33E-04
Without annual manual test	PFD_{AVG} = 1,82E-04	PFD_{AVG} = 9,11E-04	PFD_{AVG} = 1,82E-03

λ_{sd} = 1,56E-07 1/h

λ_{su} = 7,66E-07 1/h

λ_{dd} = 1,30E-09 1/h

λ_{du} = 4,16E-08 1/h

SFF = 95%; HFT = 0; architecture suitable for SIL 2

Table 21: Summary for [CONF 10] with density 0,7 g/cm³

	T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
With annual manual test	PFD_{AVG} = 1,75E-04	PFD_{AVG} = 3,00E-04	PFD_{AVG} = 4,56E-04
Without annual manual test	PFD_{AVG} = 1,75E-04	PFD_{AVG} = 8,73E-04	PFD_{AVG} = 1,75E-03

λ_{sd} = 1,56E-07 1/h

λ_{su} = 7,68E-07 1/h

λ_{dd} = 1,30E-09 1/h

λ_{du} = 3,99E-08 1/h

SFF = 95%; HFT = 0; architecture suitable for SIL 2

The boxes marked in yellow (▭) mean that the calculated PFD_{AVG} values are within the allowed range for SIL2 or SIL 3 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 or 3,50E-04. The boxes marked in green (▭) mean that the calculated PFD_{AVG} values are within the allowed range for SIL 2 or SIL 3 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 or 3,50E-04.

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A user of Liquiphant M/S with PFM output FEL 57 and Nivotester FTL325P or FTL375P 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 section 5.2 to 5.11 along with all assumptions.

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