Failure Modes, Effects and Diagnostic Analysis

Project:
Vibration Transducer Supply Unit 9147

Company:
R. STAHL Schaltgeräte GmbH
Waldenburg
Germany

Contract No.: STAHL 13/06-082
Report No.: STAHL 13/06-082 R025
Version V1, Revision R0; July 2013
Jan Hettenbach

The document was prepared using best effort. The authors make no warranty of any kind and shall not be liable in any event for incidental or consequential damages in connection with the application of the document.

Management Summary

This report summarizes the results of the hardware assessment in the form of a Failure Modes, Effects, and Diagnostic Analysis (FMEDA) of the Vibration Transducer Supply Unit 9147 in the version listed in the drawings referenced in section 2.4.1.

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.

The failure rates used in this analysis are from the *exida* Electrical & Mechanical Component Reliability Handbook for Profile 1.

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. These failure rates are valid for the useful lifetime of the Vibration Transducer Supply Unit 9147, see Appendix B.

The failure rates listed in this report do not include failures due to wear-out of any components. They reflect random failures and include failures due to external events, such as unexpected use, see section 4.2.3.

The Vibration Transducer Supply Unit 9147 can be considered to be a Type A[1] element with a hardware fault tolerance of 0. The failure rates according to IEC 61508:2010 for the Vibration Transducer Supply Unit 9147 are listed in Table 1. The basic configuration of the Vibration Transducer Supply Unit 9147 has two channels. For safety application, only one channel may be used.

Table 1: Covered input type definition of Vibration Transducer Supply Unit 9147

Part	Description
9147/10-99-10	Single channel Vibration Transducer Supply Unit 9147 with two-wire and three- wire input configuration, with negative input and output signal level
9147/20-99-10	Dual channel Vibration Transducer Supply Unit 9147 with two-wire and three- wire input configuration, with negative input and output signal level. Only one channel used for safety application.

[1] Type A element: "Non-complex" element (all failure modes are well defined); for details see 7.4.4.1.2 of IEC 61508-2.

Table 2: Vibration Transducer Supply Unit 9147 with 2- wire input

	***exida* Profile 1**
Failure category	**Failure rates (in FIT)**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**0**
Fail Dangerous Detected (λ_{DD})	**188**
Fail Dangerous Detected (λ_{DD})	0
Fail High (H)[2]	23
Fail Low (L)[3]	165
Fail Annunciation Detected (λ_{AD})	0
Fail Dangerous Undetected (λ_{DU})	**95**

Fail Annunciation Undetected (λ_{AU})	11
No effect	215
No part	33

Total failure rate (safety function)	**283**

Safe failure fraction (SFF)	**66%**
SIL AC	**SIL2**
PFH	**9.5E-08 1/h**

[2] Fail H failures are signals < -20.5V

[3] Fail L failures are signals > -0.5V

Table 3: Vibration Transducer Supply Unit 9147 with 3- wire input

	exida **Profile 1**
Failure category	**Failure rates (in FIT)**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**0**
Fail Dangerous Detected (λ_{DD})	**184**
Fail Dangerous Detected (λ_{DD})	0
Fail High (H)[4]	23
Fail Low (L)[5]	161
Fail Annunciation Detected (λ_{AD})	0
Fail Dangerous Undetected (λ_{DU})	**80**

Fail Annunciation Undetected (λ_{AU})	11
No effect	217
No part	32

Total failure rate (safety function)	**264**

Safe failure fraction (SFF)	**69%**
SIL AC	**SIL2**
PFH	**8.0E-08 1/h**

[4] Fail H failures are signals < -20.5V

[5] Fail L failures are signals > -0.5V

Table of Contents

1 Purpose and Scope

This document shall describe the results of the hardware assessment in the form of the Failure Modes, Effects and Diagnostic Analysis carried out on the Vibration Transducer Supply Unit 9147. From this, failure rates, Safe Failure Fraction (SFF) and example PFD_{AVG} values are calculated.

The FMEDA builds the basis for an evaluation whether a sensor subsystem, including the described Vibration Transducer Supply Unit 9147 meets the average Probability of Failure on Demand (PFD_{AVG}) requirements and if applicable the architectural constraints / minimum hardware fault tolerance requirements per IEC 61508 / IEC 61511. It **does not** consider any calculations necessary for proving intrinsic safety.

2 Project Management

2.1 *exida*

exida is one of the world's leading product certification and knowledge companies specializing in automation system safety and availability with over 300 years of cumulative experience in functional safety. Founded by several of the world's top reliability and safety experts from assessment organizations and manufacturers, *exida* is a global company with offices around the world. *exida* offers training, coaching, project oriented consulting services, internet based safety engineering tools, detailed product assurance and certification analysis and a collection of on-line safety and reliability resources. *exida* maintains a comprehensive failure rate and failure mode database on process equipment.

2.2 Roles of the parties involved

R. STAHL Schaltgeräte GmbH	Manufacturer of the Vibration Transducer Supply Unit 9147 and carried out the FMEDA.
exida	Reviewed the FMEDAs and issued this report.

R. STAHL Schaltgeräte GmbH contracted *exida* in June 2013 to review the FMEDA and to issue the report.

2.3 Standards and Literature used

The services delivered by *exida* were performed based on the following standards / literature.

[N1]	IEC 61508-2:2010	Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems; 2nd edition
[N2]	SN 29500-1:01.2004 SN 29500-1 H1:12.2005 SN 29500-2:12:2004 SN 29500-3:12.2004 SN 29500-4:03.2004 SN 29500-5:06.2004 SN 29500-7:11.2005 SN 29500-9:11.2005 SN 29500-10:12.2005 SN 29500-11:08.1990 SN 29500-12:03.1994 SN 29500-13:03.1994 SN 29500-14:03.1994	Siemens standard with failure rates for components
[N3]	Mechanical Component Reliability Handbook, 3rd Edition, 2012	*exida* LLC, Electrical & Mechanical Component Reliability Handbook, Third Edition, 2012, ISBN 978-1-934977-05-7

2.4 Reference documents

2.4.1 Documentation provided by the customer

[D1]	9147 6 020 001 0_02.pdf	Schematic diagram of 12.02.2012
[D2]	9147 0 000 050 0_00.pdf	Specification and failure test results of 28.06.2012
[D3]	9147 0 000 054 0_00.xlsx	Failure test protocol during development
[D4]	9147 0 000 051 0_02.efm	FMEDA of Vibration Transducer Supply Unit 9147 Version 02 of 17.07.2013
[D5]	9147 0 000 052 0_02.efm	FMEDA of Vibration Transducer Supply Unit 9147 Version 02 of 17.07.2013

2.4.2 Documentation generated by *exida*

[R1]	Summary FMEDA results Vibration Transducer Supply Unit 9147.xls of 09.07.2013
[R2]	PFDavg Calc Vibration Transducer Supply Unit 9147.xls of 09.07.2013

2.5 *exida* tools used

[T1]	SILcal V7	FMEDA Tool

3 Product Description

The Vibration Transducer Supply Unit 9147 can be considered as a Type A [6] element according to IEC 61508, having a hardware fault tolerance of 0.

A sensor input signal with negative signal amplitude between -0.5V and -20.5V is transmitted isolated to the output. The sensor can be connected by two- wire or three- wire connection and is supplied from the Vibration Transducer Supply Unit 9147.

Figure 2 shows the connection diagram of the Vibration Transducer Supply Unit 9147. Both channels together cannot be used for redundant signal transmission in safety applications because of a common use of the power supply unit. The connection diagram shows the 2- wire sensor input and the 3- wire sensor input variant.

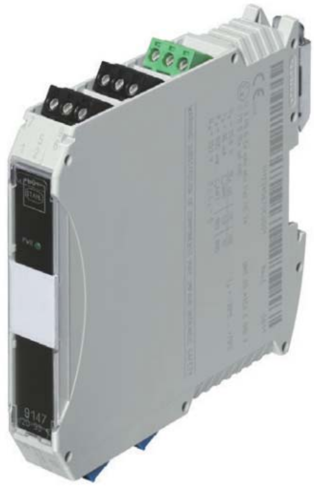

Figure 1: Product picture of Vibration Transducer Supply Unit 9147

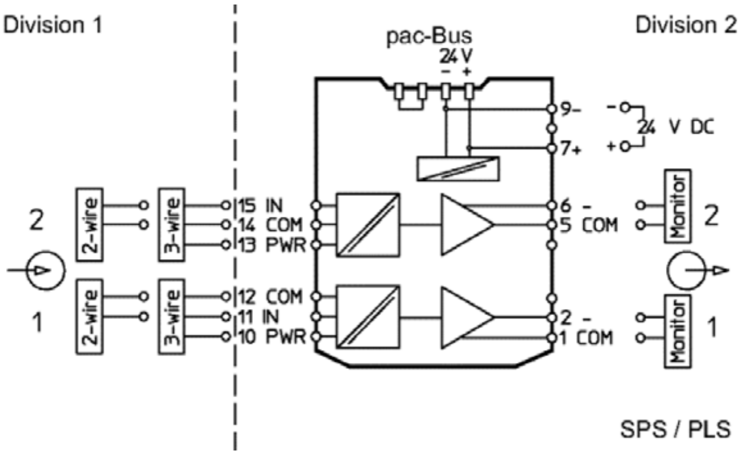

Figure 2: Connection diagram of two- channel Vibration Transducer Supply Unit 9147

[6] Type A element: "Non-complex" element (all failure modes are well defined); for details see 7.4.4.1.2 of IEC 61508-2.

4 Failure Modes, Effects, and Diagnostic Analysis

The Failure Modes, Effects, and Diagnostic Analysis was performed by R. STAHL Schaltgeräte GmbH and reviewed by *exida*. The results are documented [D4] and [D5].

4.1 Description of the failure categories

In order to judge the failure behavior of the Vibration Transducer Supply Unit 9147, the following definitions for the failure of the device were considered.

Fail-Safe State
The fail-safe state is defined as the output reaching the user defined threshold value.

Fail Safe
A safe failure (S) is defined as a failure that plays a part in implementing the safety function that:

a) results in the spurious operation of the safety function to put the EUC (or part thereof) into a safe state or maintain a safe state; or,

b) increases the probability of the spurious operation of the safety function to put the EUC (or part thereof) into a safe state or maintain a safe state.

Fail Dangerous
A dangerous failure (D) is defined as a failure that plays a part in implementing the safety function that:

a) prevents a safety function from operating when required (demand mode) or causes a safety function to fail (continuous mode) such that the EUC is put into a hazardous or potentially hazardous state; or,

b) decreases the probability that the safety function operates correctly when required.

Fail Dangerous Undetected
Failure that is dangerous and that is not being diagnosed by internal diagnostics (DU).

Fail Dangerous Detected
Failure that is dangerous but is detected by internal or external diagnostics (DD).

Fail High
Failure that causes the voltage output signal to go to the maximum output voltage (< - 20.5 V).

Fail Low
Failure that causes the voltage output signal to go to the minimum output voltage (> - 0.5 V).

Annunciation
Failure that does not directly impact safety but does impact the ability to detect a future fault (such as a fault in a diagnostic circuit). Annunciation failures are divided into annunciation detected (AD) and annunciation undetected (AU) failures. The Vibration Transducer Supply Unit 9147 has no special diagnostic function, but failures of the redundant switch off path are classified as AU failures.

No effect
Failure mode of a component that plays a part in implementing the safety function but is neither a safe failure nor a dangerous failure.

No part
Component that plays no part in implementing the safety function but is part of the circuit diagram and is listed for completeness.

4.2 Methodology – FMEDA, Failure Rates

4.2.1 FMEDA

A Failure Modes and Effects Analysis (FMEA) is a systematic way to identify and evaluate the effects of different component failure modes, to determine what could eliminate or reduce the chance of failure, and to document the system under consideration.

An FMEDA (Failure Mode Effect and Diagnostic Analysis) is an FMEA extension. It combines standard FMEA techniques with extensions to identify online diagnostics techniques and the failure modes relevant to safety instrumented system design. It is a technique recommended to generate failure rates for each important category (safe detected, safe undetected, dangerous detected, dangerous undetected, fail high, fail low) in the safety models. The format for the FMEDA is an extension of the standard FMEA format from MIL STD 1629A, Failure Modes and Effects Analysis.

4.2.2 Failure Rates

The failure rate data used by *exida* in this FMEDA is from the Electrical and Mechanical Component Reliability Handbook [N3] which was derived using over ten billion unit operational hours of field failure data from multiple sources and failure data from various databases. The rates were chosen in a way that is appropriate for safety integrity level verification calculations. The rates were chosen to match operating stress conditions typical of an industrial field environment similar to *exida* Profile 1. It is expected that the actual number of field failures due to random events will be less than the number predicted by these failure rates.

For hardware assessment according to IEC 61508 only random equipment failures are of interest. It is assumed that the equipment has been properly selected for the application and is adequately commissioned such that early life failures (infant mortality) may be excluded from the analysis.

Failures caused by external events however should be considered as random failures. Examples of such failures are loss of power or physical abuse.

The assumption is also made that the equipment is maintained per the requirements of IEC 61508 or IEC 61511 and therefore a preventative maintenance program is in place to replace equipment before the end of its “useful life”.

The user of these numbers is responsible for determining their applicability to any particular environment. Accurate plant specific data may be used for this purpose. If a user has data collected from a good proof test reporting system such as *exida* SILStat^{TM} that indicates higher failure rates, the higher numbers shall be used. Some industrial plant sites have high levels of stress. Under those conditions the failure rate data is adjusted to a higher value to account for the specific conditions of the plant.

4.2.3 Assumptions

The following assumptions have been made during the Failure Modes, Effects, and Diagnostic Analysis of the Vibration Transducer Supply Unit 9147.

- Failure rates are constant, wear out mechanisms are not included.
- Propagation of failures is not relevant.
- The device is installed per manufacturer’s instructions.
- Sufficient tests are performed prior to shipment to verify the absence of vendor and/or manufacturing defects that prevent proper operation of specified functionality to product specifications or cause operation different from the design analyzed.
- External power supply failure rates are not included.
- The Mean Time To Restoration (MTTR) after a safe failure is 24 hours.
- For safety applications only the described variants are considered.
- Only one channel is part of the FMEDA assessment and can be used for safety application. The second channel must not be used for the same safety application, because of possible common cause failures in the common power supply.
- Failures with less than 2% of full span are uncritical and within the specification of the Vibration Transducer Supply Unit 9147.
- The connected control logic considers signal levels outside the range of -0.5V and -20.5V as failure.

4.3 Results of the assessment

$DC_D = \lambda_{DD} / (\lambda_{DD} + \lambda_{DU})$

$\lambda_{total} = + \lambda_{SD} + \lambda_{SU} + \lambda_{DD} + \lambda_{DU}$

$MTBF = MTTF + MTTR = (1 / (\lambda_{total} + \lambda_{no\ part} + \lambda_{AU})) + 24\ h$

According to IEC 61508 the architectural constraints of an element must be determined. This can be done by following the 1_H approach according to 7.4.4.2 of IEC 61508-2 or the 2_H approach according to 7.4.4.3 of IEC 61508-2.

The 1_H approach involves calculating the Safe Failure Fraction for the entire element.

The 2_H approach involves assessment of the reliability data for the entire element according to 7.4.4.3.3 of IEC 61508-3.

This assessment supports the 1_H approach.

According to 3.6.15 of IEC 61508-4, the Safe Failure Fraction is the property of a safety related element that is defined by the ratio of the average failure rates of safe plus dangerous detected failures and safe plus dangerous failures. This ratio is represented by the following equation:

$SFF = (\Sigma\lambda_S\ avg + \Sigma\lambda_{DD}\ avg) / (\Sigma\lambda_S\ avg + \Sigma\lambda_{DD}\ avg + \Sigma\lambda_{DU}\ avg\ )$

When the failure rates are based on constant failure rates, as in this analysis, the equation can be simplified to:

$SFF = (\Sigma\lambda_S + \Sigma\lambda_{DD}) / (\Sigma\lambda_S + \Sigma\lambda_{DD} + \Sigma\lambda_{DU}\ )$

Where:

$\lambda_{S\ =}$ Fail Safe

$\lambda_{DD\ =}$ Fail Dangerous Detected

$\lambda_{DU=}$ Fail Dangerous Undetected

As the Vibration Transducer Supply Unit 9147 is only one part of an element, the architectural constraints should be determined for the entire sensor element.

4.3.1 Vibration Transducer Supply Unit 9147 with 2- wire input

The FMEDA carried out on the Vibration Transducer Supply Unit 9147 with 2- wire input leads under the assumptions described in section 4.2.3 and 4.3 to the following failure rates:

Table 4: Vibration Transducer Supply Unit 9147 with 2- wire input

	***exida* Profile 1**
Failure category	**Failure rates (in FIT)**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**0**
Fail Dangerous Detected (λ_{DD})	**188**
Fail Dangerous Detected (λ_{DD})	0
Fail High (H) [7]	23
Fail Low (L) [8]	165
Fail Annunciation Detected (λ_{AD})	0
Fail Dangerous Undetected (λ_{DU})	**95**

Fail Annunciation Undetected (λ_{AU})	11
No effect	215
No part	33

Total failure rate (safety function)	**283**

Safe failure fraction (SFF)	**66%**
SIL AC	**SIL2**
PFH	**9.5E-08 1/h**

[7] Fail H failures are signals < -20.5V

[8] Fail L failures are signals > -0.5V

4.3.2 Vibration Transducer Supply Unit 9147 with 3- wire input

The FMEDA carried out on the Vibration Transducer Supply Unit 9147 with 3- wire leads under the assumptions described in section 4.2.3 and 4.3 to the following failure rates:

Table 5: Vibration Transducer Supply Unit 9147 with 3- wire input

	***exida* Profile 1**
Failure category	**Failure rates (in FIT)**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**0**
Fail Dangerous Detected (λ_{DD})	**184**
Fail Dangerous Detected (λ_{DD})	0
Fail High (H) [9]	23
Fail Low (L) [10]	161
Fail Annunciation Detected (λ_{AD})	0
Fail Dangerous Undetected (λ_{DU})	**80**

Fail Annunciation Undetected (λ_{AU})	11
No effect	217
No part	32

Total failure rate (safety function)	**264**

Safe failure fraction (SFF)	**69%**
SIL AC	**SIL2**
PFH	**8.0E-08 1/h**

[9] Fail H failures are signals < -20.5V

[10] Fail L failures are signals > -0.5V

5 Using the FMEDA Results

The following section describes how to apply the results of the FMEDA.

5.1 Example PFD_{AVG} calculation

It is the responsibility of the Safety Instrumented Function designer to do calculations for the entire SIF. *exida* recommends the accurate Markov based exSILentia tool for this purpose.

The following results must be considered in combination with PFD_{AVG} values of other devices of a Safety Instrumented Function (SIF) in order to determine suitability for a specific Safety Integrity Level (SIL).

An average Probability of Failure on Demand (PFD_{AVG}) calculation is performed for Vibration Transducer Supply Unit 9147 considering a proof test coverage of 90% (see Appendix A.1) and a mission time of 10 years. The failure rate data used in this calculation are displayed in sections [R1]. The resulting PFD_{AVG} values for a variety of proof test intervals are displayed in Table 6. Both inputs (input I and input II) have the same PFD_{AVG} values.

For SIL2 applications, the PFD_{AVG} value needs to be < 1.00E-02 [11].

Table 6: PFD_{AVG} values

	T[Proof] = 1 year	T[Proof] = 2 years	T[Proof] = 5 years
9147 - 2 wire	PFD_{AVG} = 7.95E-04	PFD_{AVG} = 1.17E-03	PFD_{AVG} = 2.29E-03
9147 - 3 wire	PFD_{AVG} = 6.70E-04	PFD_{AVG} = 9.86E-04	PFD_{AVG} = 1.93E-03

This means that for a SIL2 application, the PFD_{AVG} for a 1-year Proof Test Interval considering is approximately equal to 7.9% for the 2 wire configuration.

Figure 3 shows the time dependent curve of PFD_{AVG}.

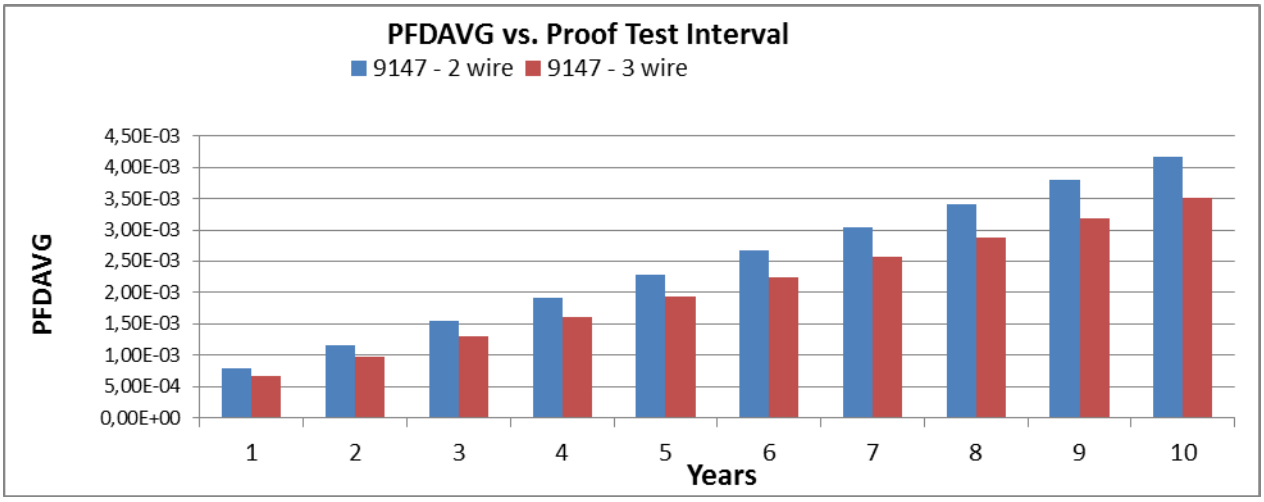

Figure 3: PFD_{AVG}(t) for Vibration Transducer Supply Unit 9147

[11] According to IEC61505-2:2010, 7.4.5.3, the ratio of the diagnostic test rate to the demand rate must equal or exceed 100.

6 Terms and Definitions

FIT	Failure In Time (1x10-9 failures per hour)
FMEDA	Failure Mode Effect and Diagnostic Analysis
HFT	Hardware Fault Tolerance
Low demand mode	Mode, where the frequency of demands for operation made on a safety-related system is no greater than twice the proof test frequency.
PFD_{AVG}	Average Probability of Failure on Demand
SFF	Safe Failure Fraction, summarizes the fraction of failures, which lead to a safe state and the fraction of failures which will be detected by diagnostic measures and lead to a defined safety action.
SIF	Safety Instrumented Function
SIL	Safety Integrity Level
SIS	Safety Instrumented System – Implementation of one or more Safety Instrumented Functions. A SIS is composed of any combination of sensor(s), logic solver(s), and final element(s).
PLC	Programmable Logic Controller
Type A element	“Non-complex” element (all failure modes are well defined); for details see 7.4.4.1.2 of IEC 61508-2.

7 Status of the Document

7.1 Liability

exida prepares FMEDA reports based on methods advocated in International standards. Failure rates are obtained from a collection of industrial databases. *exida* accepts no liability whatsoever for the use of these numbers or for the correctness of the standards on which the general calculation methods are based.

Due to future potential changes in the standards, best available information and best practices, the current FMEDA results presented in this report may not be fully consistent with results that would be presented for the identical product at some future time. As a leader in the functional safety market place, *exida* is actively involved in evolving best practices prior to official release of updated standards so that our reports effectively anticipate any known changes. In addition, most changes are anticipated to be incremental in nature and results reported within the previous three year period should be sufficient for current usage without significant question.

Most products also tend to undergo incremental changes over time. If an *exida* FMEDA has not been updated within the last three years and the exact results are critical to the SIL verification you may wish to contact the product vendor to verify the current validity of the results.

7.2 Releases

Version History:	V1R0:	Editorial changes, July 30, 2013
	V0R1:	Initial draft; July 17, 2013
Author:	Jan Hettenbach	
Review:	Stephan Aschenbrenner (*exida*), Andreas Bagusch (R. STAHL Schaltgeräte GmbH)	
Release Status:	V1R0 Released to R. STAHL Schaltgeräte GmbH	

7.3 Release Signatures

Hettenbach

Dipl. -Ing. (Univ.) Jan Hettenbach | Dipl.-Ing. (Univ.) Stephan Aschenbrenner, Partner

Appendix A: Possibilities to reveal dangerous undetected faults during the proof test

According to section 7.4.5.2 f) of IEC 61508-2 proof tests shall be undertaken to reveal dangerous faults which are undetected by diagnostic tests.

This means that it is necessary to specify how dangerous undetected faults which have been noted during the FMEDA can be detected during proof testing.

Appendix A shall be considered when writing the safety manual as it contains important safety related information.

Appendix A.1: Possible proof tests to detect dangerous undetected faults

A suggested proof test consists of the following steps, as described in Table 7. It is assumed that this test will detect 99% of possible dangerous failures.

Table 7: Steps for proof test

Step	Action
1.	Bypass the safety function and take appropriate action to avoid a false trip.
2.	Apply a input signal with a defined frequency and amplitude at the Vibration Transducer Supply Unit 9147.
3.	Measure if the output signal of the Vibration Transducer Supply Unit 9147 is within the frequency and amplitude specification.
4.	Apply a signal amplitude > - 0.5V and < - 20.5V
5.	Check if the connected control unit switches into safe state.
6.	Remove the bypass from the monitoring system or otherwise restore normal operation.

Appendix B: Impact of lifetime of critical components on the failure rate

According to section 7.4.9.5 of IEC 61508-2, a useful lifetime, based on experience, should be assumed.

Although a constant failure rate is assumed by the probabilistic estimation method (see section 4.2.3) this only applies provided that the useful lifetime[12] of components is not exceeded. Beyond their useful lifetime, the result of the probabilistic calculation method is meaningless, as the probability of failure significantly increases with time. The useful lifetime is highly dependent on the component itself and its operating conditions – temperature in particular (for example, electrolyte capacitors can be very sensitive).

This assumption of a constant failure rate is based on the bathtub curve. Therefore it is obvious that the PFD_{AVG} calculation is only valid for components which have this constant domain and that the validity of the calculation is limited to the useful lifetime of each component.

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

Table 8 shows which components are contributing to the dangerous undetected failure rate and therefore to the PFD_{AVG} calculation and what their estimated useful lifetime is.

Table 8: Useful lifetime of components contributing to λ_{du}

Type	Name	Useful life
Opto-coupler - With bipolar output	O01A	More than 10 years

When plant experience indicates a shorter useful lifetime than indicated in this appendix, the number based on plant experience should be used.

[12] Useful lifetime is a reliability engineering term that describes the operational time interval where the failure rate of a device is relatively constant. It is not a term which covers product obsolescence, warranty, or other commercial issues.

Appendix C: *exida* Environmental Profiles

Table 9 *exida* Environmental Profiles

***exida* Profile**	**1**	**2**	**3**	**4**	**5**	**6**
Description (Electrical)	Cabinet mounted/ Climate Controlled	Low Power Field Mounted	General Field Mounted	Subsea	Offshore	N/A
		no self-heating	self-heating			
Description (Mechanical)	Cabinet mounted/ Climate Controlled	General Field Mounted	General Field Mounted	Subsea	Offshore	Process Wetted
IEC 60654-1 Profile	B2	C3	C3	N/A	C3	N/A
		also applicable for D1	also applicable for D1		also applicable for D1	
Average Ambient Temperature	30C	25C	25C	5C	25C	25C
Average Internal Temperature	60C	30C	45C	5C	45C	Process Fluid Temp.
Daily Temperature Excursion (pk-pk)	5C	25C	25C	0C	25C	N/A
Seasonal Temperature Excursion (winter average vs. summer average)	5C	40C	40C	2C	40C	N/A
Exposed to Elements/Weather Conditions	No	Yes	Yes	Yes	Yes	Yes
Humidity[13]	0-95% Non-Condensing	0-100% Condensing	0-100% Condensing	0-100% Condensing	0-100% Condensing	N/A
Shock[14]	10 g	15 g	15 g	15 g	15 g	N/A
Vibration[15]	2 g	3 g	3 g	3 g	3 g	N/A
Chemical Corrosion[16]	G2	G3	G3	G3	G3	Compatible Material
Surge[17]						
Line-Line	0.5 kV	0.5 kV	0.5 kV	0.5 kV	0.5 kV	N/A
Line-Ground	1 kV	1 kV	1 kV	1 kV	1 kV	
EMI Susceptibility[18]						
80MHz to 1.4 GHz	10V /m	10V /m	10V /m	10V /m	10V /m	N/A
1.4 GHz to 2.0 GHz	3V/m	3V/m	3V/m	3V/m	3V/m	
2.0Ghz to 2.7 GHz	1V/m	1V/m	1V/m	1V/m	1V/m	
ESD (Air)[19]	6kV	6kV	6kV	6kV	6kV	N/A

[13] Humidity rating per IEC 60068-2-3

[14] Shock rating per IEC 60068-2-6

[15] Vibration rating per IEC 60770-1

[16] Chemical Corrosion rating per ISA 71.04

[17] Surge rating per IEC 61000-4-5

[18] EMI Susceptibility rating per IEC 6100-4-3

[19] ESD (Air) rating per IEC 61000-4-2