Failure Modes, Effects and Diagnostic Analysis

Project:
Pneumatic controller type 869*-***

Customer:

Bürkert Werke GmbH & Co. KG
Ingelfingen
Germany

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Management summary

This report summarizes the results of the hardware and mechanical assessment carried out on the pneumatic controller type 869*-*** in the versions listed in the mechanical drawings referenced in section 2.4.1. Table 4 gives an overview of the different configurations that belong to the considered pneumatic controller type 869*-***.

The hardware and mechanical 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 and Table 2 showing all considered pneumatic controllers. All types are closed in safe state.

Table 1: Configuration overview of ON/OFF control heads and pneumatic controller

8690	**Pneumatic Controller with optical position indicator…**
8690-E*-***	….for installation on single acting process valves with pilot operated solenoid valve 6524-C (NC)
8690-D*-***	….for installation on double acting process valves with pilot operated solenoid valve 6525-H (NC)
8691	**Control head with sensor element, integrated pilot control and status display…**
8691-E*-**-****-E-*	…for installation on single acting process valves with pilot operated solenoid valve 6524-C (NC). The power supplies for the solenoid valve and sensor/System module aren't galvanic isolated.
8691-D*-**-****-E-*	…for installation on double acting process valves with pilot operated solenoid valve 6525-H (NC). The power supplies for the solenoid valve and sensor/System module aren't galvanic isolated.
8691-E*-**-****-3-*	…for installation on single acting process valves with pilot operated solenoid valve 6524-C (NC). The power supplies for the solenoid valve and sensor/System module aren't galvanic isolated. The sensor/system element and solenoid valve are supplied by field bus only.
8691-D*-**-****-3-*	…for installation on double acting process valves with pilot operated solenoid valve 6525-H (NC). The power supplies for the solenoid valve and sensor/System module aren't galvanic isolated. The sensor/system element and solenoid valve are supplied by field bus only.
8691-E*-**-****-T-*	…for installation on single acting process valves with pilot operated solenoid valve 6524-C (NC). The power supplies for the solenoid valve is galvanic isolated from the sensor/System module. The sensor/system element is supplied by field bus only.
8691-D*-**-****-T-*	…for installation on double acting process valves with pilot operated solenoid valve 6525-H (NC). The power supplies for the solenoid valve is galvanic isolated from the sensor/System module. The sensor/system element is supplied by field bus only.
8695	**Control head with sensor element, integrated pilot control and status display…**
8695-E*-**-****-E-*	…for installation on single acting process valves with one direct acting solenoid valve 6144-C (NC). The power supplies for the solenoid valve and sensor/System module aren't galvanic isolated.
8695-D*-**-****-E-*	…for installation on double acting process valves with one direct acting

	solenoid valve 6144-C (NC) and one direct-acting solenoid valve 6144-D (NO). The power supplies for the solenoid valve and sensor/System module aren't galvanic isolated.
8695-E*-**-****-3-*	…for installation on single acting process valves with one direct acting solenoid valve 6144-C (NC). The power supplies for the solenoid valve and sensor/System module aren't galvanic isolated. The sensor/system element and solenoid valve are supplied by field bus only.
8695-D*-**-****-3-*	…for installation on double acting process valves with one direct acting solenoid valve 6144-C (NC) and one direct-acting solenoid valve 6144-D (NO). The power supplies for the solenoid valve and sensor/System module aren't galvanic isolated. The sensor/system element and solenoid valve are supplied by field bus only.
8695-E*-**-****-T-*	…for installation on single acting process valves with one direct acting solenoid valve 6144-C (NC). The power supplies for the solenoid valve is galvanic isolated from the sensor/System module. The sensor/system element is supplied by field bus only.
8695-D*-**-****-T-*	…for installation on double acting process valves with one direct acting solenoid valve 6144-C (NC) and one direct-acting solenoid valve 6144-D (NO). The power supplies for the solenoid valve is galvanic isolated from the sensor/System module. The sensor/system element is supplied by field bus only.
8697	**Pneumatic Controller with optical position indicator…**
8697-E*-***	….for installation on single acting process valves with direct acting solenoid valve 6144-C (NC)

Table 2: Configuration overview of digital Electro Pneumatic Positioner

8692/8693	**Digital electro-pneumatic Positioner with sensor element, integrated pilot control, HMI display and control unit…**
8692/8693-E1-***	…. for installation on single acting control valves with 2 pilot operated solenoid valves 6144-C (NC). The safety function is the safe position, when power supply is disconnected. The SAFEPOS function via digital input isn't part of this FMEDA.
8694	**Digital electro-pneumatic Basic Positioner with sensor element, integrated pilot control and control unit…**
8694-E1-***	….for installation on single acting control valves with 2 pilot operated solenoid valves 6144-C (NC). The safety function is the safe position, when power supply is disconnected. The SAFEPOS function via digital input isn't part of this FMEDA.
8696	**Digital electro-pneumatic Basic Positioner with sensor element, integrated pilot control and control unit…**
8696-E1-***	….for installation on single acting control valves with 2 pilot operated solenoid valves 6144-C (NC). The safety function is the safe position, when power supply is disconnected. The SAFEPOS function via digital input isn't part of this FMEDA.

For safety applications only the described valve functions have been considered. All other possible valve functions are not covered by this report.

Bürkert Werke GmbH & Co. KG and *exida* together did a quantitative analysis of the pneumatic controller type 869*-*** to calculate the failure rates using *exida*'s component database (see [N2]) for the different electronic and mechanical components.

All pneumatic controllers 869*-*** are classified as Type A[1] elements with a hardware fault tolerance of 0.

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 4.2.2.

The following table shows how the above stated requirements are fulfilled under worst-case assumptions. Table 3: Summary – failure rates per IEC 61508:2010

Table 4: Summary results of ON/OFF Control heads and pneumatic Controller – failure rates per IEC 61508:2010

		λ_{safe}	$\lambda_{dangerous}$	SFF [2]	SIL AC [3]	PL (calculated according ISO 13849-1:2015, Table 2)
8690-E*-***	**Profile 2[4]**	324 FIT	241 FIT	57%	SIL1	d
8690-D*-***	**Profile 2**	376 FIT	482 FIT	43%	SIL1	d
8691-E*--****-E-***	**Profile 2**	325 FIT	267 FIT	54%	SIL1	d
8691-D*--****-E-***	**Profile 2**	377 FIT	508 FIT	42%	SIL1	d
8691-E*--****-3-*** **8691-E*-**-****-T-***	**Profile 2**	325 FIT	241 FIT	57%	SIL1	d
8691-D*--****-3-*** **8691-D*-**-****-T-***	**Profile 2**	377 FIT	482 FIT	43%	SIL1	d
8695-E*--****-E-***	**Profile 2**	270 FIT	52 FIT	83%	SIL2	e
8695-D*--****-E-***	**Profile 2**	321 FIT	78 FIT	80%	SIL2	e
8695-E*--****-3-*** **8695-E*-**-****-T-***	**Profile 2**	271 FIT	26 FIT	91%	SIL3	e
8695-D*--****-3-*** **8695-D*-**-****-T-***	**Profile 2**	322 FIT	51 FIT	86%	SIL2	e
8697-E*-***	**Profile 2**	249 FIT	25 FIT	90%	SIL3	e

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

[2] The complete actuator subsystem will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[3] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply all related IEC 61508 requirements are fulfilled.

[4] See appendix 3 for detailed definitions.

Table 5: Summary results of digital electro-pneumatic Positioner – failure rates per IEC 61508:2010

		λ_{safe}	$\lambda_{dangerous}$	SFF [5]	SIL AC [6]	PL (calculated according ISO 13849-1:2015, Table 2)
8692-E1-*; 8693-E1-*	**Profile 2**	512 FIT	72 FIT	85%	SIL2	d
8694-E1-*	**Profile 2**	384 FIT	51 FIT	88%	SIL2	c
8696-E1-*	**Profile 2**	327 FIT	51 FIT	86%	SIL2	d

A user of the considered pneumatic controller type 869*-*** 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 is presented in sections 5.2 to 5.10 along with all assumptions.

The failure rates are valid for the useful life of the considered pneumatic controller type 869*-*** (see Appendix 2) when operating as defined in the considered scenarios.

[5] The complete actuator subsystem will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[6] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply all related IEC 61508 requirements are fulfilled.

Table of Contents

1 Purpose and Scope

This document shall describe the results of the hardware and mechanical assessment carried out on the pneumatic controller type 869*-*** in the versions listed in the mechanical drawings referenced in section 2.4.1.

The FMEDA builds the basis for an evaluation whether the described pneumatic controller type 869*-*** in the versions listed meet the average Probability of Failure on Demand (PFD_{AVG}) requirements and the architectural constraints / minimum hardware fault tolerance requirements per IEC 61508. 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 accredited Certification Bodies and knowledge companies specializing in automation system safety, availability, and cybersecurity with over 500 person years of cumulative experience in functional safety, alarm management, and cybersecurity. Founded by several of the world's top reliability and safety experts from manufacturers, operators and assessment organizations, *exida* is a global corporation with offices around the world. *exida* offers training, coaching, project oriented consulting services, safety engineering tools, detailed product assurance and ANSI accredited functional safety and cybersecurity certification. *exida* maintains a comprehensive failure rate and failure mode database on electronic and mechanical equipment and a comprehensive database on solutions to meet safety standards such as IEC 61508.

2.2 Roles of the parties involved

Bürkert Werke GmbH & Co. KG	Manufacturer of the pneumatic controller type 869*-***.
exida	Performed the hardware and mechanical assessment.

Bürkert Werke GmbH & Co. KG contracted *exida* in November 2018 with the update of the FMEDA of the above mentioned devices.

2.3 Standards / 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
[N2]	Electrical & Mechanical Component Reliability Handbook, 4th Edition, 2017	*exida* L.L.C, Electrical & Mechanical Component Reliability Handbook, Fourth Edition, 2017
[N3]	IEC 60654-1:1993-02, second edition	Industrial-process measurement and control equipment – Operating conditions – Part 1: Climatic conditions

2.4 Reference documents

2.4.1 Documentation provided by the customer

[D1]	MA8690-Standard-EU-ML.pdf	Operating instructions "Pneumatic controller type 8690" 0801/03_EU-ml_00805640
[D2]	MA8691-Standard-EU-ML.pdf	Operating instructions "Control head type 8691" 0801/01_EU-ML_00806086
[D3]	MA8695-Standard-EU-ML.pdf	Operating instructions "Control head type 8695" 0806/00_EU-ML_00805569
[D4]	DS8690-standard-EU-EN.pdf	Datasheet „Pneumatic control unit type 8690" 0808/0_EU-en_00895080
[D5]	DS8691-Standard-EU-EN.pdf	Datasheet "Control head type 8691" 0809/1_EU-en_00895081

[D6]	DS8695-Standard-EU-EN.pdf	Datasheet “Control head type 8695” 0808/0_EU-en_00895094
[D7]	8690_Schaltplan_D0 00651987.pdf	Circuit diagram “LP roh pneumatische Ansteuerung MAIA” DO 00651987 Version G
[D8]	8690BG01-IndexE-9000088627.pdf	Mechanical drawing “Pneumatische Ansteuerung” 9000088627 Version E
[D9]	8691_Schaltplan_D0 00651961.pdf	Circuit diagram “LP best. Steuerkopf MAIA 24V/DC” DO 00651961 Version G
[D10]	8691BG01-IndexD-9000079145.pdf	Mechanical drawing “Steuerkopf” 9000079145 Version J
[D11]	8695_Anschlussmodul_IndexA_9000105806.pdf	Mechanical drawing “Anschlussmodul pneumatisch D50” 9000105806 Version D
[D12]	9000088627 Index I.pdf	Mechanical drawing for 8690 Index I of 28.11.2017
[D13]	00677246.pdf	Circuit diagram of controller board Index A for 8691, 8692, 8693, 8694, 8695, 8696
[D14]	9000079145.pdf	Mechanical drawing for 8691 Index J of 01.12.2017
[D15]	9000091176.pdf	Mechanical drawing for 8692, 8693 Index K of 19.03.2018
[D16]	D000693856 Index C .pdf	Circuit diagram for 8692, 8693 Index C of 30.05.2017
[D17]	D000581907.pdf	Circuit diagram for 8694 Index A of 07.03.2019
[D18]	9000105638.pdf	Mechanical drawing for 8694 Index F of 05.11.2014
[D19]	D000581857.pdf	Circuit diagram for 8695 Index B of 11.02.2019
[D20]	D000581826.pdf	Circuit diagram for 8695, 8696 Index B of 17.04.2018
[D21]	9000105588.pdf	Mechanical drawing for 8696 Index C of 25.11.2014
[D22]	9000240740.pdf	Mechanical drawing for 8697 Index A of 08.07.2013
[D23]	8695BG01-IndexA-9000105457.pdf	Mechanical drawing “Steuerkopf D50” 9000105457 Version F
[D24]	9000078055_IndexH_Anschlussmodul pneumatisch_8690_8691.pdf	Mechanical drawing “Anschlussmodul pneumatisch” 9000078055 Version O
[D25]	E101-05V02_Schaltplan_Controller_8691_8695.pdf	Circuit diagram “BUR02 Electronics Board” E101-05V02 of 03.03.06
[D26]	3_2-Wege Flipper Ventil.pdf	Mechanical drawing “3/2-way Solenoid Valve”, 9000201599, Version A of 08.01.2013
[D27]	9000240740.pdf	Mechanical drawing “Position Indicator, Stellungsrückmelder”, Model: 8697, 9000240740, Version A of 08.07.2013

[D28]	Anschlussmodul pneum.pdf	Mechanical drawing “Pneumatic connection module, Anschlussmodul pneumatisch”, Model 8695, 9000241237, Version A of 17.06.2013
[D29]	Einbaustecker M12x1.pdf	Mechanical drawing “Plug M12x1, Einbaustecker M12x1”, Model 8697, 9000241199 of 19.06.2013
[D30]	Fluid Modul.pdf	Mechanical drawing “Fluid Module, Fluidmodul”, Model 8695, 9000256684, Rev. 01 of 20.06.2013
[D31]	Leiterplatte.pdf	Mechanical drawing “Circuit Board, Leiterplatte”, Model 8697, 9000243550, Rev. 01 of 22.04.2013
[D32]	MA8697_PneumAnsteuerung_EUml_01_810081.pdf	Operating Instructions Type 8697,
[D33]	Platinenhalter kpl.pdf	Mechanical drawing “Platinum holder complete, Platinenhalter kompl.”, Model 8697, 9000241192, Rev. 01 of 22.04.2013
[D34]	D000581826_ Schaltplan.pdf	Circuit diagram “LP ROH 8791 STM32 IOL BUS 24V” Version B of 8691-**-**-****-3-*, 8691-**-**-****-T-*, 8695-**-**-****-3-* and 8695-**-**-****-T-*

2.4.2 Documentation generated by *exida*

[R1]	FMEDA_V8_8690_D_V3R0.efm of 26.04.2019
[R2]	FMEDA_V8_8690_E_V3R0.efm of 26.11.2018
[R3]	FMEDA_V8_8691_D_3,T_V4R0.efm of 26.04.2019
[R4]	FMEDA_V8_8691_D_E_V3R0.efm of 26.04.2019
[R5]	FMEDA_V8_8691_E_3,T_V4R0.efm of 26.04.2019
[R6]	FMEDA_V8_8691_E_E_V3R0.efm of 26.11.2018
[R7]	FMEDA_V8_8692_3_V1R1.efm of 27.03.2019
[R8]	FMEDA_V8_8694_V1R0.efm of 11.04.2019
[R9]	FMEDA_V8_8695_D_3,T_V4R0.efm of 11.04.2019
[R10]	FMEDA_V8_8695_D_E_V3R0.efm of 26.04.2019
[R11]	FMEDA_V8_8695_E_3,T_V4R0.efm of 26.04.2019
[R12]	FMEDA_V8_8695_E_E_V3R0.efm of 26.11.2018
[R13]	FMEDA_V8_8696_V1R1.efm of 11.04.2019
[R14]	FMEDA_V8_8697 V3R0.efm of 12.06.19

3 Description of the analyzed element

The 869x pneumatic control unit is optimized for integrated mounting on the 20xx or 21xx process valve series as shown in Figure 1. Mechanical or inductive limit switches or a contact free analog position sensor register the position of the valve. The integrated pilot valve controls single or double acting actuators.

The design of the control unit with the actuator type 21xx enables an internal control air channel without external tubing. Besides the electrical position feedback signal the status of the device is shown directly on the control head itself.

The pneumatic controller types 869x are classified as Type A[7] elements with a hardware fault tolerance of 0.

Figure 1: Pneumatic controller type 8690-* with possible process valves**

The FMEDA has been carried out on the parts indicated in Figure 2.

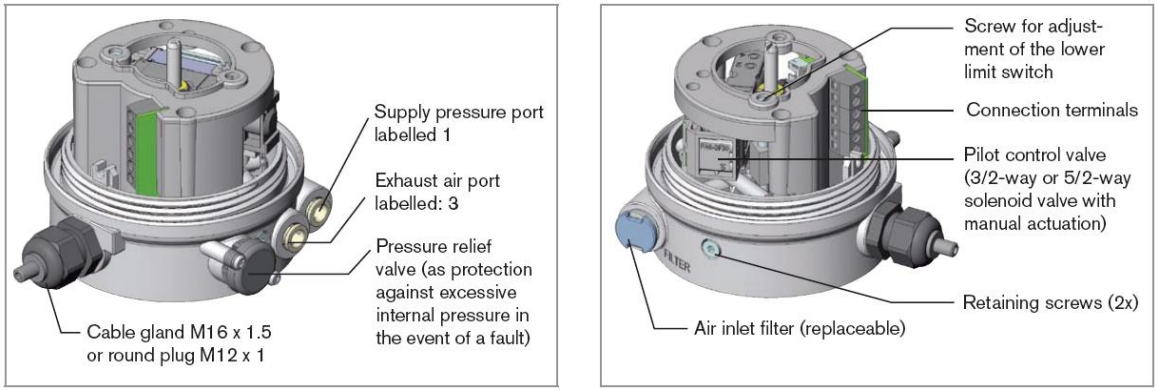


Figure 2: Block diagram of the pneumatic controller type 8690-*

The figures shown above are also valid for the other types as the principles are identical.

[7] Type A element: "Non-complex" subsystem (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 done together with Bürkert Werke GmbH & Co. KG and is documented in [R1] to [R14].

4.1 Description of the failure categories

In order to judge the failure behavior of the pneumatic controller type 869*-***, the following definitions for the failure of the products were considered.

Fail-Safe State	The fail-safe state is defined as the connected valve being open/closed when electrically or pneumatically de-energized.
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.
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.
Dangerous Undetected	Failure that is dangerous and that is not being diagnosed by internal or external diagnostics (DU).
Dangerous Detected	Failure that is dangerous but is detected by internal or external diagnostics (DD). These failures may be converted to the selected fail-safe state.
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.
External Leakage	Failure that causes process fluids to leak outside of the valve. External leakage is not considered as part of the safety function and therefore this failure rate is not included in the Safe Failure Fraction calculation.

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 in consideration.

A FMEDA (Failure Modes, Effects, and Diagnostic Analysis) is a FMEA extension. It combines standard FMEA techniques with extension 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) 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 rates and failure modes used in this analysis are from the exida Electrical Component Reliability Handbook (see [N2]). The rates were chosen in a way that is appropriate for safety integrity level verification calculations and the intended applications. 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 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. 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.

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™ that indicates higher failure rates, the higher numbers shall be used.

4.3 Assumptions

The following assumptions have been made during the Failure Modes, Effects, and Diagnostic Analysis of the pneumatic controller type 869*-***.

- Failure rates are constant, wear out mechanisms are not included.
- Propagation of failures is not relevant.
- 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.
- Materials are compatible with process conditions and process fluids.
- The Mean Time To Restoration (MTTR) after a safe failure is 24 hours.
- External power supply failure rates are not included.
- All devices are operated in the low demand mode of operation.
- The pneumatic controller type 869*-*** is installed per the manufacturer's instructions.
- Practical fault insertion tests can demonstrate the correctness of the failure effects assumed during the FMEDAs.
- The stress levels are average for an industrial outdoor environment and can be compared to exida Profile 2 with temperature limits within the manufacturer's rating. Other environmental characteristics are assumed to be within the manufacturer's ratings.
- Only the described versions and circuit functions are used for safety applications.
- Mechanical limit switches are outside the scope of this analysis.
- Manual override must not be used for safety applications.
- Clean and dry operating air is used per ANSI/ISA-7.0.01-1996 Quality Standard for Instrument Air.

5 Results

λ_{total} consists of the sum of all component failure rates. This means:

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

$SFF = 1 - \lambda_{DU} / \lambda_{total}$

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

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 61508-2.

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:

λ_S = Fail Safe

λ_{DD} = Fail Dangerous Detected

λ_{DU} = Fail Dangerous Undetected

As the pneumatic controller type 869*-*** are only one part of an element, the architectural constraints should be determined for the entire final element.

5.1 Air quality failures

The product failure rates that are displayed in this section are failure rates that reflect the situation where the device is used with clean filtered air. Additionally, contamination from poor control air quality may affect the function or air flow in the device. For applications where these assumptions do not apply, the user must estimate the failure rates due to contaminated air and add this failure rate to the product failure rates.

5.2 Pneumatic controller type 8690-***

The FMEDA carried out on the pneumatic controller type 8690-*** leads under the assumptions described in section 4.3 and the definitions given in section 4.1 to the following failure rates:

Table 6: Pneumatic controller type 8690-E*-* – IEC 61508 failure rates**

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**324**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**241**

No effect	353
No part	88

Total failure rate of the safety function (λ_{Total})	**565**
Safe failure fraction (SFF)[8]	**57%**

SIL AC[9]	**-**

[8] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[9] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

Table 7: Pneumatic controller type 8690-D*-* – IEC 61508 failure rates**

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**376**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**482**
No effect	353
No part	88
Total failure rate of the safety function (λ_{Total})	**858**
Safe failure fraction (SFF)[10]	**43%**
SIL AC[11]	**-**

[10] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[11] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

5.3 Pneumatic controller type 8691-**-**-****-E-*

The FMEDA carried out on the pneumatic controller type 8691-**-**-****-E-* leads under the assumptions described in section 4.3 and the definitions given in section 4.1 to the following failure rates:

Table 8: Pneumatic controller type 8691-E*--****-E-* – IEC 61508 failure rates**

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**325**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**267**
No effect	382
No part	102
Total failure rate of the safety function (λ_{Total})	**592**
Safe failure fraction (SFF)[12]	**54%**
SIL AC[13]	**-**

[12] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[13] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

Table 9: Pneumatic controller type 8691-D*--****-E-* – IEC 61508 failure rates**

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**377**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**508**
No effect	382
No part	102
Total failure rate of the safety function (λ_{Total})	**885**
Safe failure fraction (SFF)[14]	**42%**
SIL AC[15]	**-**

[14] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[15] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

5.4 Pneumatic controller type 8691-**-**-****-3-*, 8691-**-**-****-T-*

The FMEDA carried out on the pneumatic controller type 8691-**-**-****-3-* and 8691-**-**-****-T-* leads under the assumptions described in section 4.3 and the definitions given in section 4.1 to the following failure rates:

Table 10: Pneumatic controller type 8691-E*--****-3-* and 8691-E*-**-****-T-* – IEC 61508 failure rates**

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**325**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**241**
No effect	360
No part	89
Total failure rate of the safety function (λ_{Total})	**566**
Safe failure fraction (SFF)[16]	**57%**
SIL AC[17]	**SIL 1**

[16] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[17] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

Table 11: Pneumatic controller type 8691-D*--****-3-* and 8691-D*-**-****-T-* – IEC 61508 failure rates**

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**377**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**482**
No effect	360
No part	89
Total failure rate of the safety function (λ_{Total})	**859**
Safe failure fraction (SFF)[18]	**43%**
SIL AC[19]	**SIL 1**

[18] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[19] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

5.5 Pneumatic controller type 8692-E1-*, 8693-E1-*

The FMEDA carried out on the pneumatic controller type type 8692-E1-* and 8693-E1-* leads under the assumptions described in section 4.3 and the definitions given in section 4.1 to the following failure rates:

Table 12: Pneumatic controller type 8692-E1-* and 8693-E1-* – IEC 61508 failure rates

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**412**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**72**

No effect	373
No part	125

Total failure rate of the safety function (λ_{Total})	**484**
Safe failure fraction (SFF)[20]	**85%**

SIL AC[21]	**SIL 2**

[20] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[21] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

5.6 Pneumatic controller type 8694-E1-*

The FMEDA carried out on the pneumatic controller type type 8694-E1-* leads under the assumptions described in section 4.3 and the definitions given in section 4.1 to the following failure rates:

Table 13: Pneumatic controller type 8694-E1-* – IEC 61508 failure rates

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**384**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**51**
No effect	364
No part	83
Total failure rate of the safety function (λ_{Total})	**435**
Safe failure fraction (SFF)[22]	**88%**
SIL AC[23]	**SIL 1**

[22] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[23] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

5.7 Pneumatic controller type 8695-**-**-****-E-*

The FMEDA carried out on the pneumatic controller type 8695-**-**-****-E-* leads under the assumptions described in section 4.3 and the definitions given in section 4.1 to the following failure rates:

Table 14: Pneumatic controller type 8695-E*--****-E-* – IEC 61508 failure rates**

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**270**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**52**

No effect	286
No part	102

Total failure rate of the safety function (λ_{Total})	**322**
Safe failure fraction (SFF)[24]	**83%**

SIL AC[25]	**SIL 1**

[24] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[25] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

Table 15: Pneumatic controller type 8695-D*--****-E-* – IEC 61508 failure rates**

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**321**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**78**
No effect	286
No part	102
Total failure rate of the safety function (λ_{Total})	**399**
Safe failure fraction (SFF)[26]	**80%**
SIL AC[27]	**SIL 1**

[26] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[27] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

5.8 Pneumatic controller type 8695-**-**-****-3-*, 8695-**-**-****-T-*,

The FMEDA carried out on the pneumatic controller type 8695-**-**-****-3-* and 8695-**-**-****-T-* leads under the assumptions described in section 4.3 and the definitions given in section 4.1 to the following failure rates:

Table 16: Pneumatic controller type 8695-E*--****-3-* and 8695-E*-**-****-T-*– IEC 61508 failure rates**

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**271**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**26**

No effect	263
No part	89

Total failure rate of the safety function (λ_{Total})	**297**
Safe failure fraction (SFF)[28]	**91%**

SIL AC[29]	**SIL 3**

[28] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[29] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

Table 17: Pneumatic controller type 8695-D*--****-3-* and 8695-D*-**-****-T-*– IEC 61508 failure rates**

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**322**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**51**
No effect	263
No part	89
Total failure rate of the safety function (λ_{Total})	**373**
Safe failure fraction (SFF)[30]	**86%**
SIL AC[31]	**SIL 2**

[30] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[31] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

5.9 Pneumatic controller type 8696-E1-*

The FMEDA carried out on the pneumatic controller type 8696-E1-* leads under the assumptions described in section 4.3 and the definitions given in section 4.1 to the following failure rates:

Table 18: Pneumatic controller type 8696-E1-*– IEC 61508 failure rates

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**327**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**51**
No effect	266
No part	89
Total failure rate of the safety function (λ_{Total})	**378**
Safe failure fraction (SFF)[32]	**86%**
SIL AC[33]	**SIL 2**

[32] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[33] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

5.10 Pneumatic controller type 8697-E*-***

The FMEDA carried out on the pneumatic controller type 8697-*** leads under the assumptions described in section 4.3 and the definitions given in section 4.1 to the following failure rates:

Table 19: Pneumatic controller type 8697-E*-*– IEC 61508 failure rates**

	Profile 2
Failure category	**Failure rate [FIT]**
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**249**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**25**
No effect	226
No part	184
Total failure rate of the safety function (λ_{Total})	**274**
Safe failure fraction (SFF)[34]	**90%**
SIL AC[35]	**SIL 3**

[34] The complete actuator element will need to be evaluated to determine the overall Safe Failure Fraction. The number listed is for reference only.

[35] SIL AC (architectural constraints) means that the calculated values are within the range for hardware architectural constraints for the corresponding SIL but does not imply that all related IEC 61508 requirements are fulfilled.

6 Using the FMEDA results

Using the failure rate data displayed in section 5, and the failure rate data for the associated element devices, an average the Probability of Failure on Demand (PFD_{AVG}) calculation can be performed for the entire safety function.

Probability of Failure on Demand (PFD_{AVG}) calculation uses several parameters, many of which are determined by the particular application and the operational policies of each site. Some parameters are product specific and the responsibility of the manufacturer. Those manufacturer specific parameters are given in this third party report.

Probability of Failure on Demand (PFD_{AVG}) calculation is the responsibility of the owner/operator of a process and is often delegated to the SIF designer. Product manufacturers can only provide a PFD_{AVG} by making many assumptions about the application and operational policies of a site. Therefore use of these numbers requires complete knowledge of the assumptions and a match with the actual application and site.

Probability of Failure on Demand (PFD_{AVG}) calculation is best accomplished with *exida´s* exSILentia tool. The mission time used for the calculation depends on the PFD_{AVG} target and the useful life of the product. The failure rates for all the devices of the safety function and the corresponding proof test coverages are required to perform the PFD_{AVG} calculation. The proof test coverage of the suggested proof test for the 869*-*** is listed in Appendix 2. This is combined with the dangerous failure rates after proof test for other devices to establish the proof test coverage for the entire safety function.

When performing testing at regular intervals, the 869*-*** contribute less to the overall PFD_{AVG} of the Safety Instrumented Function.

The following section gives a simplified example on how to apply the results of the FMEDA.

Example PFD_{AVG} calculation

An average Probability of Failure on Demand (PFD_{AVG}) calculation is performed for 869*-***. The failure rate data used in this calculation are displayed in sections 5.2 to 5.10. A mission time of 10 years has been assumed, a Mean Time To Restoration of 24 hours and a maintenance capability of 100%. Table 4 lists the results for different proof test intervals considering an average proof test coverage of 90% (see Appendix 1).

Table 20: Pneumatic controller type 869*-* – PFD_{AVG} values**

Configuration	T[Proof] = 1 year	T[Proof] = 2 years	T[Proof] = 5 years
8690-E*-***	PFD_{AVG} = 2.01E-03	PFD_{AVG} = 2.96E-03	PFD_{AVG} = 5.81E-03
8690-D*-***	PFD_{AVG} = 4.01E-03	PFD_{AVG} = 5.91E-03	PFD_{AVG} = 1.16E-02
8691-E*-**-****-E-*	PFD_{AVG} = 2.22E-03	PFD_{AVG} = 3.27E-03	PFD_{AVG} = 6.43E-03
8691-D*-**-****-E-*	PFD_{AVG} = 4.23E-03	PFD_{AVG} = 6.23E-03	PFD_{AVG} = 1.22E-02
8691-E*-**-****-3-* 8691-E*-**-****-T-*	PFD_{AVG} = 2.01E-03	PFD_{AVG} = 2.96E-03	PFD_{AVG} = 5.81E-03
8691-D*-**-****-3-* 8691-D*-**-****-T-*	PFD_{AVG} = 4.01E-03	PFD_{AVG} = 5.91E-03	PFD_{AVG} = 1.16E-02
8695-E*-**-****-E-*	PFD_{AVG} = 4.33E-04	PFD_{AVG} = 6.38E-04	PFD_{AVG} = 1.25E-03
8695-D*-**-****-E-*	PFD_{AVG} = 6.49E-04	PFD_{AVG} = 9.57E-04	PFD_{AVG} = 1.88E-03
8695-E*-**-****-3-* 8695-E*-**-****-T-*	PFD_{AVG} = 2.16E-04	PFD_{AVG} = 3.19E-04	PFD_{AVG} = 6.26E-04
8695-D*-**-****-3-* 8695-D*-**-****-T-*	PFD_{AVG} = 4.24E-04	PFD_{AVG} = 6.25E-04	PFD_{AVG} = 1.23E-03
8697-E*-***	PFD_{AVG} = 2.08E-04	PFD_{AVG} = 3.07E-04	PFD_{AVG} = 6.02E-04
8692-E1-* 8693-E1-*	PFD_{AVG} = 2.01E-03	PFD_{AVG} = 2.96E-03	PFD_{AVG} = 5.81E-03
8694-E1-*	PFD_{AVG} = 4.24E-04	PFD_{AVG} = 6.25E-04	PFD_{AVG} = 1.23E-03
8696-E1-*	PFD_{AVG} = 4.24E-04	PFD_{AVG} = 6.25E-04	PFD_{AVG} = 1.23E-03

For SIL2 the overall PFD_{AVG} shall be better than 1.00E-02. As the 869*-*** is contributing to the entire safety function they should only consume a certain percentage of the allowed range. Assuming 10% of this range as a reasonable budget they should be better than or equal to 1.0E-03.

7 Terms and Definitions

FIT	Failure In Time ($1x10^{-9}$ failures per hour)
FMEDA	Failure Modes, Effects, and Diagnostic Analysis
HFT	Hardware Fault Tolerance
Low demand mode	Mode, where the demand interval for operation made on a safety-related system is greater than twice the proof test interval.
MTBF	Mean Time Between Failures
MTTR	Mean Time To Restoration
PFD_{AVG}	Average Probability of Failure on Demand
PL	Performance Level (ISO 13849)
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
Type A element	“Non-complex” subsystem (all failure modes are well defined); for details see 7.4.4.1.2 of IEC 61508-2.
T[Proof]	Proof Test Interval

8 Status of the document

8.1 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.

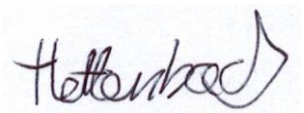
Due to future potential changes in the standards, best available information and best practices, the current FMEDA results presented in this report may not be fully consistent with results that would be presented for the identical product at some future time. As a leader in the functional safety market 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.

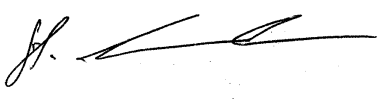
Most products also tend to undergo incremental changes over time. If an *exida* FMEDA has not been updated within the last three years and the exact results are critical to the SIL verification you may wish to contact the product vendor to verify the current validity of the results.

8.2 Releases

Version History:	V3R2:	Update after review; June 14, 2019
	V3R1:	New types included; May 6, 2019
	V3R0:	Review comments incorporated; March 4, 2019
	V2R1:	Include new FMEDA results, February 25, 2019
	V2R0:	Updated according to IEC 61508:2010, Type 8697 added; December 6, 2013
	V1R0:	Review comments incorporated; November 3, 2008
	V0R1:	Initial version; October 22, 2008
Authors:	Jan Hettenbach	
Review:	V3R1:	Kim Biewer (Bürkert Werke GmbH & Co. KG); June 7, 2019
	V3R0:	Stephan Aschenbrenner (*exida*); April 30, 2019
Release status:	V3R2: Released to Bürkert Werke GmbH & Co. KG	

8.3 Release Signatures





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

Appendix 1: 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 1 shall be considered when writing the safety manual as it contains important safety related information.

A possible proof test consists of the following steps, as described in Table 21.

Table 21 Steps for Proof Test

Step	Action
1	Take appropriate action to avoid a false trip
2	Inspect the device for any visible damage, corrosion or contamination.
3	Force the pneumatic controller type 869*-*** to open the connected valve when electrically or pneumatically de-energized and verify that the connected valve goes into the safe state.
4	Force the pneumatic controller type 869*-*** to close the connected valve when electrically or pneumatically de-energized and verify that the connected valve goes into the safe state.
5	Restore the loop to full operation
6	Restore normal operation

It is assumed that this proof test will detect approximately 90% of possible “du” failures in the device.

Appendix 2: 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 0) this only applies provided that the useful lifetime[36] 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 22 shows which components with reduced useful lifetime are contributing to the dangerous undetected failure rate and therefore to the PFD_{AVG} calculation and what their estimated useful lifetime is.

Table 22: Useful lifetime of components with reduced useful lifetime contributing to λ_{du}

Type	Useful life
Mechanical parts	Approximately 10 years

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

Major factors influencing useful life are the air quality, ambient temperature and the air circulation around the solenoid.

[36] 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 3: *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[37]	0-95% Non-Condensing	0-100% Condensing	0-100% Condensing	0-100% Condensing	0-100% Condensing	N/A
Shock[38]	10 g	15 g	15 g	15 g	15 g	N/A
Vibration[39]	2 g	3 g	3 g	3 g	3 g	N/A
Chemical Corrosion[40]	G2	G3	G3	G3	G3	Compatible Material
Surge[41]						
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[42]						
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)[43]	6kV	6kV	6kV	6kV	6kV	N/A

[37] Humidity rating per IEC 60068-2-3
[38] Shock rating per IEC 60068-2-6
[39] Vibration rating per IEC 60770-1
[40] Chemical Corrosion rating per ISA 71.04
[41] Surge rating per IEC 61000-4-5
[42] EMI Susceptibility rating per IEC 6100-4-3
[43] ESD (Air) rating per IEC 61000-4-2