Failure Modes, Effects and Diagnostic Analysis

Project:

Direct-acting solenoid valves
2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-***
Pilot-operated solenoid valves
2/2-way 5282-*-*** with pilot control type 331-*-***,
3/2-way 6524-*-*** with pilot control type 6144-*-*** and
5/2-way 6525-*-*** with pilot control type 6144-*-*** and
3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106
3/2-way 6534-C-***

Customer:

Bürkert Werke GmbH & Co. KG
Ingelfingen
Germany

Contract No.: Buerkert 19/07-048
Report No.: Buerkert 12/10-97-C R003
Version V4, Revision R1, February 2020

Stephan Aschenbrenner

Management summary

This report summarizes the results of the hardware assessment carried out on the direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-***. Table 1 gives an overview of the different versions that belong to the considered valves.

The 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. For full assessment purposes all requirements of IEC 61508 must be considered.

Table 1: Version overview

330-A-***[1]	2/2-way solenoid valve with pivoted armature and manual override for liquid, gaseous and aggressive media; when de-energized, normally closed with spring action, standard version with threaded port connection
331-A-***	2/2-way solenoid valve with pivoted armature and manual override for liquid, gaseous and aggressive media; when de-energized, normally closed with spring action, standard version with flange connection
330-B-***	2/2-way solenoid valve with pivoted armature and manual override for liquid, gaseous and aggressive media; when de-energized, normally open with spring action, standard version with threaded port connection
331-B-***	2/2-way solenoid valve with pivoted armature and manual override for liquid, gaseous and aggressive media; when de-energized, normally open with spring action, standard version with flange connection
330-C-***	3/2-way solenoid valve with pivoted armature and manual override for liquid, gaseous and aggressive media; when de-energized, normally closed with spring action, standard version with threaded port connection
331-C-***	3/2-way solenoid valve with pivoted armature and manual override for liquid, gaseous and aggressive media; when de-energized, normally closed with spring action, standard version with flange connection
330-D-***	3/2-way solenoid valve with pivoted armature and manual override for liquid, gaseous and aggressive media; when de-energized, normally open with spring action, standard version with threaded port connection
331-D-***	3/2-way solenoid valve with pivoted armature and manual override for liquid, gaseous and aggressive media; when de-energized, normally open with spring action, standard version with flange connection
330-T-***	3/2-way solenoid valve with pivoted armature and manual override for liquid, gaseous and aggressive media; universal function, any flow direction, standard version with threaded port connection
331-T-***	3/2-way solenoid valve with pivoted armature and manual override for liquid, gaseous and aggressive media; universal function, any flow direction, standard version with flange connection

[1] *** stands for the different certifications carried out on the considered valves.

6144-C-* **	3/2-way rocker solenoid valve for gases and liquids; when de-energized, normally closed
6144-D-* **	3/2-way rocker solenoid valve for gases and liquids; when de-energized, normally open
5282-A-* **	2/2-way solenoid valve for contaminated and aggressive fluids; when de-energized, normally closed, with 3-way pilot control type 331 or 780 (Ex version)
5282-B-* **	2/2-way solenoid valve for contaminated and aggressive fluids; when de-energized, normally open, with 3-way pilot control type 331 or 780 (Ex version)
6524-C-* **	3/2-way and 2 x 3/2-way rocker solenoid valve for gases and liquids; when de-energized, normally closed, with 3-way pilot control type 6104 or 6144
6524-D-* **	3/2-way and 2 x 3/2-way rocker solenoid valve for gases and liquids; when de-energized, normally open, with 3-way pilot control type 6104 or 6144
6525-H-* **	5/2-way rocker solenoid valve for gases and liquids; when de-energized, port 2 pressurized, port 4 exhausted, with 3-way pilot control type 6104 or 6144
6526-C-* **	3/2-way rocker solenoid valve for pneumatics; when de-energized, normally closed, with 3-way pilot control type 6106
6527-H-* **	5/2-way rocker solenoid valve for pneumatics; when de-energized, port 2 pressurized, port 4 exhausted, with 3-way pilot control type 6106
6534-C-* **	3/2-way solenoid valve 6534 for air; C – closed in rest position – pressure port 1 (P/NC), working port 2 (A/OUT) after port 3 (R/NO) open"

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 direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-*** to calculate the failure rates using Profile 3[2] of *exida's* component database (see [N3]) for the different mechanical components.

The two valves of the 2 x 3/2-way rocker solenoid valve 6524-*-*** shall not be used in the same safety function, e.g. to increase the hardware fault tolerance to achieve a higher SIL, as they contain common components. The FMEDA applies to either valve used in a single safety function. The two valves may be used in separate safety functions if due regard is taken of the possibility of common failures.

The direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-*** are considered to be Type A[3] elements with a hardware fault tolerance of 0.

The failure rate data used for this analysis meets the *exida* criteria for Route 2_H, see Section 6.2. Therefore, the direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control

[2] See appendix 3 for detailed definitions

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

type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-*** can be classified as 2_H devices when the listed failure rates are used. **When 2_H data is used for all of the devices in an element, then the element meets the hardware architectural constraints up to SIL 2 at HFT=0 for low demand mode applications or SIL 2 / SIL3 at HFT=1 for high and low demand mode applications.** If Route 2_H is not applicable for the entire element, the architectural constraints will need to be evaluated per Route 1_H.

The following table shows how the above stated requirements are fulfilled under worst-case assumptions.

	λ_{safe}	$\lambda_{dangerous}$	**PL** [4] **(calculated according ISO 13849-1:2015, Table 2)**
330-*-* and 331-*-*** **	50 FIT	77 FIT	e
6144-*-* **	51 FIT	26 FIT	e
5282-A/B-* (circuit function A or B)**	50 FIT	120 FIT	d
6524-*-* with pilot control type 6144-*-*** **	51 FIT	192 FIT	d
6525-H-* (circuit function H) with pilot control type 6144-*-*** **	51 FIT	260 FIT	d
6526-C-* (circuit function C) with pilot control type 6106**	75 FIT	80 FIT	e
6527-H-* (circuit function H) with pilot control type 6106**	75 FIT	287 FIT	d
6534-C	112 FIT	170 FIT	d

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.

A user of the direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-*** 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 section 5 along with all assumptions.

Failure of the air supply shall be included in the average Probability of Failure on Demand (PFD_{AVG}) of the Safety Instrumented Function. If an accumulator system is used to protect against air supply failure, the accumulator subsystem needs to be reviewed and the dangerous failure rates of the accumulator subsystem shall be added to the actuator failure rates.

The failure rates are valid for the useful life of the direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-*** (see Appendix 2).

[4] The Performance Level (PL) is not based on B_{10d} values or any cyclic tests but is based on $\lambda_{dangerous}$.

Table of Contents

1 Purpose and Scope

This document shall describe the results of the mechanical assessment carried out on the direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-***.

The FMEDA builds the basis for an evaluation whether the described direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-*** 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.com*

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 direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-***.
exida	Performed the hardware assessment.

Bürkert Werke GmbH & Co. KG contracted *exida* in July 2019 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]	ISO 13849-1:2015	Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design
[N3]	Mechanical Component Reliability Handbook, 4th Edition, 2016	*exida* LLC, Electrical & Mechanical Component Reliability Handbook, Fourth Edition, 2016 (pending publication, not publicly available at the time of this report)

2.4 *exida* tools used

[T1]	SILcal V8	FMEDA Tool
[T2]	exSILentia V3	Integrated Safety Lifecycle Tool, PFD-Calculation

ABD 1000095704 DE Version: D Status: RL (released | freigegeben) printed: 21.06.2024

2.5 Reference documents

2.5.1 Documentation provided by the customer

[D1]	DS0330-Standard-EU-EN.pdf	Data sheet 330-*-***
[D2]	DS0331-Standard-US-EN.pdf	Data sheet 331-*-***
[D3]	DS5282-Standard-EU-EN.pdf	Data sheet 5282-*-***
[D4]	DS6524-Standard-EU-EN.pdf	Data sheet 6524-*-***
[D5]	DS6525-Standard-EU-EN.pdf	Data sheet 6525-*-***
[D6]	DS6144-standard-EU-EN.pdf	Data sheet 6144-*-***
[D7]	9000103656_0330.pdf	Diagram "3/2-Wege-Magnetventil Standardausführung" 0330 BG01 Version 3 of 26.11.98
[D8]	9000066546_5282.pdf	Diagram "2/2-Wege MV WWA, B Standardausführung" 5282 BG01 Version D of 17.08.05
[D9]	9000027518_6524.pdf	Diagram 6524 BG01 Version D02 of 23.03.06
[D10]	9000027520_6524.pdf	Diagram "3/2-Wege-Ventil WWC – INT" 6524 BG03 Version B01 of 22.06.06
[D11]	9000027573_6525.pdf	Diagram "5/2-Wege Ventil" 6525 BG01 Version C01 of 28.06.06
[D12]	9000103656_0330.pdf	Parts list 330 material no. 168 959
[D13]	9000066546_5282.pdf	Parts list 5282 material no. 134 458
[D14]	9000027518_6524.pdf	Parts list 6524 material no. 144 933
[D15]	9000027573_6525.pdf	Parts list 6525 material no. 156 733
[D16]	SIL 2 valves 25.07.06.doc	Overview of available certificates for the considered valves
[D17]	Vergleich 6144 6104 2_2008-04-07.doc	Comparison between type 6104-*-*** and type 6144-*-***
[D18]	9000089865_6144.pdf	Mechanical drawing "Lamellenventil" 9000089865 version F of 13.08.07
[D19]	9000089216_6144.pdf	Mechanical drawing "Lamelle kpl." 9000089216 version O of 24.04.08
[D20]	9000201599_6144.pdf	Mechanical drawing "3/2-way Solenoid Valve", Model: 6144, 9000201599 version A of 08.01.2013
[D21]	9000254953_6526.pdf	Mechanical drawing "3/2-way Valve WWC", Model: 6526, 9000254953 version 01 of 10.06.2013
[D22]	6526 3_2_Wege Ventil WWC.pdf	Mechanical drawing "3/2-Wege Ventil WW C"; Model: 6526, 9000234806 of 09.10.2012
[D23]	DS6526-Standard-DE-DE.pdf	Data sheet „3/2-Wege-Magnetventil für Pneumatik", 6526, version C of 05.10.2012
[D24]	STL -Zulassung 3_2-way Valve WWC.pdf	Parts list "Stückliste – Zulassung, 3/2-Wege Ventil WWC / 3/2-way Valve WWC, Typ 6526", number 485325 of 10.06.2013

[D25]	STL -Zulassung Vorsteuerventil.pdf	Parts list “Stückliste – Zulassung, Vorsteuerventil / Pilot Valve, Typ V106”, number 485352 of 10.06.2013
[D26]	9000200953_V106.pdf	Machanical drawing “Pilot Valve”, Model V106, 9000200953 version 01 of 07.11.2011
[D27]	9000254964_6527.pdf	Mechanical drawing “5/2-way Valve WWH”, Model 6527, 9000254964 version 01 of 11-06-2013
[D28]	DS6527-Standard-DE-DE.pdf	Data sheet „5/2-Wege-Magnetventil für Pneumatik“, Model 6527, Version C of 05.10.2012
[D29]	STL -Zulassung 5_2-way Valve WWC.pdf	Parts list “Stückliste – Zulassung, 3/2-Wege Ventil WWC / 3/2-way Valve WWC, Typ 6527”, Number 485435 of 11.06.2013
[D30]	Typ_6534_SK04.PDF	Mechanical drawing “SIL-Type 6534” 9000468807 of 29.07.2019
[D31]	Typ_6534_Stückliste.pdf	Parts list “SIL-Type 6534” 9000468808 of 29.07.2019

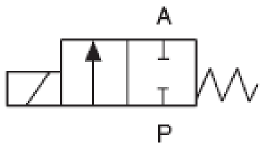
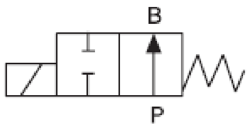
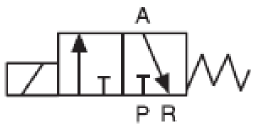
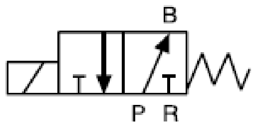
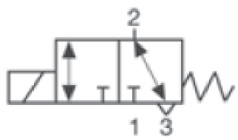
2.5.2 Documentation generated by *exida*

[R1]	FMEDA V8 0330 circuit function A and C V2R0.efm of 29.04.2013
[R2]	FMEDA V8 0330 circuit function B and D V2R0.efm of 29.04.2013
[R3]	FMEDA V8 5282 circuit function A V2R0.efm of 29.04.2013
[R4]	FMEDA V8 5282 circuit function B V2R0.efm of 29.04.2013
[R5]	FMEDA V8 6524 NC V2R0.efm of 19.04.2013
[R6]	FMEDA V8 6524 NC with 6144 V2R1.efm of 06.12.2013
[R7]	FMEDA V8 6524 NO V2R0.efm of 22.04.2013
[R8]	FMEDA V8 6524 NO with 6144 V2R1.efm of 06.12.2013
[R9]	FMEDA V8 6525 H V2R0.efm of 22.04.2013
[R10]	FMEDA V8 6525 H with 6144 V2R0.efm of 06.12.2013
[R11]	FMEDA_V8_6144 NC V0R1.efm of 08.08.2013
[R12]	FMEDA_V8_6526 NC V0R1.efm of 27.06.2013
[R13]	FMEDA_V8_6527 V0R1.efm of 01.07.2013
[R14]	FMEDA V8 6534 NC V1R0.efm of 10.12.2019
[R15]	2H Nachweis.zip of 21.01.2020

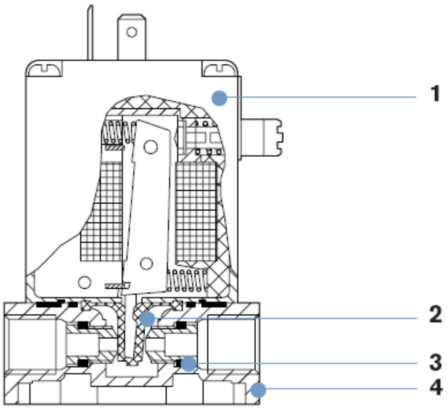
3 Description of the analyzed modules

The direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-*** are considered to be Type A components with a hardware fault tolerance of 0.

3.1 2/2 or 3/2-way direct-acting solenoid valves 330-*-*** and 331-*-***

Circuit function	Symbol
A: 2/2-way valve, normally closed	
B: 2/2-way valve, normally open	
C: 3/2-way valve, normally closed	
D: 3/2-way valve, normally open	
T: 3/2-way valve, universal function, any flow direction	

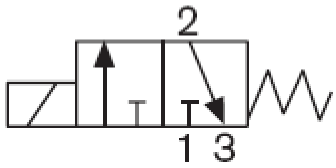
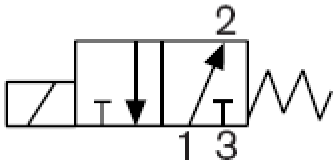
The types 330-*-*** and 331-*-*** are direct-acting 2/2 or 3/2-way pivoted armature solenoid valves. They are available in many circuit functions for opening, closing, dosing, mixing and distribution.



1	Coil	Epoxy
2	Isolating diaphragm	see ordering chart
3	O-Ring	see ordering chart
4	Valve body	1.4401 Stainless steel resp. brass

Figure 1: Assembly drawing

3.2 3/2-way direct-acting solenoid valve 6144-*-***

Circuit function	Symbol
C: 3/2-way valve, direct acting, de-energized port 2 exhausted	
D: 3/2-way valve, direct acting, de-energized port 2 pressurized	

The Type 6144 is a direct-action 3/2-way solenoid valve designed for neutral gases and liquids. Through the movement between the 2 end positions, the switching element (flipper) seals one of the two opposing valve seats and connects the other to the working port. This movement is caused by the solenoids magnetic field pushing a permanent magnet that is fixed to the flipper element. Furthermore, integrated medium separation enables use above and beyond pneumatic applications. Depending on the case of operation, various flange connections are available that are suitable for both individual and block mounting.

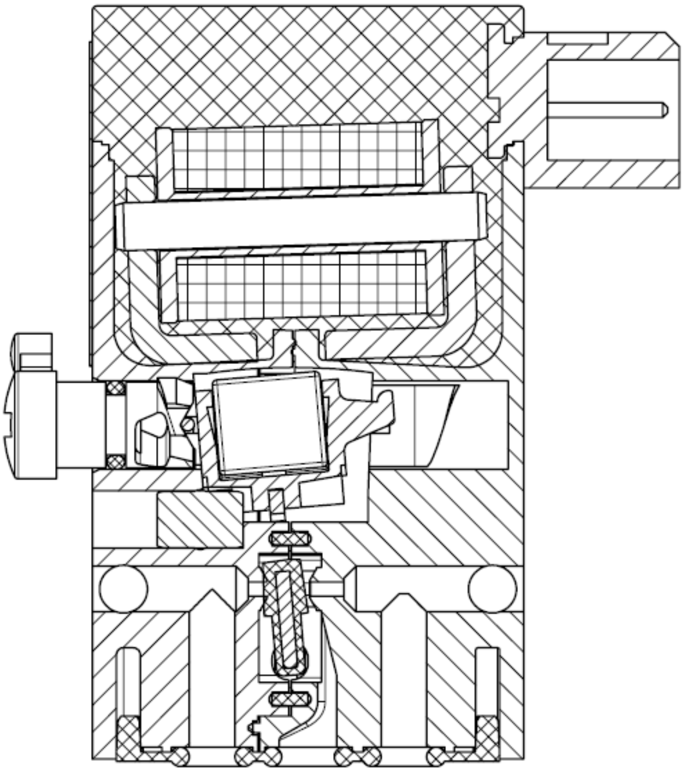
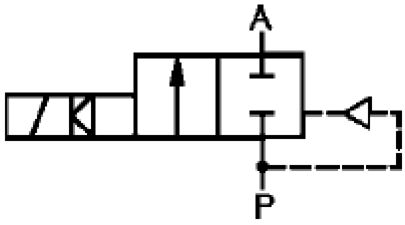
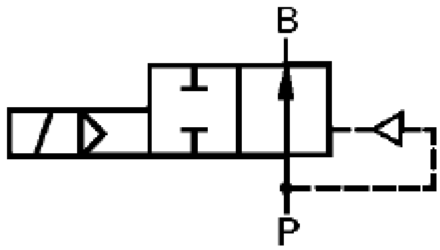


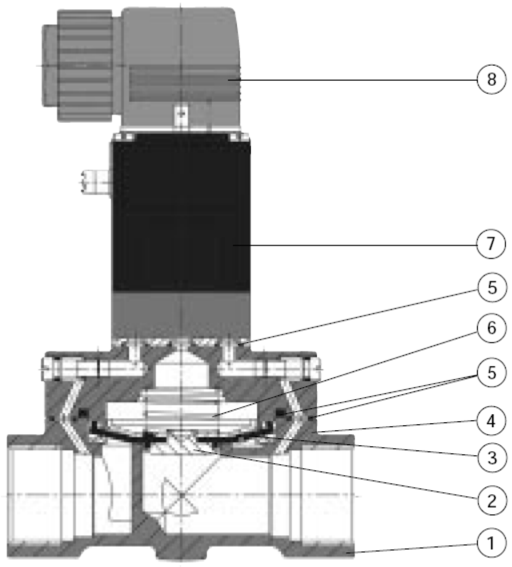
Figure 2: Assembly drawing

3.3 2/2-way pilot-operated solenoid valve 5282-*-***

Circuit function	Symbol
A: 2/2-way, normally closed with 3-way pilot control	
B: 2/2-way, normally open with 3-way pilot control	

This valve is for slightly contaminated, dirty and aggressive fluids with high reliability. It is an internally piloted solenoid valve. The pilot valve is switched via a pivoted armature system which isolates the actuator from the fluid.

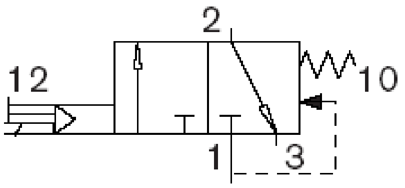
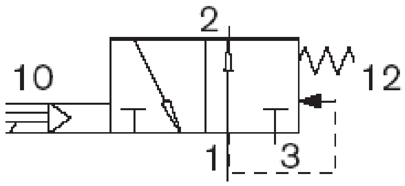
Opening and closing times can be adjusted by integrated restrictor screws, which delay the pressure rise and drop above the diaphragm.



1	Valve body:	Brass, 1.4581 stainless steel
2	Diaphragm support:	Brass, 1.4581 stainless steel
3	Diaphragm:	NBR, EPDM, FPM
4	Cover:	Brass, 1.4581 stainless steel
5	O-rings:	NBR, EPDM, FPM
6	Spring:	1.4310 stainless steel
7	Coil:	Epoxy
8	Cable plug:	Polyamide

Figure 3: Assembly drawing

3.4 3/2-way pilot-operated solenoid valve 6524-*-***

<table>
<tr><th>Circuit function</th><th>Symbol</th></tr>
<tr><td>C: 3/2-way, normally closed</td><td>
</td></tr>
<tr><td>D: 3/2-way, normally open</td><td>
</td></tr>
</table>

The Type 6524-*-*** consist of a pilot rocker valve Type 6104 or a pilot flipper valve Type 6144 and a pneumatic seat valve. The rocker principle allows switching of high pressures together with low power consumption and fast response times. All valves are equipped with manual override as a standard.

The 2 x 3/2-way valve version is the combination of two pilot rocker solenoid valves type 6104 or two pilot flipper solenoid valves Type 6144 and a pneumatic seat valve.

The two valves of the 2 x 3/2-way rocker solenoid valve 6524-*-*** shall not be used in the same safety function, e.g. to increase the hardware fault tolerance to achieve a higher SIL, as they contain common components. The FMEDA applies to either valve used in a single safety function. The two valves may be used in separate safety functions if due regard is taken of the possibility of common failures.

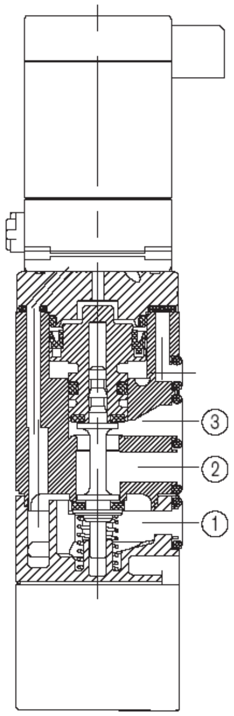
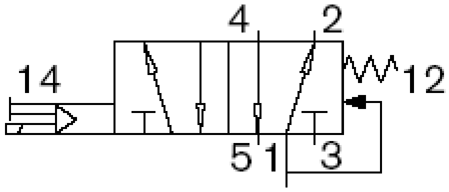


Figure 4: Assembly drawing

3.5 5/2-way pilot-operated solenoid valve 6525-*-***

Circuit function	Symbol
H: 5/2-way, port 2 pressurized, port 4 exhausted	

The Type 6525-*-*** consists of a pilot rocker valve Type 6104 or a pilot flipper valve Type 6144 and a pneumatic seat valve. The rocker / flipper principle allows switching of high pressures together with low power consumption and fast response times. All valves are equipped with manual override as a standard.

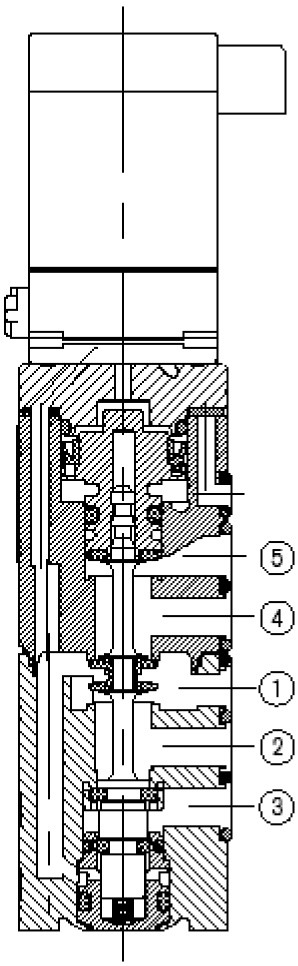
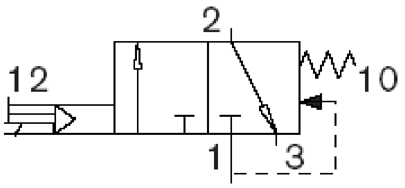


Figure 5: Assembly drawing

3.6 3/2-way pilot-operated solenoid valve 6526-*-***

Circuit function	Symbol
C: 3/2-way, normally closed	

The Type 6526-*-*** consists of a pneumatic valve body fitted with Type 6106 rocker pilot valve. The rocker principle allows switching of high pressures together with low power consumption and fast response times. The extendable Type 6526-*-*** can be used for block modules (tag connectors in front) or for entire valve islands. All valves are equipped with manual override as a standard.

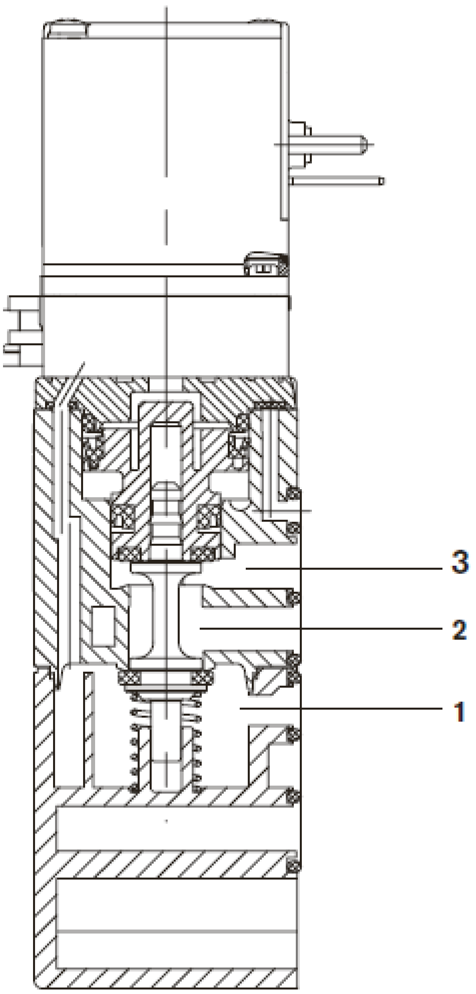
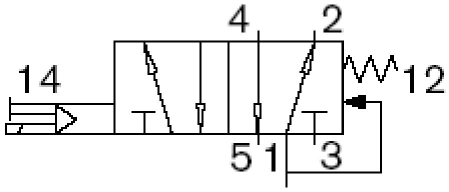


Figure 6: Assembly drawing

3.7 5/2-way pilot-operated solenoid valve 6527-*-***

Circuit function	Symbol
H: 5/2-way, port 2 pressurized, port 4 exhausted	

The Type 6527-*-*** consists of a pneumatic valve body fitted with Type 6106 rocker pilot valve. The rocker principle allows switching of high pressures together with low power consumption and fast response times. The extendable Type 6527-*-*** can be used for block modules (tag connectors in front) or for entire valve islands. All valves are equipped with manual override as a standard.

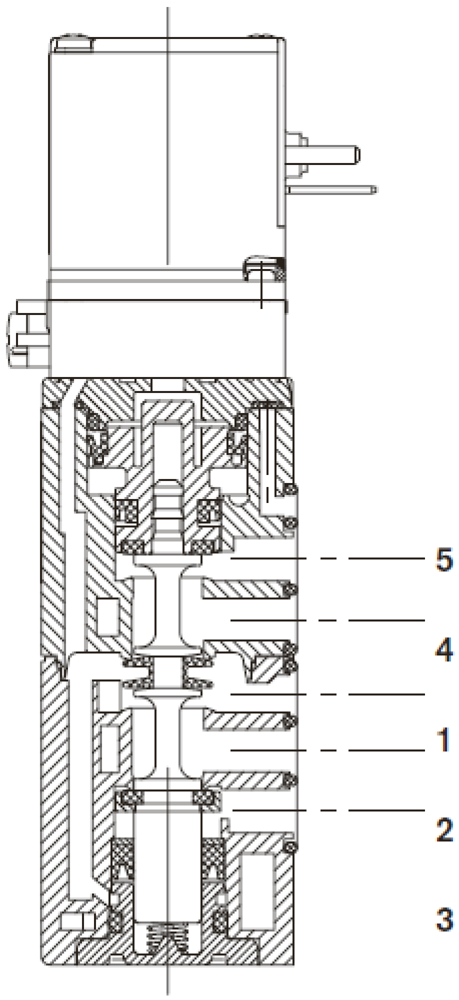
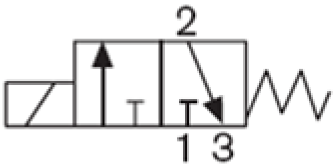


Figure 7: Assembly drawing

3.8 3/2-way pilot-operated solenoid valve 6534-C-***

Circuit function	Symbol
C: 3/2-way solenoid valve 6534 for air; C – closed in rest position – pressure port 1 (P/NC), working port 2 (A/OUT) after port 3 (R/NO) open	

The Type 6534-C-*** is a pneumatic slide valve. The mode of operation is based on a soft sealing slide principle. Pneumatic slide valves are equipped with manual operation. Manual operation works without the voltage being applied to the valve terminal and allows the valves to be switched manually. Manual operation is not a safety function and not considered in this report.

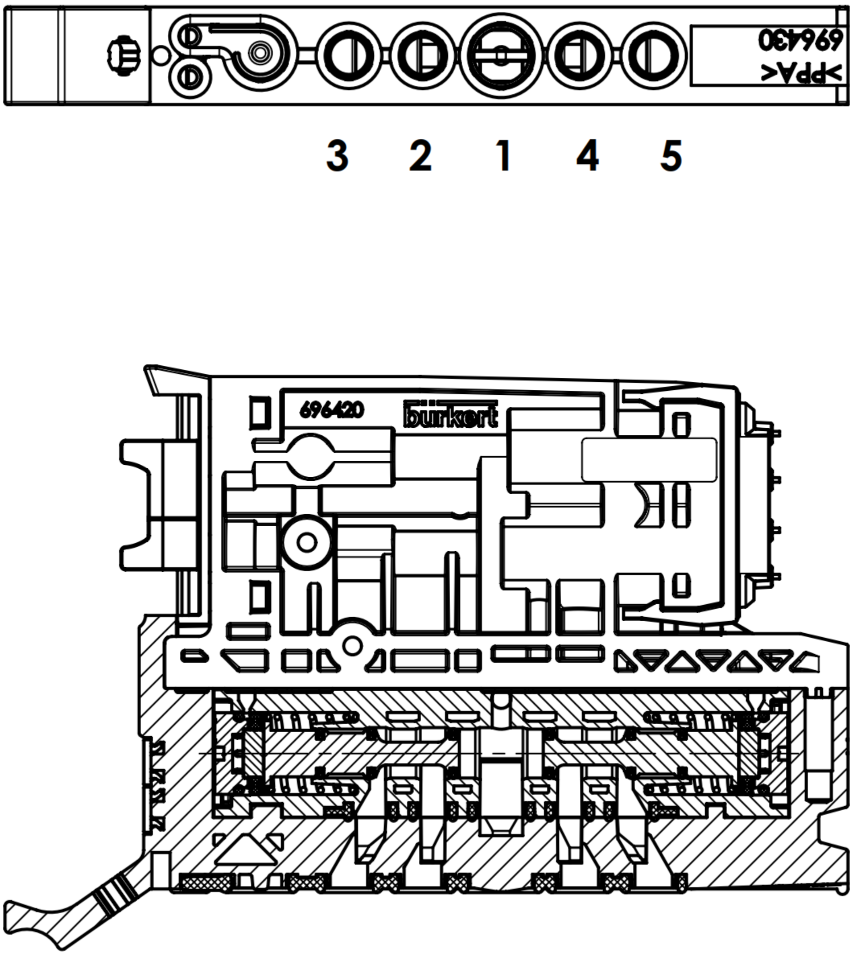


Figure 8: Assembly drawing

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 [R11].

4.1 Description of the failure categories

In order to judge the failure behavior of the direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-***, the following definitions for the failure of the products were considered.

General

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.

330-*-*, 331-*-***, 6144-*-*** (circuit function A and C)**

Fail-Safe State	The fail-safe state is defined as the output being closed without electrically operated.

330-*-*, 331-*-*** and 6144-*-*** (circuit function B and D)**

Fail-Safe State	The fail-safe state is defined as the output being open without electrically operated.

5282-A-* (circuit function A)**

Fail-Safe State	The fail-safe state is defined as the output being closed without electrically operated.

5282-B-* (circuit function B)**

Fail-Safe State	The fail-safe state is defined as the output being open without electrically operated.

6524-C-* and 6526-C-*** (circuit function C)**

Fail-Safe State	The fail-safe state is defined as the output being closed without electrically operated.

6524-D-* (circuit function D)**

Fail-Safe State	The fail-safe state is defined as the output being open without electrically operated.

6525-H-* and 6527-H-*** (circuit function H)**

Fail-Safe State	The fail-safe state is defined as port 2 being pressurized (1 -> 2), port 4 being exhausted (4 -> 5) and port 3 being closed without electrically operated (circuit function H).

6534-C-* (circuit function C)**

Fail-Safe State	The fail-safe state is defined as the output being closed without electrically operated.

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, 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 Handbooks [N3] which was derived using over 200 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 *exida* Profile 3 (General Field Equipment), see Appendix 3: *exida* Environmental Profiles. The *exida* profile chosen was judged to be the best fit for the product and application information submitted by Bürkert Werke GmbH & Co. KG. 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, physical abuse, or problems due to intermittent instrument air or hydraulic fluid quality.

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. *exida* Environmental Profiles listing expected stress levels can be found in Appendix 3: *exida* Environmental Profiles. 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.

4.2.3 Assumptions

The following assumptions have been made during the Failure Modes, Effects, and Diagnostic Analysis of the direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-***.

- 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.
- All devices are operated in the low demand mode of operation.
- External power supply failure rates are not included.
- Practical fault insertion tests can demonstrate the correctness of the failure effects assumed during the FMEDAs.
- Clean medium is applied to the valve.
- The valves are installed per the manufacturer's instructions.
- Only the described versions and circuit functions are used for safety applications.
- 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.
- The type 6144 has a minimum distance of 5 mm from other ferromagnetic materials in order to avoid malfunctioning during operating conditions.

5 Results of the assessment

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

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

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

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 61508-2.

The failure rate data used for this analysis meets the *exida* criteria for Route 2_H, see Section 6.2. Therefore, the direct-acting solenoid valves 2/2 or 3/2-way 330-*-***, 331-*-*** and 6144-*-*** and the pilot-operated solenoid valves 2/2-way 5282-*-*** with pilot control type 331-*-***, 3/2-way 6524-*-*** with pilot control type 6144-*-*** and 5/2-way 6525-*-*** with pilot control type 6144-*-*** and 3/2-way 6526-*-*** and 5/2-way 6527-*-*** with pilot control type 6106 and 3/2-way 6534-C-*** can be classified as 2_H devices when the listed failure rates are used. **When 2_H data is used for all of the devices in an element, then the element meets the hardware architectural constraints up to SIL 2 at HFT=0 for low demand mode applications or SIL 2 / SIL3 at HFT=1 for high and low demand mode applications.** If Route 2_H is not applicable for the entire element, the architectural constraints will need to be evaluated per Route 1_H.

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 Air supply failures

Failure of the air supply shall be included in the average Probability of Failure on Demand (PFD_{AVG}) of the Safety Instrumented Function. If an accumulator system is used to protect against air supply failure, the accumulator subsystem needs to be reviewed and the dangerous failure rates of the accumulator subsystem shall be added to the actuator failure rates.

5.3 330-*-*** and 331-*-***

The FMEDA carried out on the 2/2 or 3/2-way direct-acting solenoid valves 330-*-*** and 331-*-*** leads under the assumptions described in section 4.2.3 and 5 to the following failure rates:

Table 2: Summary for 330-*-* and 331-*-*** - IEC 61508:2010 failure rates**

Failure category	Failure rate [FIT]
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**50**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**77**
No effect	104
No part	51
Total failure rate of the safety function (λ_{Total})	**127**
MTBF	**405 years**

ABD 1000095704 DE Version: D Status: RL (released | freigegeben) printed: 21.06.2024

5.4 6144-*-***

The FMEDA carried out on the 2/2 or 3/2-way direct-acting solenoid valve 6144-*-*** leads under the assumptions described in section 4.2.3 and 5 to the following failure rates:

Table 3: Summary for 6144-*-* - IEC 61508:2010 failure rates**

Failure category	Failure rate [FIT]
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**51**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**26**

No effect	72
No part	23

Total failure rate of the safety function (λ_{Total})	**77**

MTBF	**668 years**

5.5 5282-A-*** (circuit function A)

The FMEDA carried out on the 2/2-way pilot-operated solenoid valves 5282-A-*** leads under the assumptions described in section 4.2.3 and 5 to the following failure rates:

Table 4: Summary for 5282-A-* - IEC 61508:2010 failure rates**

Failure category	Failure rate [FIT]
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**50**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**120**

No effect	173
No part	146

Total failure rate of the safety function (λ_{Total})	**170**

MTBF	**234 years**

5.6 5282-B-*** (circuit function B)

The FMEDA carried out on the 2/2-way pilot-operated solenoid valves 5282-B-*** leads under the assumptions described in section 4.2.3 and 5 to the following failure rates:

Table 5: Summary for 5282-B-* - IEC 61508:2010 failure rates**

Failure category	Failure rate [FIT]
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**50**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**120**
No effect	173
No part	146
Total failure rate of the safety function (λ_{Total})	**170**
MTBF	**234 years**

5.7 6524-*-*** with pilot control type 6144-*-***

The FMEDA carried out on the 3/2-way and 2 x 3/2-way rocker solenoid valves 6524-*-*** with pilot control type 6144-*-*** leads under the assumptions described in section 4.2.3 and 5 to the following failure rates:

Table 6: Summary for 6524-*-* with pilot control type 6144-*-*** - IEC 61508:2010 failure rates**

Failure category	Failure rate [FIT]
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**51**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**192**

No effect	406
No part	66

Total failure rate of the safety function (λ_{Total})	**243**

MTBF	**160 years**

5.8 6525-H-*** (circuit function H) with pilot control type 6144-*-***

The FMEDA carried out on the 5/2-way rocker solenoid valve 6525-H-*** with pilot control type 6144-*-*** in circuit function H leads under the assumptions described in section 4.2.3 and 5 to the following failure rates:

Table 7: Summary for 6525-H-* with pilot control type 6144-*-*** - IEC 61508:2010 failure rates**

Failure category	Failure rate [FIT]
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**51**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**260**

No effect	542
No part	70

Total failure rate of the safety function (λ_{Total})	**311**

MTBF	**124 years**

5.9 6526-C-*** (circuit function C) with pilot control type 6106

The FMEDA carried out on the 3/2-way rocker solenoid valve 6526-C-*** with pilot control type 6106 in circuit function C leads under the assumptions described in section 4.2.3 and 5 to the following failure rates:

Table 8: Summary for 6526-C-* with pilot control type 6106-*-*** - IEC 61508:2010 failure rates**

Failure category	Failure rate [FIT]
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**75**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**80**

No effect	397
No part	33

Total failure rate of the safety function (λ_{Total})	**155**

MTBF	**195 years**

5.10 6527-H-*** (circuit function H) with pilot control type 6106

The FMEDA carried out on the 5/2-way rocker solenoid valve 6527-H-*** with pilot control type 6106 in circuit function H leads under the assumptions described in section 4.2.3 and 5 to the following failure rates:

Table 9: Summary for 6527-H-* with pilot control type 6106-*-*** - IEC 61508:2010 failure rates**

Failure category	Failure rate [FIT]
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**75**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**287**

No effect	287
No part	27

Total failure rate of the safety function (λ_{Total})	**362**

MTBF	**169 years**

5.11 6534-C-*** (circuit function C)

The FMEDA carried out on the 3/2-way pilot-operated solenoid valve 6534-C-*** in circuit function C leads under the assumptions described in section 4.2.3 and 5 to the following failure rates:

Table 10: Summary for 6534-C-* - IEC 61508:2010 failure rates**

Failure category	Failure rate [FIT]
Fail Safe Detected (λ_{SD})	**0**
Fail Safe Undetected (λ_{SU})	**112**
Fail Dangerous Detected (λ_{DD})	**0**
Fail Dangerous Undetected (λ_{DU})	**170**

No effect	903
No part	0

Total failure rate of the safety function (λ_{Total})	**282**

MTBF	**96 years**

6 Using the FMEDA results

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 section describes how to apply the results of the FMEDA.

6.1 Example PFD_{AVG} calculation

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 a single (1oo1) 5/2-way pilot-operated solenoid valve 6527-H-*** (circuit function H) with pilot control type 6106 with *exida's* exSILentia tool. The failure rate data used in this calculation are displayed in section 5 (worst-case results). A mission time of 10 years has been assumed, a Mean Time To Restoration of 24 hours and a maintenance capability of 100%. Table 11 lists the results of the 5/2-way pilot-operated solenoid valve 6527-H-*** (circuit function H) with pilot control type 6106 (worst-case results as an example) for different proof test intervals considering a poof test coverage of 90% (see Appendix 1).

Table 11: PFD_{AVG} values

T[Proof] = 1 year	T[Proof] = 2 years	T[Proof] = 5 years
PFD_{AVG} = 2,38E-03	PFD_{AVG} = 3,51E-03	PFD_{AVG} = 6,88E-03

For SIL1 the overall PFD_{AVG} shall be better than 1.00E-01. As the 5/2-way pilot-operated solenoid valves 6527-H-*** (circuit function H) with pilot control type 6106 are 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 1.00E-02. The calculated PFD_{AVG} values are within the allowed range for SIL 1 according to table 2 of IEC 61508-1 and do fulfill the assumption to not claim more than 10% of the allowed range, i.e. to be better than or equal to 1.00E-02.

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

The resulting PFD_{AVG} graph generated from the exSILentia tool for a proof test of 1 year is displayed in Figure 9.

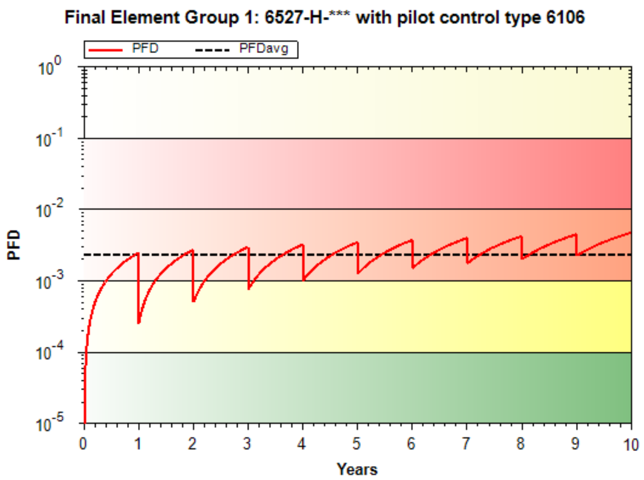


Figure 9: PFD_{AVG} value with proof test interval of 1 year

6.2 *exida* Route 2_H Criteria

IEC 61508:2010 2nd edition describes the Route 2_H alternative to Route 1_H architectural constraints. The standard states:

"based on data collected in accordance with published standards (e.g., IEC 60300-3-2: or ISO 14224); and, be evaluated according to

- the amount of field feedback; and
- the exercise of **expert judgment**; and when needed
- the undertake of specific tests,

in order to estimate the average and the uncertainty level (e.g., the 90% confidence interval or the probability distribution) of each reliability parameter (e.g., failure rate) used in the calculations."

exida has interpreted this to mean not just a simple 90% confidence level in the uncertainty analysis, but a high confidence level in the entire data collection process. As IEC 61508:2010 2nd edition does not give detailed criteria for Route 2_H, *exida* has established the following:

1. field unit operational hours of 100,000,000 per each component; and
2. a device and all of its components have been installed in the field for one year or more; and
3. operational hours are counted only when the data collection process has been audited for correctness and completeness; and
4. failure definitions, especially "random" versus "systematic" are checked by *exida*; and
5. every component used in an FMEDA meets the above criteria.

This set of requirements is chosen to assure high integrity failure data suitable for safety integrity verification.

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.
MTTR	Mean Time To Restoration
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
Type A element	"Non-complex" element (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:	V4R1:	Editorial changes after external review; February 12, 2020
	V4R0:	Assessment changed from route 1_H to route 2_H; devices added and removed; January 23, 2020
	V3R0:	Updated according to IEC 61508:2010 edition, solenoid valves 6526 and 6527 added; December 6, 2013
	V2R1:	Editorial changes; October 20, 2008
	V2R0:	Direct-acting solenoid valve 6144-*-*** added; October 16, 2008
	V1, R0:	Review comments incorporated; September 29, 2006
	V0, R2:	Types 331-*-***, 6524-*-*** and 6525-*-*** added; August 2, 2006
	V0, R1:	Initial version; July 25, 2006
Authors:	Stephan Aschenbrenner	
Review:	V4R0:	Kim Biewer (Bürkert); February 6, 2020
		Jan Hettenbach (*exida*); January 23, 2020
	V2R0:	Silvia Wiedmann (Bürkert); October 20, 2006
	V0, R2:	Otto Walch (Bürkert); August 2, 2006
	V0, R2:	Rachel Amkreutz (*exida*); September 26, 2006
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8.3 Release Signatures

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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.

The proof test consists of a full stroke of the solenoid valve, as described in Table 12.

Table 12: Steps for proof test

Step	Action
1.	Bypass the safety function and take appropriate action to avoid a false trip.
2.	Send a signal to the solenoid valve to perform a full stroke and verify that this is achieved.
3.	Inspect the solenoid valve for any visible damage or contamination.
4.	Remove the bypass and otherwise restore normal operation.

This test will detect more than 90% of possible dangerous failures.

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 4.2.3) this only applies provided that the useful lifetime[5] 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, which shows the typical behavior for electronic components. 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.

Based on general field failure data, a useful life period of approximately 10 to 15 years or longer is expected for the valves.

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

If the solenoid valves used with clean air in an ambient with air circulation (draft air) and an ambient temperature average of 40ºC, then a lifetime of 10 years is expected.

It is the responsibility of the end user to maintain and operate the valves per manufacturer's instructions. Furthermore, regular inspection should show that all components are clean and free from damage.

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

[5] 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 no self-heating	General Field Mounted self-heating	Subsea	Offshore	N/A
Description (Mechanical)	Cabinet mounted/ Climate Controlled	General Field Mounted	General Field Mounted	Subsea	Offshore	Process Wetted
IEC 60654-1 Profile	B2	C3 also applicable for D1	C3 also applicable for D1	N/A	C3 also applicable for D1	N/A
Average Ambient Temperature	30°C	25°C	25°C	5°C	25°C	25°C
Average Internal Temperature	60°C	30°C	45°C	5°C	45°C	Process Fluid Temp.
Daily Temperature Excursion (pk-pk)	5°C	25°C	25°C	0°C	25°C	N/A
Seasonal Temperature Excursion (winter average vs. summer average)	5°C	40°C	40°C	2°C	40°C	N/A
Exposed to Elements/Weather Conditions	No	Yes	Yes	Yes	Yes	Yes
Humidity[6]	0-95% Non-Condensing	0-100% Condensing	0-100% Condensing	0-100% Condensing	0-100% Condensing	N/A
Shock[7]	10 g	15 g	15 g	15 g	15 g	N/A
Vibration[8]	2 g	3 g	3 g	3 g	3 g	N/A
Chemical Corrosion[9]	G2	G3	G3	G3	G3	Compatible Material
Surge[10]						
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[11]						
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)[12]	6kV	6kV	6kV	6kV	6kV	N/A

[6] Humidity rating per IEC 60068-2-3
[7] Shock rating per IEC 60068-2-27
[8] Vibration rating per IEC 60068-2-6
[9] Chemical Corrosion rating per ISA 71.04
[10] Surge rating per IEC 61000-4-5
[11] EMI Susceptibility rating per IEC 6100-4-3
[12] ESD (Air) rating per IEC 61000-4-2