Your Guide for Machine Safety

Pneumatic solutions conform ISO 13849

Reduce safety risks for your employees and improve the productivity of your machinery.

EMERSON

Optimized machine safety with Emerson

To prevent accidents at work, companies have to protect themselves against safety risks. But meeting required safety standards can present a real challenge.

Emerson's ASCO and AVENTICS products and solutions for fluid control & pneumatics make an important contribution to improving machine safety. We have extensive, long-term experience in designing pneumatic controls. Pneumatics can realize technical safety measures and is critical in industries using machines with horizontal or vertical motions especially.

Protecting people, machines, animals, the environment, and property is the top priority, best achieved using safety-related solutions for fluid control and pneumatics.

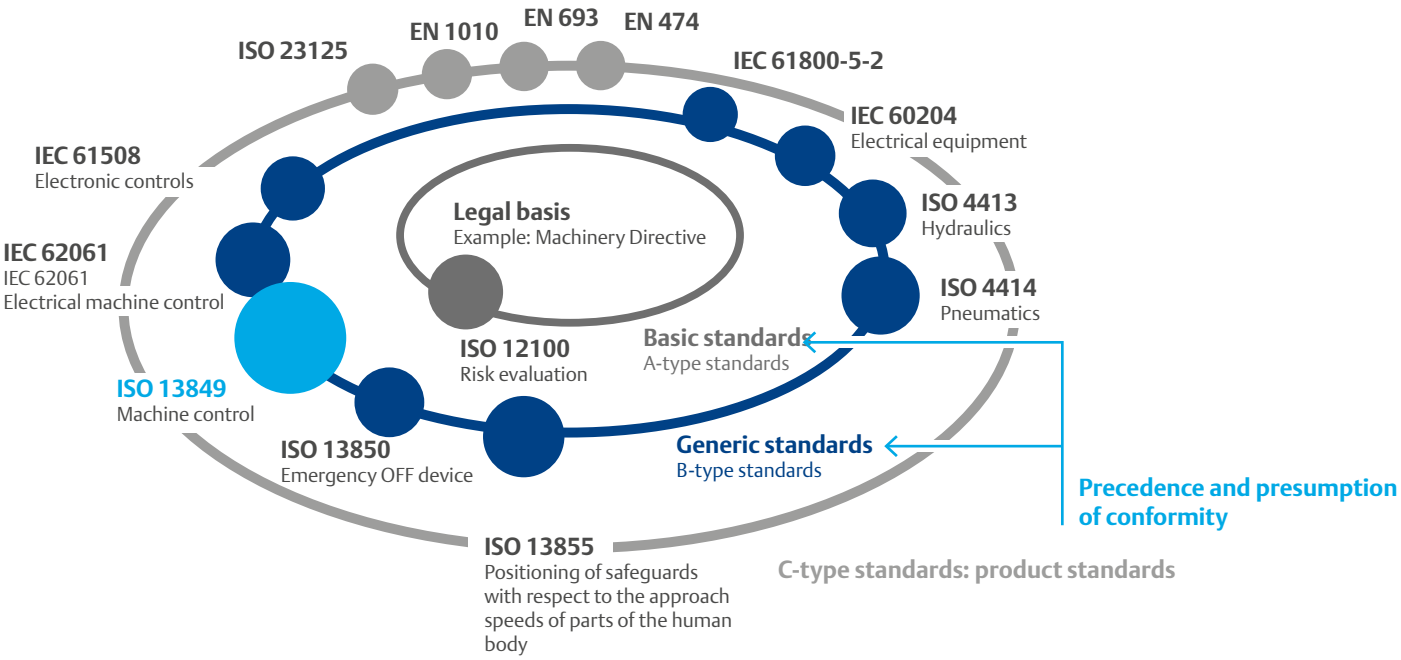
Directives and standards

The European Machinery Directive 2006/42/EC (EU Machinery Regulation EU 2023/1230 starting from January 20th, 2027) on machine engineering aims to ensure a common safety level for new machines distributed and operated in the member states. It governs safety and occupational health requirements for design and engineering. The CE mark indicates that the manufacturer has achieved an adequate level of protection.

Harmonized standards from the European standards organizations provide additional assistance to machine operators and manufacturers, since they enhance compliance with the Machinery Directive (EU Machinery Regulation EU 2023/1230 starting from January 20th, 2027) through what is called “presumption of conformity”. This principle, however, only applies to the legal requirements that the harmonized standards actually cover. Almost all laws worldwide mandate a risk assessment to analyze and assess risks and finally implement mitigating measures.

Machine-specific standards

- A-type standards (basic safety standards) define basic concepts, terminology and design principles that can be applied to machines
- B-type standards (generic safety standards) deal with a single safety aspect or protective device for a series of machines
- B1-type standards cover specific safety aspects(e.g. safety clearances, surface temperature, noise)
- B2-type standards cover protective devices (e.g. two-hand circuits, guards)
- C-type standards (machine safety standards) contain detailed safety requirements for a certain machine



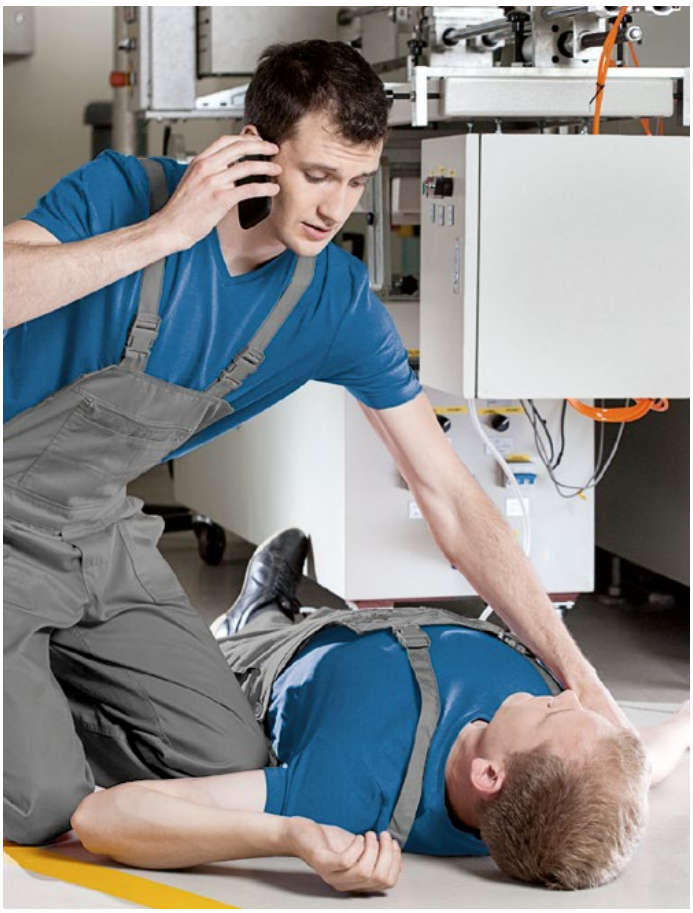
Hazards and risks: Estimate – assess – eliminate

The risk assessment process provides the basis for machine safety (see figure on pages 6, 7). The machine manufacturer starts with a risk analysis, minimizes identified risks, and finally determines whether an adequate level of safety is present.
If the answer is negative, risk reduction measures must be implemented and quantified in terms of effectiveness.
Let's take a look at some basic terms defined in ISO 12100, which provides a general description of the risk assessment process:

Hazards:
Potential sources of harm

Hazardous situation:
Situation in which a person is exposed to at least one hazard. The resulting harm can be immediate or occur over time.

Risk:
Results from a hazard and is assessed by combining the likelihood of the occurrence of harm and the severity of consequence.



▲ Dangerous electrical voltage

▲ Hot surface

▲ Keep hands clear

▲ Entanglement rotating parts

▲ Risk of entrapment

▲ Cutting hazard

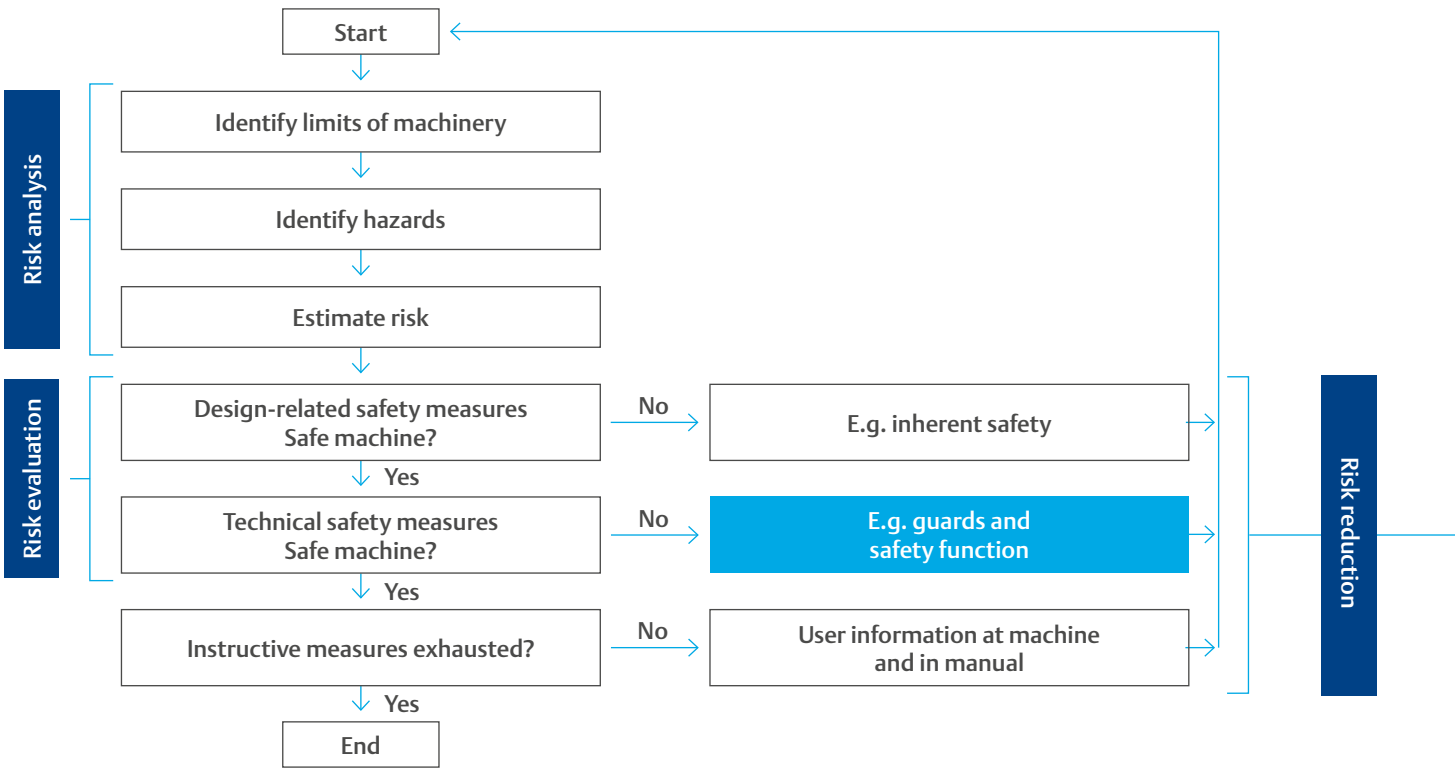
▲ Head injury hazard

Towards safe machinery: Risk assessment

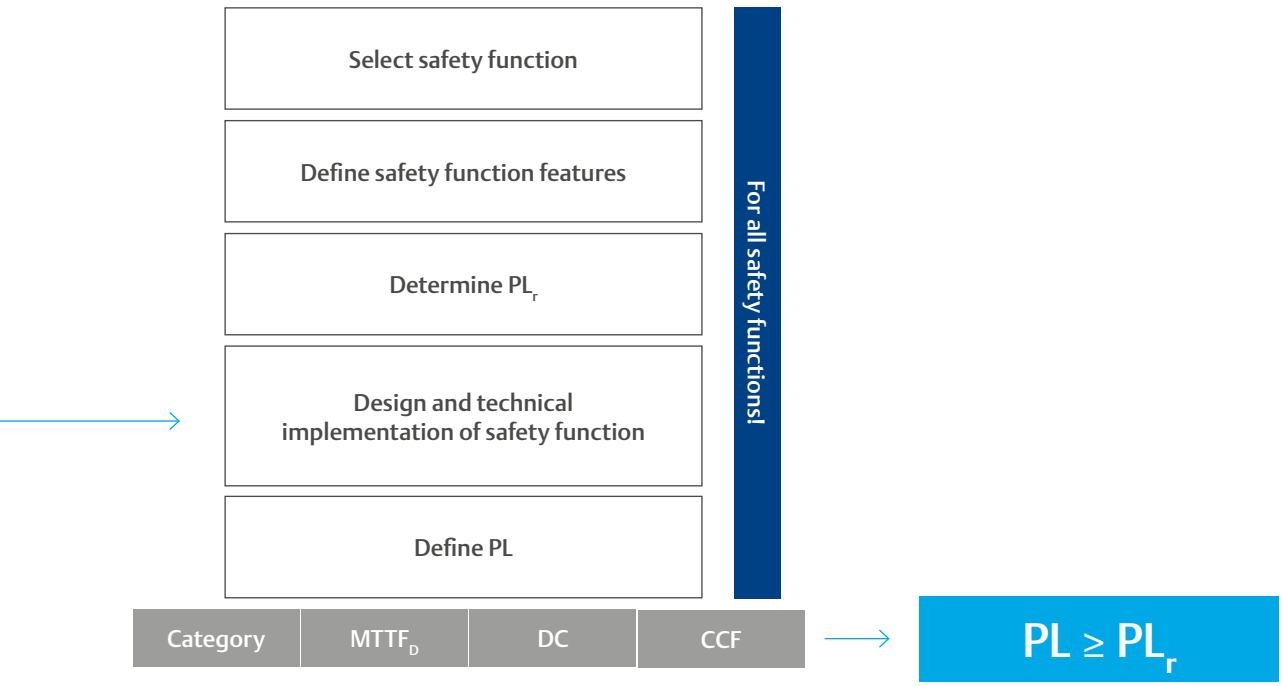
Globally, and almost without exception, statutory guidelines for the design and operation of machines mandate a risk assessment to identify potential hazards, minimize risks, and comply with applicable health and safety requirements. The process helps determine the type and quality of preventive measures or safeguards.

Risk assessment

- Must be performed by machine manufacturer; results remain with the manufacturer
- Must account for both proper use and any foreseeable misuse of the machine
- Provides an important body of proof for the manufacturer for liability claims in accident cases



The information in this guideline focuses on risk evaluation. Within the risk assessment process, we focus on implementing technical measures to mitigate risk, evaluating the safety function, and determining the performance level. The graphic below shows the risk assessment process – this guide uses examples to take you through the individual steps until the performance level is achieved. The performance level (PL) must meet or exceed the required performance level (PL_r). This depends on factors such as the control architecture (category), the mean time to dangerous failure ($MTTF_D$), diagnostic coverage (DC), and common cause failure (CCF).



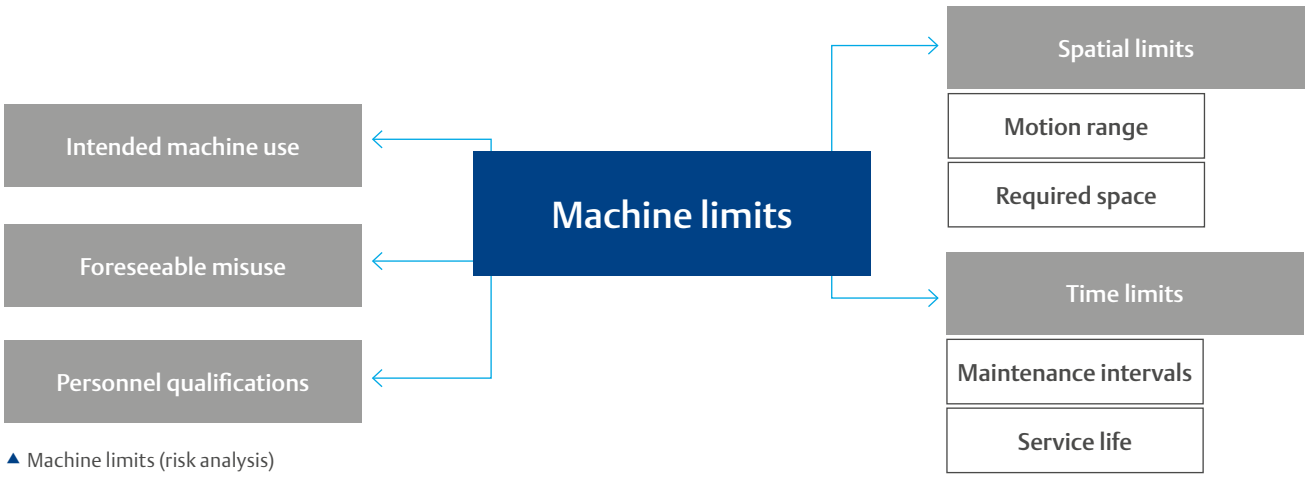
Risk assessment: Risk analysis

Risk assessment comprises three areas: risk analysis, risk evaluation, and risk reduction.

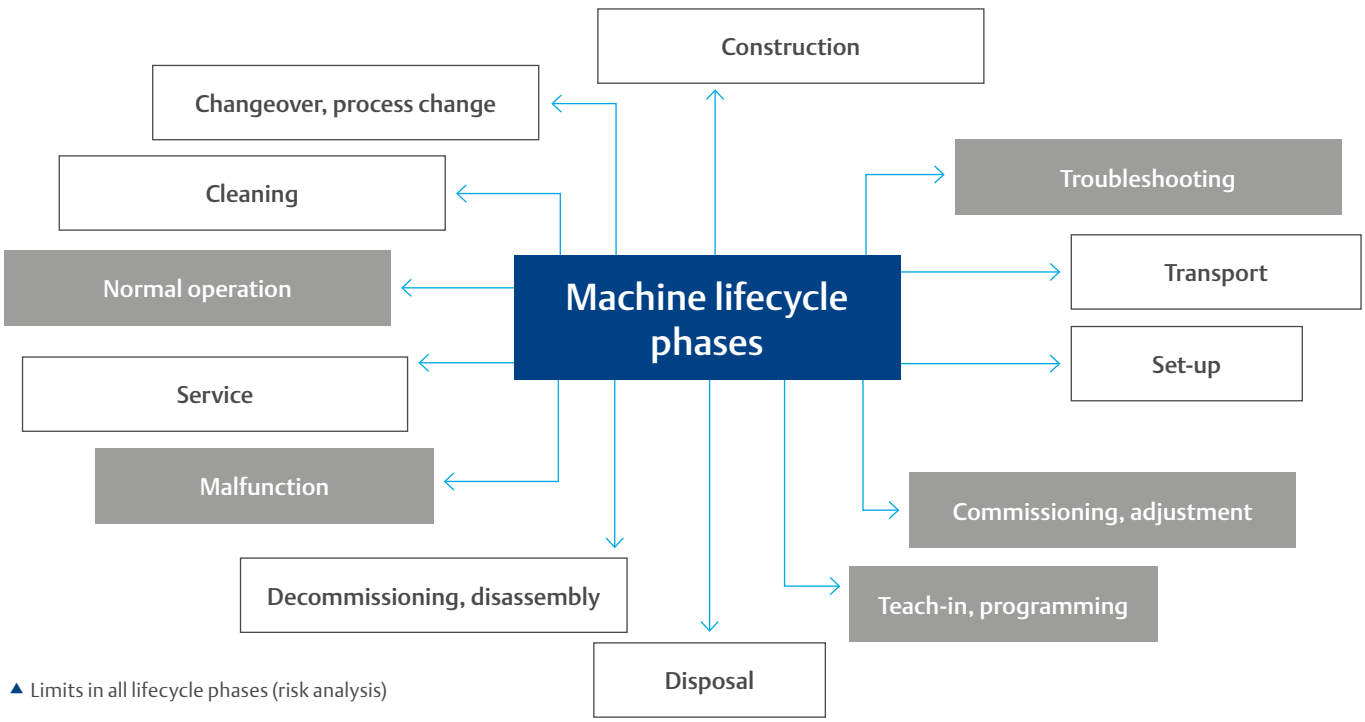
The actual risk analysis starts with defining the limits of a machine when considering all phases of its lifecycle. Once all hazards have been identified, the risk of each hazard must be estimated.

Risk analysis: machine limits
In addition to spatial limits and the overall duration of use, operating limits are a prime focus. Proper use is analyzed, including all operating modes and different intervention options, as well as reasonably foreseeable misuse.

For risk analysis, it is necessary to consider the entire machine lifecycle, from transport to installation, commissioning and cleaning, disassembly and, finally, disposal.



▲ Machine limits (risk analysis)

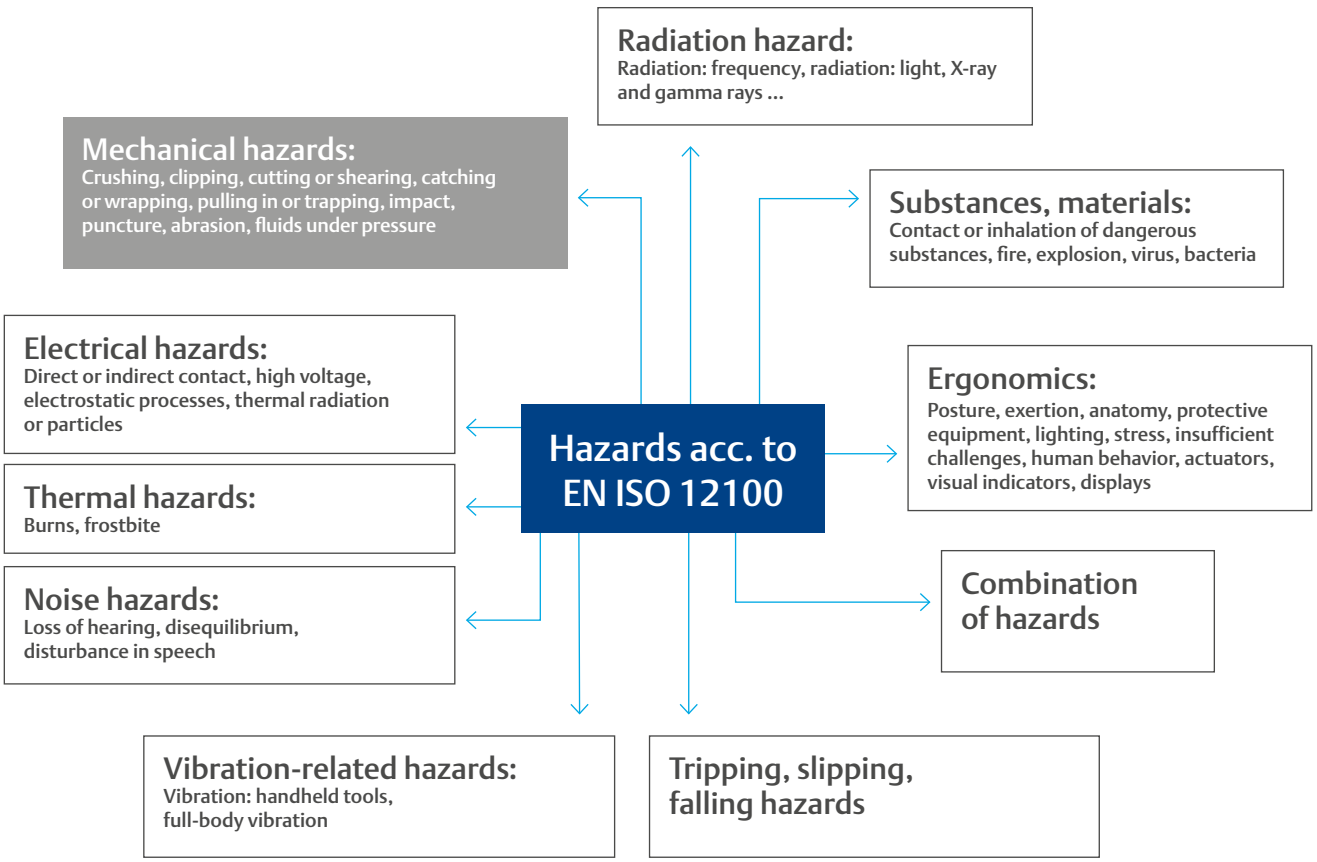


▲ Limits in all lifecycle phases (risk analysis)

Risk analysis: Identifying hazards

Warning: Contact between protected property and hazard! Standard EN ISO 12100-1 specifies all relevant potential hazards in production that may result in injury to people or animals, or damage to property.

Hazards are divided into different categories, as shown in the diagram below. Our focus is especially geared toward safe machine shut-down, safe valve exhaust, and safe pressure release in pneumatic systems and components – precisely because these mechanical hazards can result in personal injury.



Risk analysis: Risk estimation – Performance level

Risk reduction measures are derived based on the severity of possible injury, the frequency of the hazard, and the probability of its occurrence. Performance level is a technical target: it conveys the effort required to reduce risk at a machine. The target must be met as a minimum requirement.

Every safety function has a required safety level. This is described by the required performance level, PLr for short, which is defined based on the following criteria from ISO 13849-1:

S Severity of injury
S1 Minor (normally temporary injury)
S2 Serious (normally permanent injury, including death)

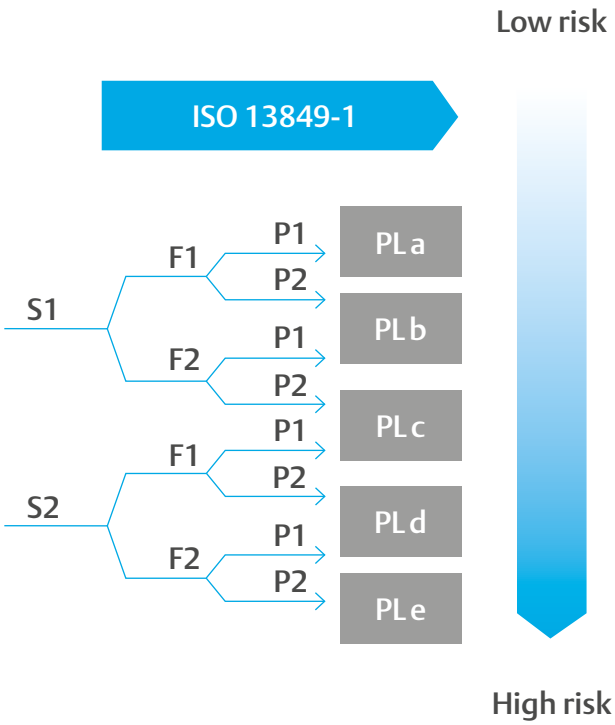
F Frequency and/or duration of exposure
F1 Rare to infrequent and/or brief
F2 Frequent to continuous and/or long

P Possibility of avoiding hazard
P1 Possible under certain conditions
P2 Scarcely possible

PL_r is distinguished based on letters from a (minimal action required) to e (extensive action required).

Risk estimation

- Manufacturers are free to apply their own process or that specified in a standard such as ISO 13849-1 or IEC 62061.



S Severity of injury
F Frequency and/or length of exposure
P Possibility of avoiding hazard or limiting harm

Risk assessment: Risk evaluation

During a risk analysis, should you conclude that risk reduction is required, you will need to adopt corresponding preventive measures to achieve an adequate safety level. The best solution is an inherently safe design. Instructional measures such as user information harbor the risk of non-compliance and are thus only permissible as supplement once all technical options to improve safety have been exhausted. Technical measures present an additional route.

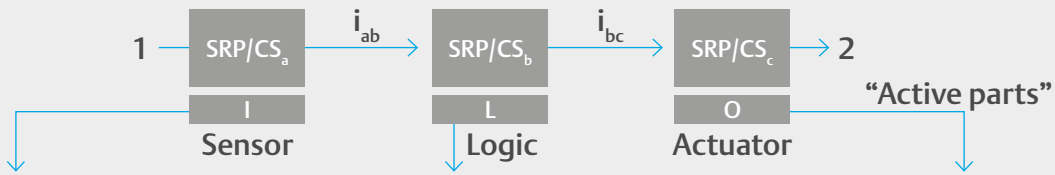
Preventive technical measures
If a machine's safety depends on a properly functioning control, this can be termed "functional safety". The "active" parts of the control are the main focus, i.e. components that detect a dangerous situation (signal recording, "I" = input), derive suitable reactions (evaluation, "L" = logic), and implement reliable measures (execution, "O" = output). The term "control" thus refers to the entire signal processing system.

Note:
"Safety-related parts of control systems" are not necessarily "safety components" as defined by the Machinery Directive. SRP/CS (Safety Related Parts of a Control System) can, however, be such safety components, e.g. two-hand controls or logic units with safety function.

Actuators (cylinders), energy supply (e.g. pressure supply or air preparation units) and connections are not directly factored into dangerous failure rates.

ISO 13849 is the generic standard for safety components in controls.

Focus on safety-related parts of control systems (SRP/CS acc. to ISO 13849-1)



Signal recording to detect potential hazard	Evaluation of hazard	Execute reaction
(Opto-)electronics E.g. emergency OFF, two-hand circuit, safety door, safety mat, light barrier, laser scanner, enabling device, mode selector, camera systems...	**Electronics** Safety relay, wiring, safety PLC, safe pneumatic logic ...	**Pneumatics** E.g. limited or safe speed, reduce pressure and force, release energy, safe direction of travel, stop or block movement (see circuit diagram examples from page 28)

I Input
L Logic
O Output

1 Start event, e.g. manual activation of button, opening a safeguard

2 Machine actuators

Implementing a safety function – your go-to guide!

Now we will look at the technical safety measures in greater detail. The question is to what extent the safety function can reduce risk. After a prior risk estimation and the definition of the required performance level (PL_r), the necessary degree of risk reduction is determined.

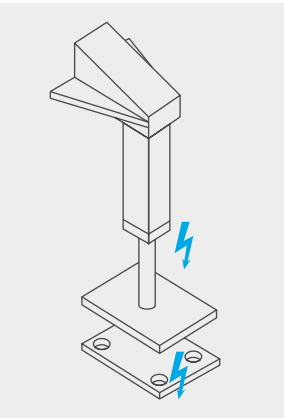
The following parameters determine whether the safety function actually mitigates risk to the required extent:

- Control architecture (category)
- Mean time to dangerous failure ($MTTF_D$)
- Diagnostic coverage (DC)
- Common cause failure (CCF)

As a general rule:
The performance level PL must at least correspond to the required PL_r.

Application example

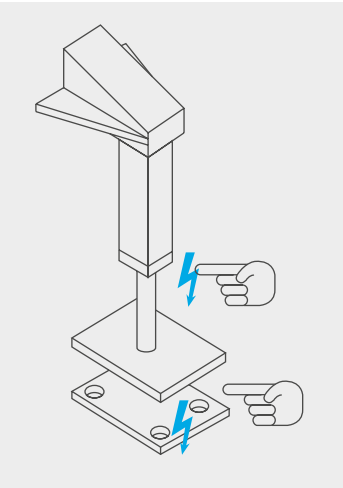
Safe stop function – halts dangerous movement and prevents unintended activation from the resting state



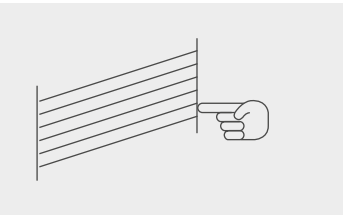
◀ Risk analysis for a forming component

Procedure:

1. Identify the hazardous situation (e.g. dangerous movements).

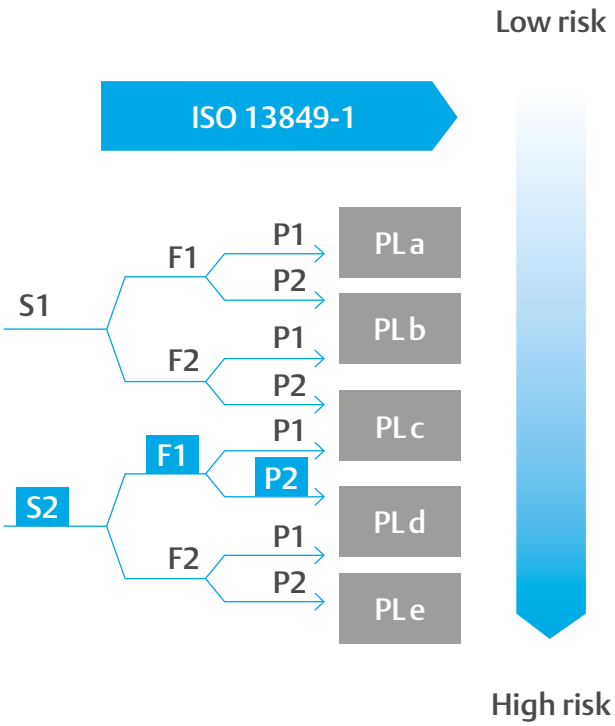


2. Determine the trigger event.



3. Define the safe state.
   Actuator stops after crossing light grille.
4. Specify the required reaction.
   Actuator is disabled.
5. Name the safety function.
   “Controlled stopping of the movement and application of the holding brake in the rest position” (see also IFA Report 2/2017).

Define PL_r: for machine part



Severity of injury

- S2: Serious injury (normally permanent, including death)

Frequency and/or duration of exposure

- F1: Rare to infrequent occurrence and/or brief exposure

Possibility of avoiding hazard

- P2 Scarcely possible

- PL_r = d

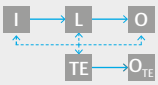
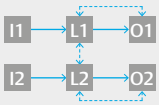
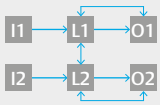
The example shows: functional failure can result in irreversible injury. The operator requires access to the machine less than once per shift. In the event of failure, he is fully exposed to the hazard.

Selecting a category

Emerson can provide assistance!

The safety control architecture determines its error tolerance. It is also the framework for all other quantifiable aspects that ultimately go into calculating the performance level of safety-related elements of the control system.

In industrial settings, the types of safety controls in machine engineering are usually limited. Most controls fit into one of the categories shown below:

Control category properties					
	Category B	Category1	Category 2	Category 3	Category 4
Structure					
Safety principles	Basic	Basic & well-tried	Basic & well-tried	Basic & well-tried	Basic & well-tried
Well-tried components	-	Yes	-	-	-
Component – $MTTF_D$ (service life)	Low–medium	High	Low–high	Low–high	High
Redundancy (2 channels)	No	No	No	Yes	Yes
Monitoring (DC)	None	None	Low–medium	Low–medium	High
Observation CCF	No	No	Yes	Yes	Yes
Failure resistance / failure cumulation	0 -	0 -	0 ϟ	1 ϟ	1 ✓
PL (possible)	a–b	b–c	a–d	a–e	e

▲ Connection between PL and categories: the **higher the risk** the safety function seeks to prevent, the **higher the category.**

I Input
L Logic
O Output
TE Test equipment
O_{TE} Test equipment output
ϟ Safety function failure
----- Monitoring
—— Connection

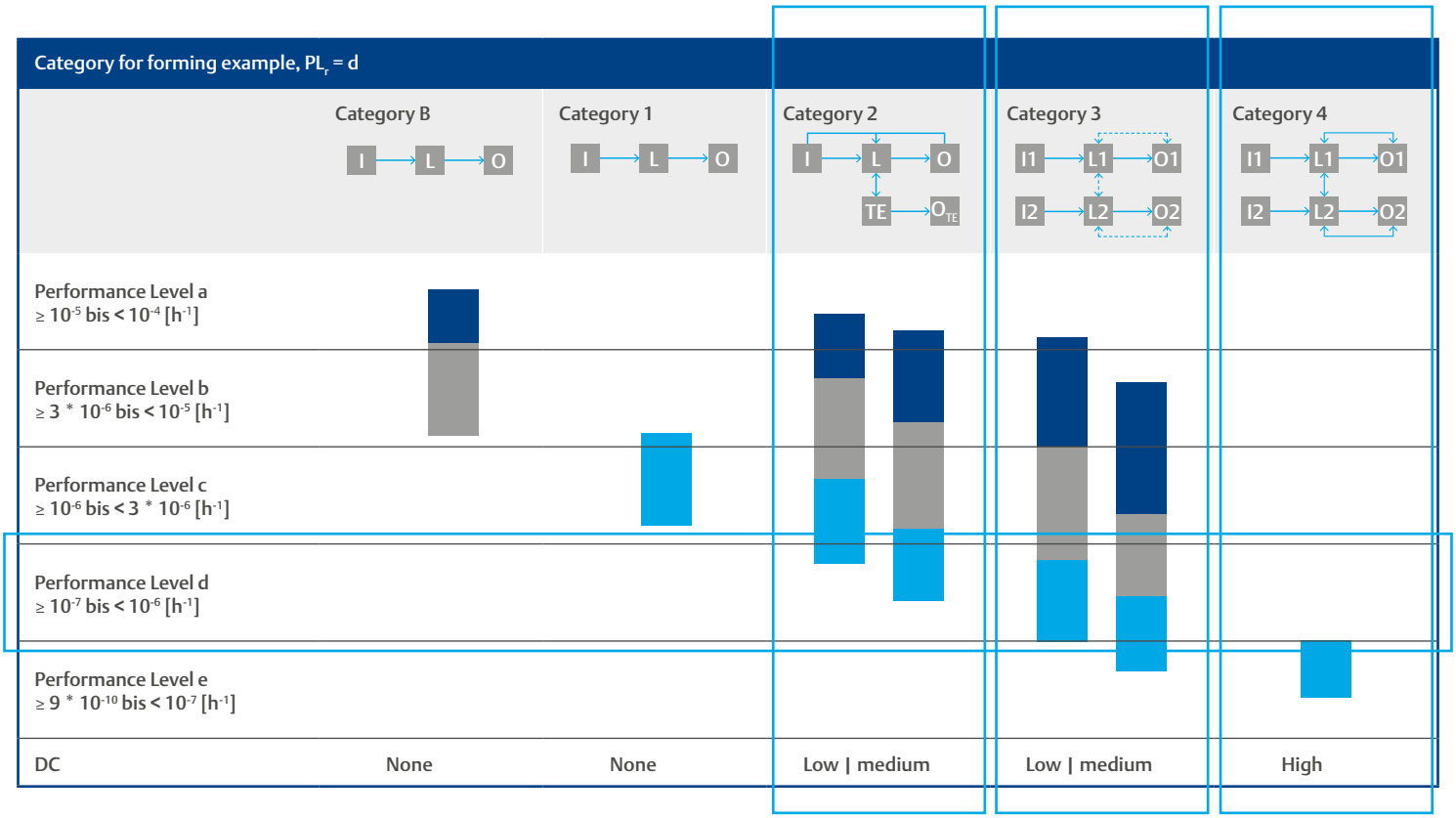
Assessment	$MTTF_D$
Low	3 years ≤ $MTTF_D$ < 10 years
Medium	10 years ≤ $MTTF_D$ < 30 years
High	30 years ≤ $MTTF_D$ < 100 years (resp. < 2.500 years in Cat. 4)

▲ Source: ISO 13849

Designation	DC range
None	DC < 60 %
Low	60 % ≤ DC < 90 %
Medium	90 % ≤ DC < 99 %
High	99 % ≤ DC

▲ Four DC classes in the simplified approach from ISO 13849-1

Possible categories for the example shown:

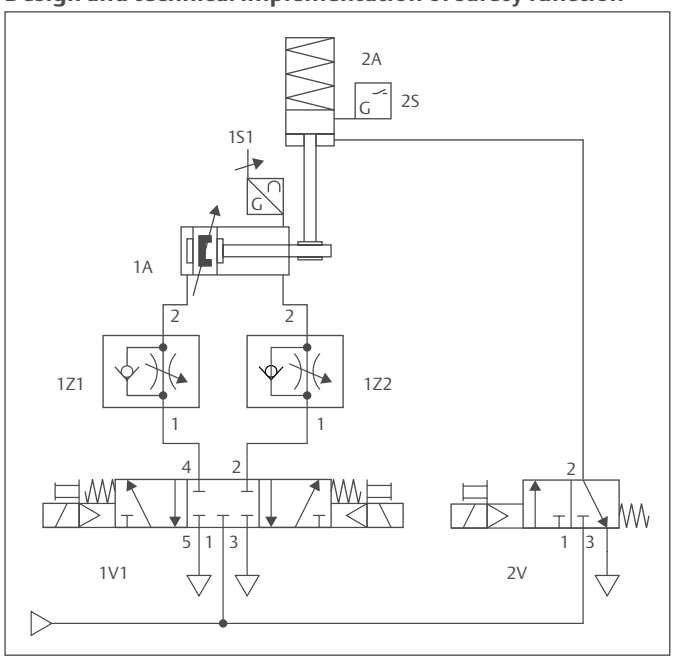


MTTF$_D$ low — n — ≥ 3 to < 10 years

MTTF$_D$ medium — m — ≥ 10 to < 30 years

MTTF$_D$ high — h — ≥ 30 to < 100 years (resp. < 2.500 years in Cat. 4)

Design and technical implementation of safety function



Redundant blocking of cylinder in vertical direction:

- With compressed air failure and in the starting position of valve 2V, the locking unit 2A can reliably stop the cylinder.
- In the locked position (center position) for valve 1V1, cylinder movement is impeded by air pressure in the chamber.
- The 2V valve can be tested with the 2S sensor. The function of the 1V1 valve and the 2A locking unit is monitored by the 1S1 distance measuring sensor.

Safety principles
Basic and well-tried safety principles (line 1 in the table on page 16 or poster) take precedence, i.e. critical errors or failures must be excluded to reduce the probability of failure.

Basic safety principles include:
- Use of suitable materials and production processes
- Correct dimensioning and forming of all components
- Highly resistant components (against various influences)
- Energy isolation (quiescent current principle)
- Ambient conditions/external protection against unexpected startup in fluid technology:
  - Pressure limitation
  - Measures to prevent contamination of pressure medium

Well-tried safety principles include:
- Overdimensioning/safety factor
- Automatic/form-fit actuation
- Limited electrical/mechanical parameters in fluid technology:
  - Secured position (excluding impulse valves)
  - Use of well-tried springs
  - Separation of safety functions from non-safety functions

Well-tried components:
In addition to the category B requirements, safety-related parts of control systems in category 1 must also be constructed as well-tried components.
Well-tried components
- Have seen successful large-scale use in the past in similar applications or
- Have been manufactured and tested by applying principles that demonstrate suitability and reliability for safety-related applications.

Annex B of ISO 13849-2 does not contain a list of well-tried pneumatic components.

Further parameters to determine performance levels

Emerson can provide assistance!

Before a final answer about the performance of a safety function can be given, $MTTF_D$, DC, and CCF must be defined.

Mean time to dangerous failure ($MTTF_D$)
$MTTF_D$ describes the mean duration in years until a dangerous system component failure.
It is a statistical value for electrical/electronic components, which is identified through trials or reliability prognoses based on failure probabilities for the components.

Assessment	$MTTF_D$
Low	3 years ≤ $MTTF_D$ < 10 years
Medium	10 years ≤ $MTTF_D$ < 30 years
High	30 years ≤ $MTTF_D$ < 100 years (resp. < 2.500 years in Cat. 4)

▲ Source: ISO 13849

Formula for determining $MTTF_D$ for a mechanical element in a channel:

$$MTTF_D = \frac{B_{10D}}{0{,}1 \bullet n_{op}}$$

$B_{10D} = B_{10} \times 2$ as recommended by IFA

Mean n_{op} (actuations/year) for the mechanical element:

$$n_{op} = \frac{d_{op} \bullet h_{op} \bullet 3600s/h}{t_{cycle}}$$

d = day, h = hours, s = second

Calculating the total $MTTF_D$ for two different channels:

$$MTTF_D = \frac{2}{3}\left[MTTF_{DC1} + MTTF_{DC2} - \frac{1}{\frac{1}{MTTF_{DC1}} + \frac{1}{MTTF_{DC2}}} \right]$$

For our 2-channel example and taking into account the following operating data, for channel 1 this means:
220 d, 16 h/d, T = 10 s -> n_{op} = 1.267.200 cycles/year and a B_{10} value for the CD07 5/3 directional valve of 24.8 million switching cycles results in an $MTTF_D$ value of 391.41 years;

For channel 2 with the following operating data:
220 d/a, 16 h/d, T = 3.600 s -> n_{op} = 3.520 cycles/year and a B_{10} value for the CD04 directional valve of 32 million switching cycles as well as a B_{10D} value of 2 million switching cycles for the LU6 locking unit results in an $MTTF_D$ value of 181.818 years for the valve and 5.682 years for the locking unit.

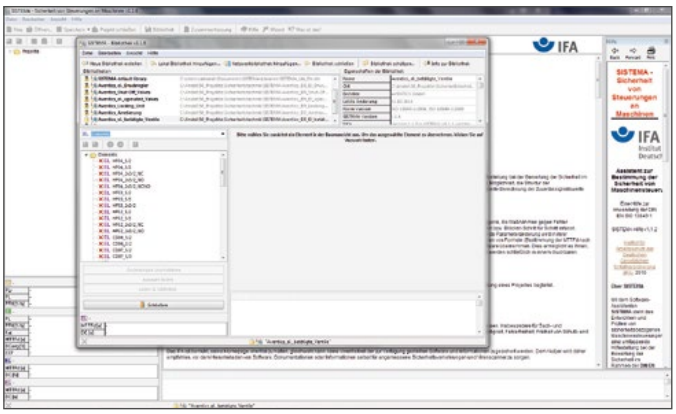
Both channels therefore have a high $MTTF_D$ value.

Identification of the $MTTF_D$ using the value B_{10} – example for lifecycle duration

The value B_{10} specifies the number of cycles until 10% of components tested in endurance trials (acc. to DIN EN ISO 19973) have exceeded the defined limits. B_{10} describes a statistical failure probability. It is an indicator for the reliability of a wearing part, evaluating the number of switching cycles for pneumatic valves, for example.

In terms of machine safety, ISO 13849-1 only considers dangerous machine failures. These are described by B_{10D}. Assuming that half of all failures are dangerous, we would apply the formula $B_{10D} = 2 \times B_{10}$. B_{10D} is required for all safety-related components in a control that are susceptible to wear and for all components directly involved in a safety function. The value for B_{10D} is used to calculate $MTTF_D$ (see page 19).

Emerson provides extensive proof of reliability for its products in order to calculate performance levels. This data can also be found in our SISTEMA libraries.



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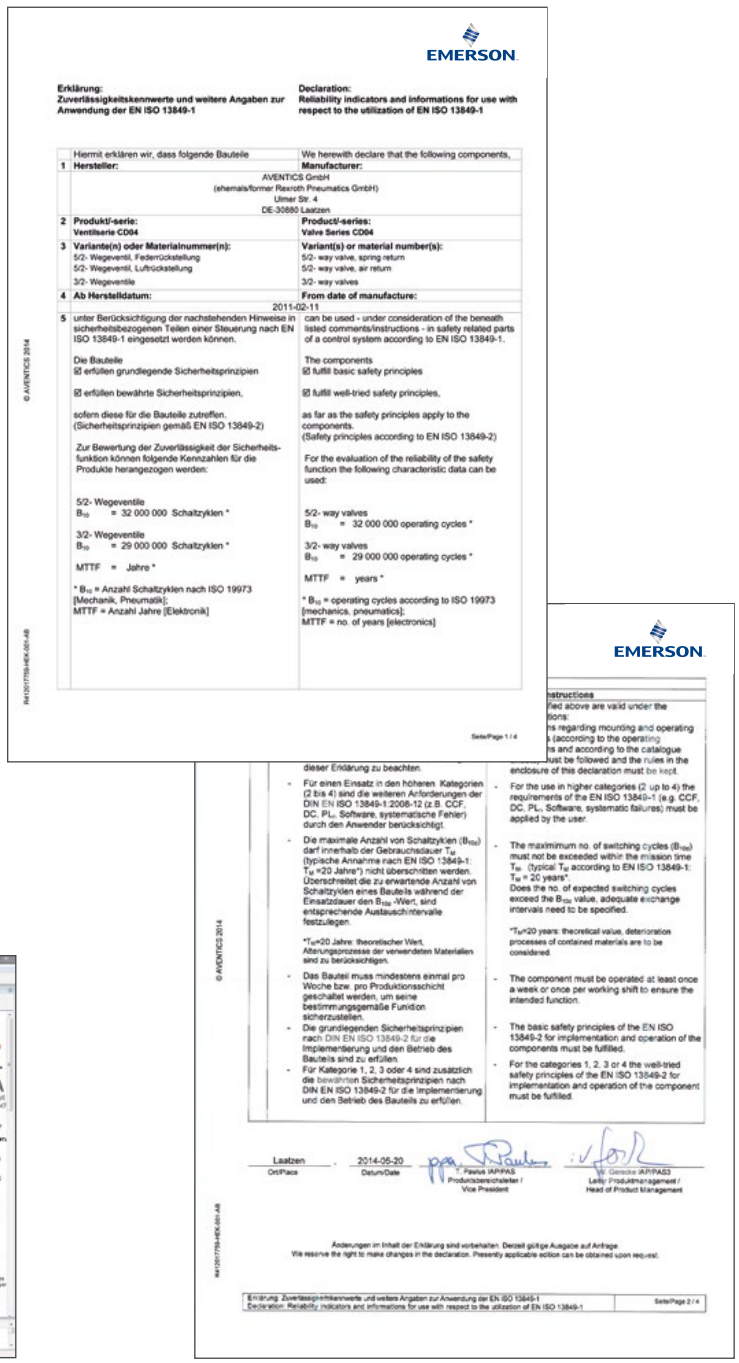

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Erklärung:
Zuverlässigkeitskennwerte und weitere Angaben zur Anwendung der EN ISO 13849-1

Declaration:
Reliability indicators and informations for use with respect to the utilization of EN ISO 13849-1

	Hiermit erklären wir, dass folgende Bauteile	We herewith declare that the following components,
1	**Hersteller:**	**Manufacturer:**
	AVENTICS GmbH (ehemals/former Rexroth Pneumatics GmbH) Ulmer Str. 4 DE-30880 Laatzen	
2	**Produkt/-serie:** **Ventilserie CD04**	**Product/-series:** **Valve Series CD04**
3	**Variante(n) oder Materialnummer(n):** 5/2- Wegeventil, Federrückstellung 5/2- Wegeventil, Luftrückstellung 3/2- Wegeventile	**Variant(s) or material number(s):** 5/2- way valve, spring return 5/2- way valve, air return 3/2- way valves
4	**Ab Herstelldatum:**	**From date of manufacture:**
	2011-02-11	
5	unter Berücksichtigung der nachstehenden Hinweise in sicherheitsbezogenen Teilen einer Steuerung nach EN ISO 13849-1 eingesetzt werden können. Die Bauteile ☑ erfüllen grundlegende Sicherheitsprinzipien ☑ erfüllen bewährte Sicherheitsprinzipien, sofern diese für die Bauteile zutreffen. (Sicherheitsprinzipien gemäß EN ISO 13849-2) Zur Bewertung der Zuverlässigkeit der Sicherheitsfunktion können folgende Kennzahlen für die Produkte herangezogen werden: 5/2- Wegeventile B_{10} = 32 000 000 Schaltzyklen * 3/2- Wegeventile B_{10} = 29 000 000 Schaltzyklen * MTTF = Jahre * * B_{10} = Anzahl Schaltzyklen nach ISO 19973 [Mechanik, Pneumatik]; MTTF = Anzahl Jahre [Elektronik]	can be used - under consideration of the beneath listed comments/instructions - in safety related parts of a control system according to EN ISO 13849-1. The components ☑ fulfill basic safety principles ☑ fulfill well-tried safety principles, as far as the safety principles apply to the components. (Safety principles according to EN ISO 13849-2) For the evaluation of the reliability of the safety function the following characteristic data can be used: 5/2- way valves B_{10} = 32 000 000 operating cycles * 3/2- way valves B_{10} = 29 000 000 operating cycles * MTTF = years * * B_{10} = operating cycles according to ISO 19973 [mechanics, pneumatics]; MTTF = no. of years [electronics]

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dieser Erklärung zu beachten.

- Für einen Einsatz in den höheren Kategorien (2 bis 4) sind die weiteren Anforderungen der DIN EN ISO 13849-1:2008-12 (z.B. CCF, DC, PL, Software, systematische Fehler) durch den Anwender berücksichtigt.
- Die maximale Anzahl von Schaltzyklen (B_{10D}) darf innerhalb der Gebrauchsdauer T_M (typische Annahme nach EN ISO 13849-1: T_M =20 Jahre*) nicht überschritten werden. Überschreitet die zu erwartende Anzahl von Schaltzyklen eines Bauteils während der Einsatzdauer den B_{10D}-Wert, sind entsprechende Austauschintervalle festzulegen.

*T_M=20 Jahre: theoretischer Wert, Alterungsprozesse der verwendeten Materialien sind zu berücksichtigen.

- Das Bauteil muss mindestens einmal pro Woche bzw. pro Produktionsschicht geschaltet werden, um seine bestimmungsgemäße Funktion sicherzustellen.
- Die grundlegenden Sicherheitsprinzipien nach DIN EN ISO 13849-2 für die Implementierung und den Betrieb des Bauteils sind zu erfüllen.
- Für Kategorie 1, 2, 3 oder 4 sind zusätzlich die bewährten Sicherheitsprinzipien nach DIN EN ISO 13849-2 für die Implementierung und den Betrieb des Bauteils zu erfüllen.

enclosure of this declaration must be kept.

- For the use in higher categories (2 up to 4) the requirements of the EN ISO 13849-1 (e.g. CCF, DC, PL, Software, systematic failures) must be applied by the user.
- The maximum no. of switching cycles (B_{10D}) must not be exceeded within the mission time T_M (typical T_M according to EN ISO 13849-1: T_M = 20 years*. Does the no. of expected switching cycles exceed the B_{10D} value, adequate exchange intervals need to be specified.

*T_M=20 years: theoretical value, deterioration processes of contained materials are to be considered.

- The component must be operated at least once a week or once per working shift to ensure the intended function.
- The basic safety principles of the EN ISO 13849-2 for implementation and operation of the components must be fulfilled.
- For the categories 1, 2, 3 or 4 the well-tried safety principles of the EN ISO 13849-2 for implementation and operation of the component must be fulfilled.

Laatzen — 2014-05-20
Ort/Place — Datum/Date

T. Pawlus IAP/PAS
Produktbereichsleiter / Vice President

W. Gerecke IAP/PAS3
Leitg. Produktmanagement / Head of Product Management

Änderungen im Inhalt der Erklärung sind vorbehalten. Derzeit gültige Ausgabe auf Anfrage.
We reserve the right to make changes in the declaration. Presently applicable edition can be obtained upon request.

Erklärung: Zuverlässigkeitskennwerte und weitere Angaben zur Anwendung der EN ISO 13849-1
Declaration: Reliability indicators and informations for use with respect to the utilization of EN ISO 13849-1

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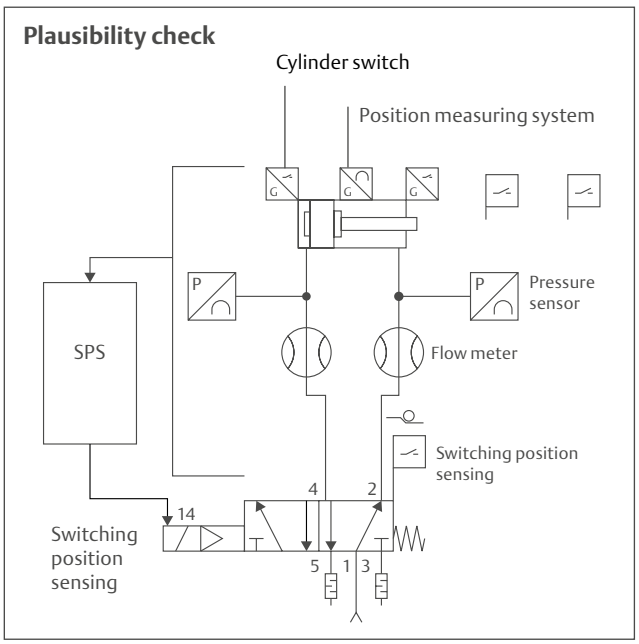
▲ Proof from Emerson

DC – diagnostic coverage

Emerson can provide assistance!

When a dangerous failure does occur, despite all preventive measures, test equipment (diagnostics or monitoring system) can detect it at an early stage to return the machine to a safe state.
Depending on the required performance level, there are requirements for the DC or diagnostic coverage value, i.e. the coverage which must be provided by testing equipment.
The performance level therefore includes the monitoring quality of the control system.
This is expressed as “diagnostic coverage”. This value describes the achievable error detection rate.
The DC value is defined as “... an expression for the effectiveness of diagnosis that can be described as the the ratio of the rate of detected dangerous failures compared to the rate of all dangerous failures.”
Whether a specific failure qualifies as “dangerous” or “safe”, mainly depends on the definition of the safety function, or in other words on the intended application. The possibility of excluding a failure also depends on the application.
This decision is therefore not usually made by the component manufacturer.
Annex E of ISO 13849-1 provides a simplified approach to estimating DC values. The engineer analyzes and evaluates the switching and the sequence of machine processes to estimate the percentage of errors that can be discovered by these measures.

Diagnostic options for pneumatics



DC values are classified as follows:

Designation	DC range
None	DC < 60 %
Low	60 % ≤ DC < 90 %
Medium	90 % ≤ DC < 99 %
High	99 % ≤ DC

▲ Four DC classes in the simplified approach from ISO 13849-1

Typical errors for safety-related parts of control systems are listed in ISO 13849-2. A typical error that could occur with directional valves is failure to lock, for example. Diagnosis occurs indirectly via the sensor at the cylinder; here, a diagnostic coverage level of 90% can be assumed. For the locking unit, a typical error might be “Failing to clamp although control input is vented”. Diagnosis is performed in this case directly by the sensor at the locking unit. For this component, diagnostic coverage of 99% can be assumed. Average diagnostic coverage can be calculated using the formula:

$$DC_{avg} = \frac{\frac{DC_1}{MTTF_{D1}} + \frac{DC_2}{MTTF_{D2}} + \ldots + \frac{DC_N}{MTTF_{DN}}}{\frac{1}{MTTF_{D1}} + \frac{1}{MTTF_{D2}} + \ldots + \frac{1}{MTTF_{DN}}}$$

After accounting for all typical errors, the DC_{avg} in our example is 93%. This translates to a medium level of diagnostic coverage.

CCF – common cause failure

CCF in our example				
Countermeasure for CCF	**Fluid technology**	**Electronics**	**Points**	
Separation of signal paths	Separation of tubing	Air and creepage distance on activated circuits	15	✓
Diversity	E.g. different valves	E.g. different processors	20	✓
Protection against overvoltage, overpressure ...	Setup acc. to EN ISO 4413 to EN ISO 4414 (pressure relief valve)	Overvoltage protection (e.g. contactors, power pack)	15	✓
Use of well-tried components	User		5	✓
FMEA in development	FMEA during initial system conception		5	✓
Competence/training	Qualification measure		5	✓
Protection against contamination and EMC	Fluid quality	EMC test	25	✓
Other effects (e.g. temperature, shock)	Compliance with EN ISO 4413 and EN ISO 4414 and product spec	Observe ambient conditions as described in product spec	10	✓
Total CCF	Total points(65 ≤ CCF ≤ 100):			95

CCF is a rating of measures to counteract “common cause failure,” or errors stemming from a common source, for example due to a high ambient temperature or intense electromagnetic interference.

Measures to combat these types of failures are listed in Annex F of ISO 13849-1 with associated point scores. Only the entire number of points or none at all can be received for each of the measures listed. If a measure is partially met, zero points are assigned.

Component manufacturers cannot provide any information related to CCF, because most measures are determined by the design of the machine.

Further measures to assess robustness

- Safety-related properties of valves in safety systems, e.g. applying the principle of energy isolation (quiescent current principle, e.g. return spring). According to ISO 13849-1, in the event of a power outage, all system components, such as pneumatic valves, must independently assume and maintain
  a safe state under permissible operating conditions (vibration, temperature, etc.).
- Basic (cat. B) and well-tried safety principles (cat. 1, 2, 3, or 4), see Table, page 16

Validation – calculating PFH_D

PFH_D – probability of dangerous failure per hour – is a value for the average probability of a dangerous failure in one hour (1/h) and the associated performance level.

Required inputs

- Required inputs
- Selected architecture expressed as category
- Average diagnostic coverage DC_{avg}
- Mean time to dangerous failure $MTTF_D$ for a channel

Validation for our example

Input data

- Category: 3
- $MTTF_D$ for each channel: “high”
- DC_{avg}: “medium”

ISO 13849-1: read out average probability of a dangerous failure per hour (or calculate using SISTEMA)

- PL according to Table = e, PL_r = d

- **Result: PL ≥ PL_r**

What if the performance level is not achieved?

- Use components with a longer service life ($MTTF_D$, B_{10})
- Achieve a higher category (e.g. category 3 instead of category 1) by adding redundant components
- Invest greater resources in monitoring the control to boost the DC value
- Separate the safety function from a normal function to increase the service life ($MTTF_D$) of components with B_{10} values through a low number of cycles
- Implement safety functions using AVENTICS circuit examples

Appendix	Technology	List of basic safety principles	List of basic safety principles	List of proven components	Fault lists and fault exclusions
		Table(s)			
A	Mechanical	A.1	A.2	A.3	A.4, A5
B	Pneumatic	B.1	B.2	-	B.3 to B.18
C	Hydraulic	C.1	C.2	-	C.3 to C.12
D	Electric (contains electronics)	D.1	D.2	D.3	C.4 to C.21

▲ Further measures to assess robustness

Pneumatic solutions to improve safety

Comprehensive machine safety expertise all under one roof. Thanks to the safety concepts of Emerson, your employees are best protected at work. At production plants, safety must come first despite machinery growing in complexity. Benefit from our pneumatic valve technologies and innovative products for your machine safety now.

Whether traditional solutions with drain valves, or innovative safety systems in line with the latest standards: The following pages give you an overview of current and efficient products, as well as their technical properties, including examples of safety functions.

Wide range of products – future-proof concepts
With AVENTICS solutions, you benefit from proven expertise based on many years of experience in equipping machines and systems in line with standards. All products include complete documentation and reliability ratings. In addition, online tools, such as free access to IFA-rated circuit examples, help ensure safe designs.

Emerson also has comprehensive experience in the area of fluid control, offering a broad spectrum of ASCO products suitable for a wide range of industries and applications.

As product brands of Emerson, both providers stand for safe products in certified quality. Some examples include valve systems with practical high-end characteristics, such as digital displays, a compact design, and all relevant connection options.

Safety starts in the design and selection of components
Take advantage of the wide range of safety concepts from Emerson with AVENTICS and ASCO products. Each and every one of our pneumatics and fluid control solutions promotes machine safety and reduces risks for your employees.

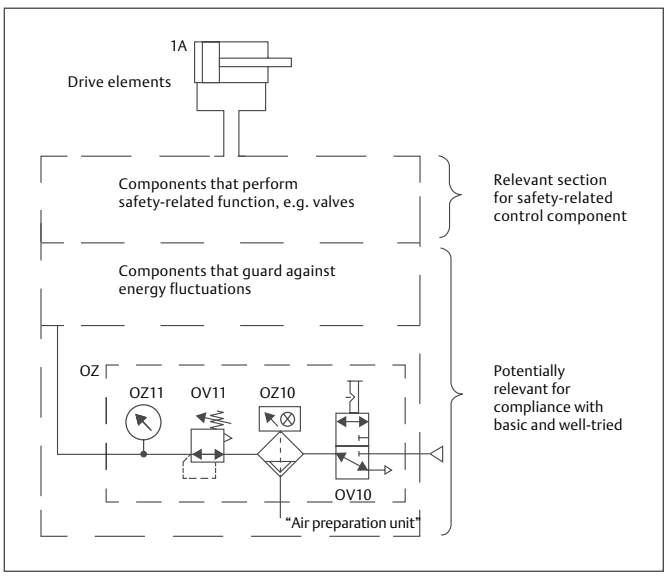
Emerson expertise

To support machine and systems manufacturers, we not only provide this guide, but also offer individualized consulting based on our long-term experience. On the next pages, you will find circuit examples and parts from our product portfolio. For additional examples, please visit www.emerson.com/en-us/expertise/automation/improving-safety-security/machine-safety

Scope of ISO 13849 for pneumatic controls

For fluid power systems, the valve area is an especially critical control component in terms of safety. More specifically: valves that control potentially hazardous movements or system states. Required safety functions can usually be achieved by other linked controls with the appropriate valve versions or even by additional mechanical solutions such as holding devices or brakes. Drive elements as well as energy conversion and transfer components in fluid power systems are usually beyond the scope of the standard.

In pneumatic systems, components must be protected against hazards associated with energy changes. Moreover, the air preparation unit used to process compressed air must be safely connected to the valve area. To reliably control possible energy changes, an exhaust valve is often used in conjunction with a pressure switch.



◀ Scope of ISO 13849 in pneumatic systems

Example:
Air preparation unit 0Z usually comprises:

- Manual shutoff valve 0V10
- Filter with water separator 0Z10 and filter monitoring
- Pressure regulator 0V11 with adequate relieving exhaust
- Pressure indicator 0Z11 for system parameter monitoring

The structures of most fluid power system controls are designed to comply with the categories 1, 3, or 4. Because category B already requires compliance with the relevant standards and basic safety principles, fluid power system controls in the categories B and 1 do not differ substantially in terms of their control structures, but instead in the higher reliability of relevant safety-related valves.

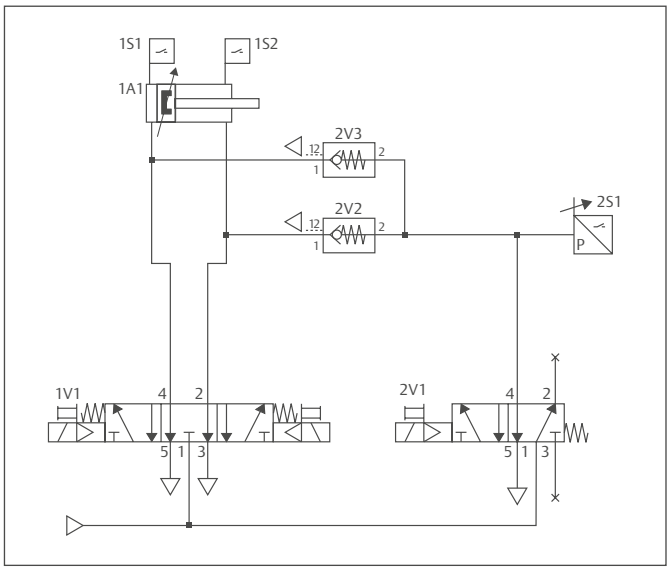
On the following pages you will find two detailed examples. Further examples can be found at www.emerson.com/en-us/expertise/automation/improving-safety-security/machine-safety

Circuit example: “Safe exhaust” (Cat. 3), potential PL a-e

The basic valve position depressurizes the system. Redundant safe exhaust is guaranteed via two exhaust pathways:

- Via non-return valves 2V2 and 2V3 and the directional valve 2V1. The minimum opening pressure of the non-return valves must be taken into account.
- Via directional valve 1V1

Cylinder extension and retraction is only possible with the combined actuation of 1V1 and 2V1. The safety-related switching position is achieved by removing the electrical control signal. Failure of one of the valves does not jeopardize the safety function.



◀ Positive IFA rating achieved

Basic valve position depressurizes the system – two exhaust pathways:

- Via non-return valves 2V2 and 2V3 and directional valve 2V1 (observe minimum opening pressure of the non-return valves)
- Via directional valve 1V1
- Valve 2V1 must be actuated to extend and retract the cylinder.

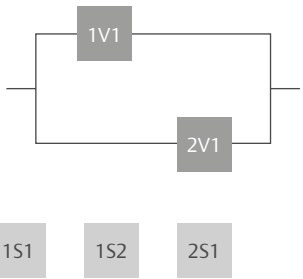
Design features

Basic and well-tried safety principles are met for all relevant components. The directional valves comply with the quiescent current principle and have sufficient positive overlap. The non-return valves must be engineered to assume an open state, even with failure, to safely exhaust the cylinder chambers. The switching valve function of 1V1 and 2V1 is periodically checked by querying the cylinder position switches 1S1 and 1S2 and the pressure switch 2S1.

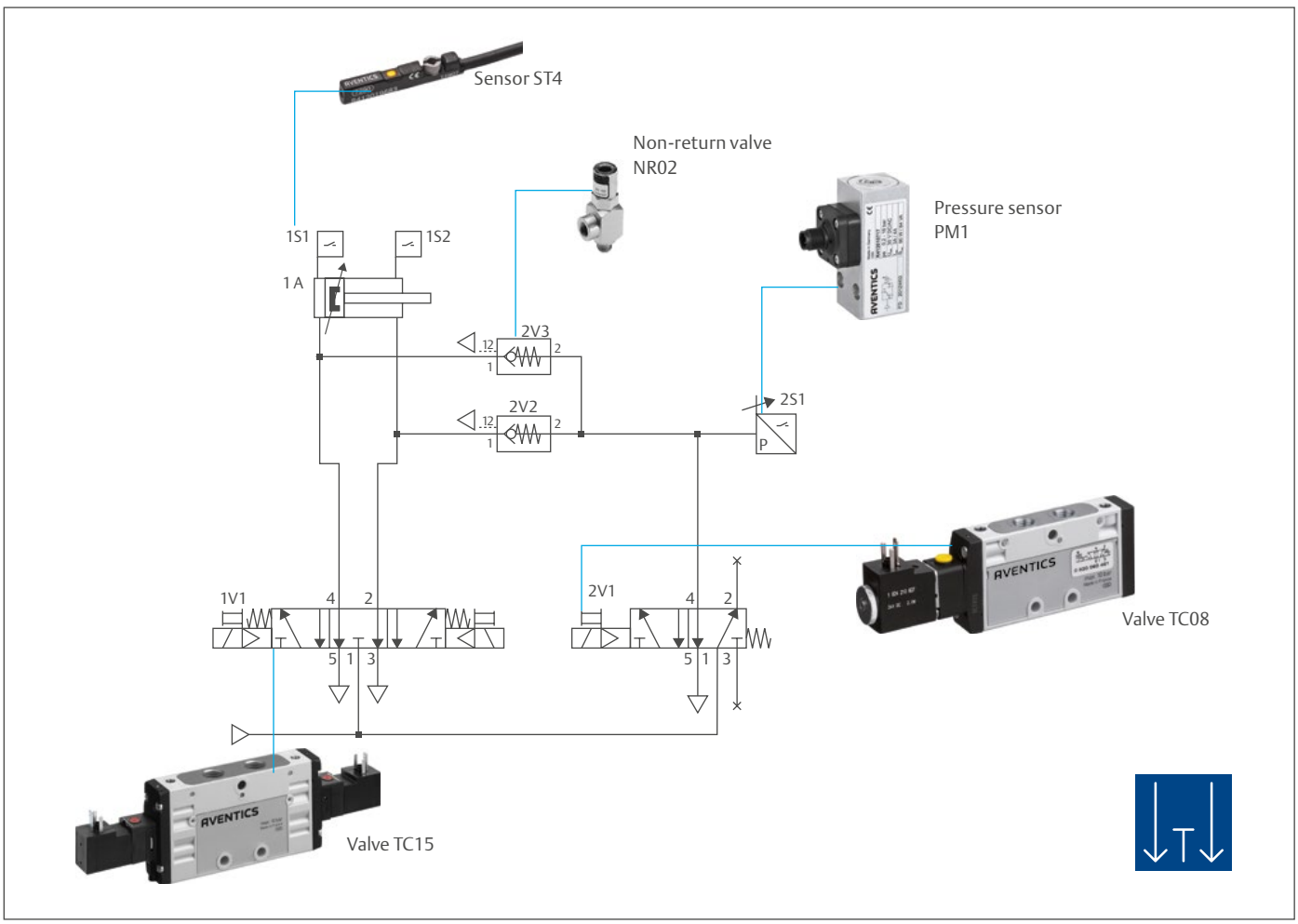
A block diagram is created from the circuit diagram.
The components are arranged

- In series when the components work together to execute a function.
- In parallel “channels” if they perform the function independently (redundant).
- There are monitoring elements in addition to the functional block diagram.
- Drive-related hazards are not taken into account.

Block diagram



Implementing safe dual-channel exhaust with AVENTICS products



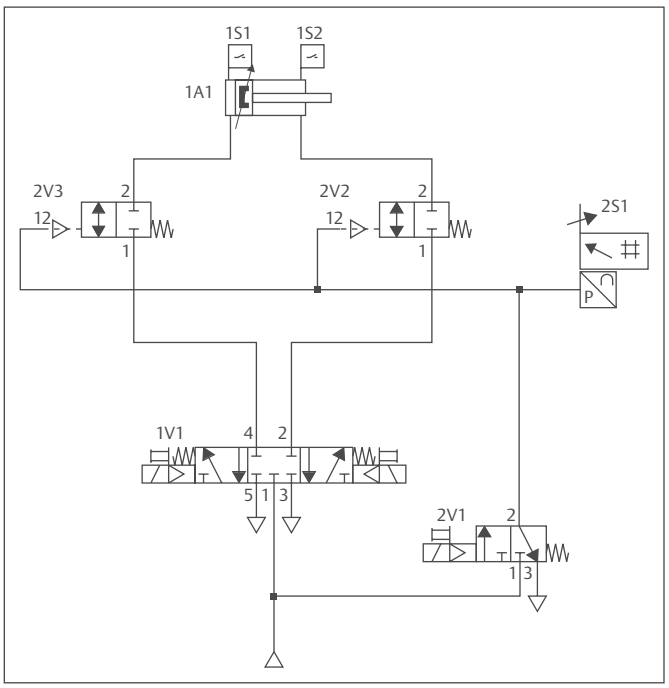
Circuit example: “Safe stop” or “holding via dual-channel chambering” (Cat. 3), potential PL a-e

In the safety function shown here, only the pneumatic control component is shown as a subsystem. For the complete safety function, additional safety-related control components (e.g. as guards and electrical logic) must be added as subsystems.

In the basic valve position, the pressure in the cylinder is chambered; the cylinder stops when forces are balanced. Stopping/holding the cylinder occurs redundantly via two paths:

- If 2V1 is not actuated, the valves 2V2 and 2V3 will remain in the locked position.
- If 1V1 is not actuated, the valve locks in the center position.

Extending and retracting the cylinder is only possible with the combined actuation of 1V and 2V1, and thus 2V2 and 2V3. The safety-related switching position is achieved by removing the electrical control signal. Failure of one of the valves does not jeopardize the safety function. Further measures are required if captive compressed air presents an additional hazard.



▲ Positive IFA rating achieved

Design features

Basic and well-tried safety principles are met for all relevant components. The directional valves comply with the quiescent current principle and have sufficient positive overlap. The function of the switching valves 1V1, 1A1, 2V1, 2V2, and 2V3 is monitored indirectly.

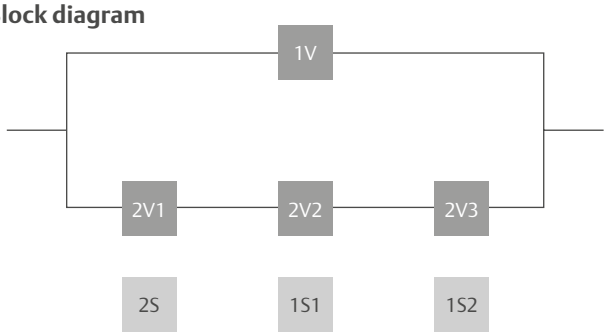
With the help of cylinder switches 1S1 and 1S2, valves 2V3 and 2V2 as well as 1V1 are regularly checked in special test cycles.

A block diagram is created from the circuit diagram

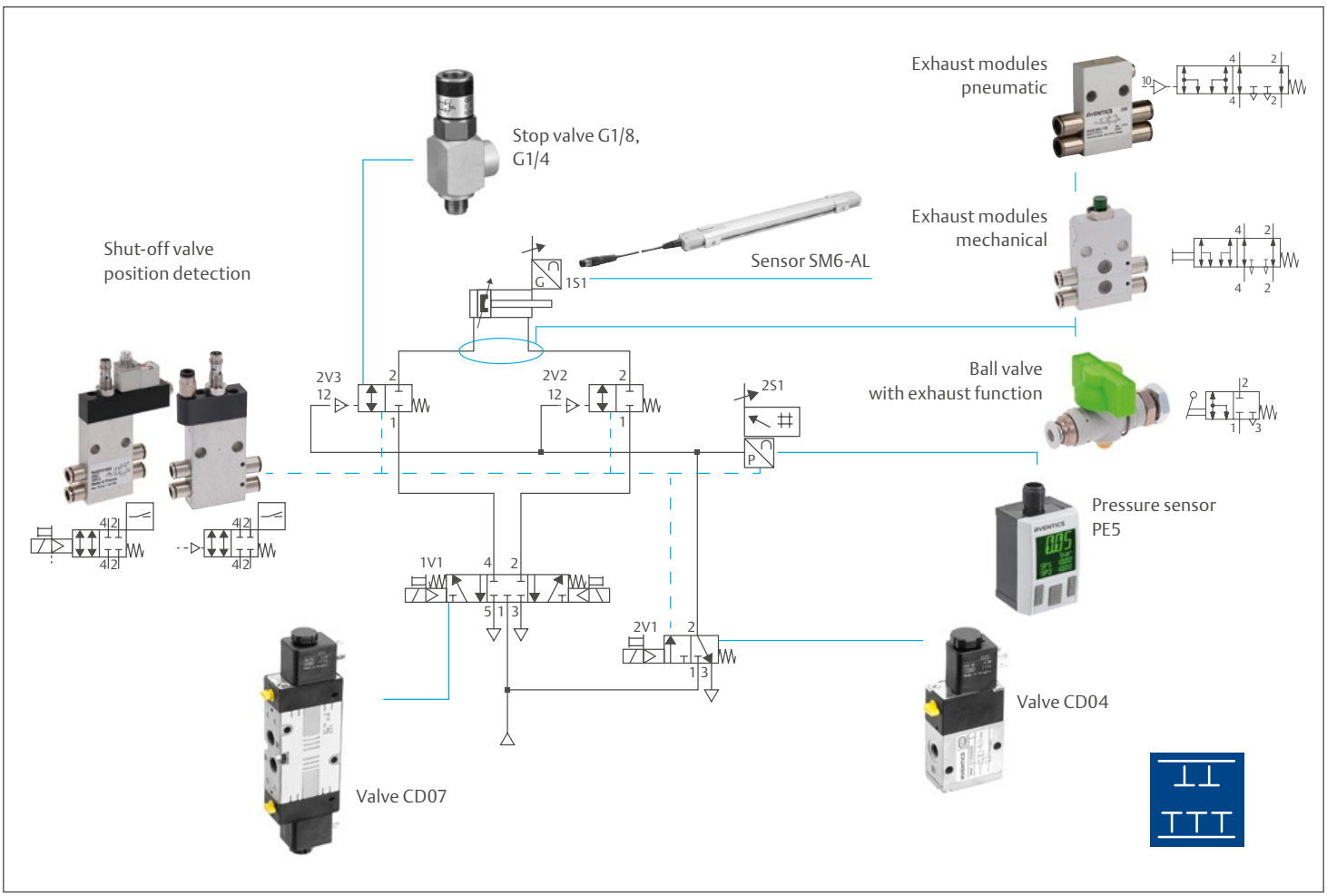
The components are arranged

- In series when the components work together to execute a function.
- In parallel “channels” if they perform the function independently (redundant).
- There are monitoring elements in addition to the functional block diagram.

Block diagram



Implementing “holding via dual-channel chambering” with AVENTICS products



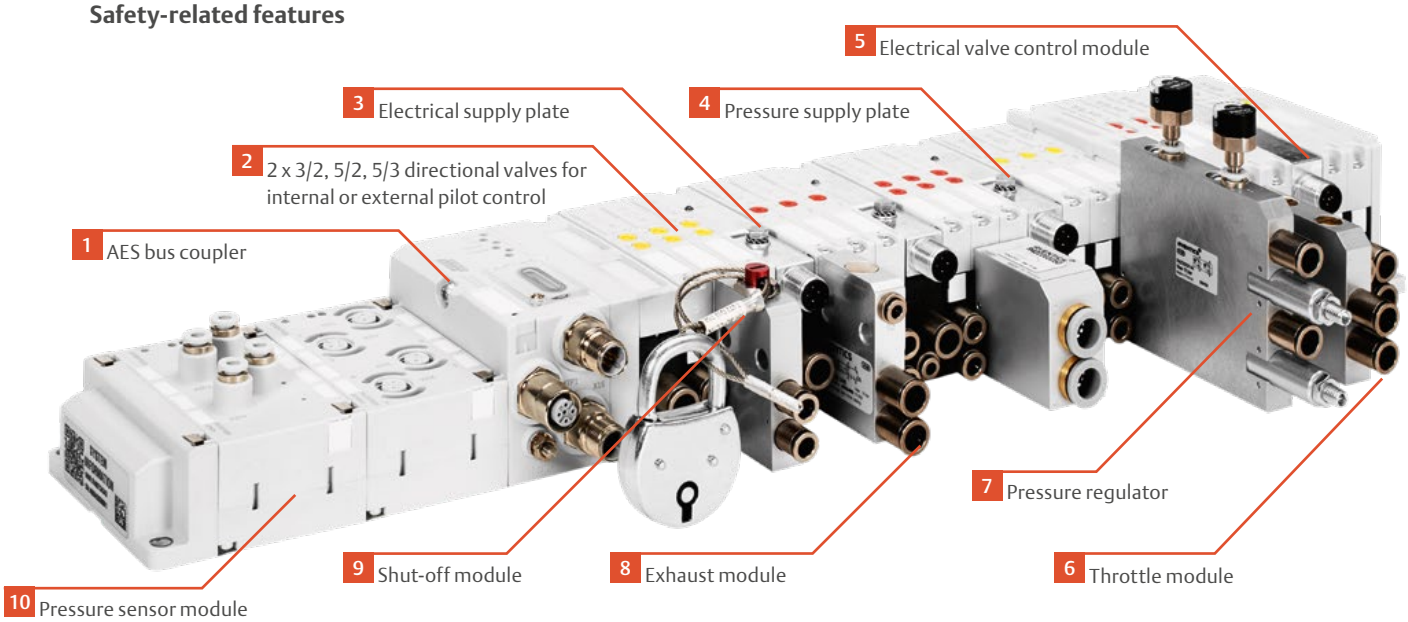
AV valve system with AES fieldbus system

Numerous electrical and pneumatic connection options make the AV system a strong performer that easily adapts to the demands of safety-related pneumatic controls.

The consistent modular design offers additional functions at your fingertips and is impressively systematic. This comfortable approach simplifies your project planning for machine safety. As a result, you can meet even the most demanding of requirements with ease, giving you a crucial competitive edge.

Though the product is not a complete safety device in itself, it can be used as part of an overall solution.

Safety-related features



▲ AV system Series AV03/AV05 with AES

1 AES bus coupler: Galvanic isolation between the logic voltage (UL) and actuator voltage (UA) in the bus coupler; this achieves a safe separation of other functions in the application. Consistent use of standardized and commercially available M12 connectors throughout the system.

2 Excellent leakage values plus easy maintenance minimizes the risk of failure. Pilot air can be controlled internally or externally: should a problem occur, the valves switch to a defined state.

3 Electrical supply plate: supplies actuator voltage to the valves. This enables independent voltage zones with any number of valves. Safety functions thus remain separate from other functions.

4 Pressure supply plate: enables mutually independent pressure zones for customized pressure supply to different circuits and ensures adequate, rapid system exhaust. Optional: Module for monitoring the switch-off voltage threshold of the valves. When falling below the voltage threshold, which disables the valve, the module provides a diagnostic message via the fieldbus. This allows you to identify why the valves were switched off.

5 The electrical valve control module for direct actuation of 2 valves in AV03 and AV05 valve systems. It can be integrated at the right end of D-Sub or fieldbus valve systems. The two following valve positions are controlled via the M12 connection.

6 Throttle module: With the two-channel pressure module, the flow in both operating lines can be limited, reducing the cylinder traversing speed. Optionally, a cover plate is available to safeguard against manipulation.

7 Pressure regulator: Reduced working pressure in the operating lines for force limitation in cylinders.

8 Exhaust module: in case of emergency stop, cylinder chambers may remain under pressure. To perform maintenance, release trapped personnel, or achieve correct workpiece positioning, the cylinder chambers must be exhausted. Targeted system component exhaust de-energizes the cylinder. The module is integrated into the valve system, making it resistant to actuator movements.

9 The shut-off module serves to separate actuators from the pneumatic supply, e.g. for maintenance purposes.

10 Pressure sensor module: processes four pneumatic inputs (pressure or vacuum) from a pneumatic control and converts the pneumatic pressure into digital information of the serial transmission system. The module provides diagnostic capabilities via LED and supply voltage monitoring. All necessary functions are integrated.

The electrical/pneumatic shut-off PD: using this shut-off module with position detection prevents compressed air from entering the operating line – even in the event of accidental actuation of the upstream 5/3 WV CC 1V1. In home position, the valve shuts off all channels. In conjunction with an upstream 5/3 WV CC in safety-relevant control chains, for example, you can achieve two channels to safeguard against accident restart or for safe stops.

The 3/2 directional valve with negative overlap: for the “safe exhaust” safety function, the valve design principle has to be taken into consideration. The 2x 3/2 NCNC directional valve with non-detenting manual override presents an alternative to the poppet valve. This valve does not have zero overlap in the switching transition, also referred to as negative overlap. Due to its design, it cannot get caught in a position where all channels are closed.

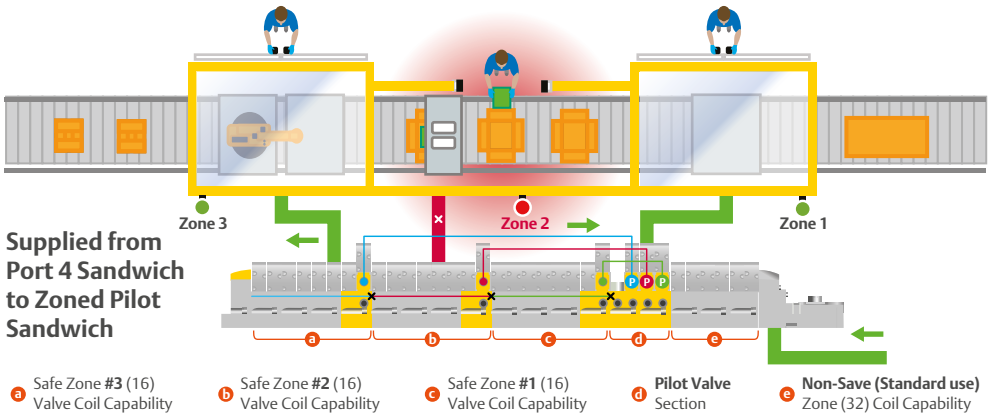
Your advantages:

- Optimized compressed air balance thanks to a small, lightweight construction
- Universal system for a variety of applications in safety-related controls
- High flexibility thanks to easy application retrofitting
- Simplified design process with Engineering Tools
- Long service life of over 150 million cycles.
- Long valve system service life without requiring maintenance

The result: one solution for all your requirements.

503 Zone Safety Valve system

The 503 Zone Safety valve system enables functional safety with up to three independent safety zones on one valve system.



Redundant channels are possible, with external supply of the electrical supply plates via safety relays or a safety PLC.
The electrical supply plate of the pilot valves is separated from the electronics voltage and the valve voltage of the G3 system. The mounted valves can also be used to control pilot-operated non-return valves, locking units, and pneumatically operated spring-return valves.

503 Zone Safety

The 503 Zone Safety valve system enables several safety zones on one Series 503 valve system. This approach helps design engineers to meet the safety requirements of Machinery Directive 2006/42/EC and ISO 13849-1. At the same time, the pneumatic complexity in the individual pneumatic safety circuits is reduced.
With this functionality, it is simple and cost-effective for original equipment manufacturers (OEMs) and end users to configure up to three safety zones in a production machine with a single Series 503 valve system. Together with other safety-related parts of the control system (SRP/CS), the 503 Zone Safety valve system enables safety functions such as safe de-energization, safe reversing, safe stopping and closing, and prevention of unexpected start-up.

One valve system – up to three safety zones

As with standard 503 valve systems, vertically stacked throttle modules, pressure regulators and other manifolds are available to provide maximum flexibility.

- Combines several safety functions in one device
- Eliminates air exhaust across the entire machine
- Increases machine productivity
- Maximizes flexibility

Series G3/580 electronic platforms
The Series G3 is a fully modular system with an innovative clip design. It enables easy module removal and replacement as well as short-term design changes without disassembling the valve system. This ensures that projects are delivered on time.

The Series G3 also features an innovative graphic display that shows clear-text diagnostic messages. It provides clear feedback when commissioning valves, enabling faster commissioning processes and shorter critical phases. Faults are easier to diagnose, and operation can continue much faster.

Series 580
The new Series 580 provides a compact and cost-effective fieldbus electronics platform for applications that do not require the extensive capabilities of the G3. It is equipped with the same G3 graphic display, easy to configure and to commission. Its compact design offers the ideal solution for tight spaces.

Digital connectivity enables simple integration

G3 electronics

- G3 electronics platform provides fieldbus and Ethernet connectivity and graphical user interface.
- Interfaces to 501, 502, 503, 2002, 2005, 2012, 2035, ISO 15407-2 & ISO 5599/II valves
- Up to 128 solenoid coils, up to 16 I/O modules per valve system, and up to 17 valve systems per communication module
- Digital, analog, RTD, NAMUR, high current I/O modules
- M12, M23 & term. strip I/O connections
- Protection: IP65/NEMA 4
- (Wireless) Auto-Recovery Module (ARM) protects configuration information from critical failure
- Power connector scheme allows output power to be removed while inputs and communication are left active

580 electronics

- 580 electronics platform provides a compact cost-efficient solution.
- Up to 32 solenoid valves per valve system
- Simple configuration, no internal wiring required

Multipol

- Multipol pneumatic spool valve system with connectivity via multiwire cable.

Supported protocols

*Zone Safety supported protocols

Series AS air preparation units – cost-effective solution for pressurization and exhaust

All functions, all sizes – the modular versatility of the Series AS air preparation units make them perfect for any application. Compact, high-performance, lightweight, and easy-to-use, these units also ensure reliable, safe, and economical continuous operation with simplified assembly and maintenance. The Series AS offers the most cost-effective solution for machine or plant section exhaust.

▲Series AS modular air preparation units

▲ Protection against unexpected start-up with Series AS

Your advantages:

- Connection thread G3/8, G1/2, G3/4 and G1
- High flow rate performance: up to 12,500 std l/min
- Integration possible in Series AS2, AS3, and AS5 air preparation units
- All Series AS mountings can be used

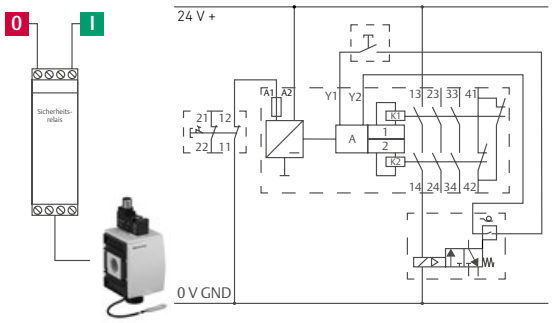
Technical features:

Series AS3 and AS5 3/2 directional shut-off valves with switching position sensing

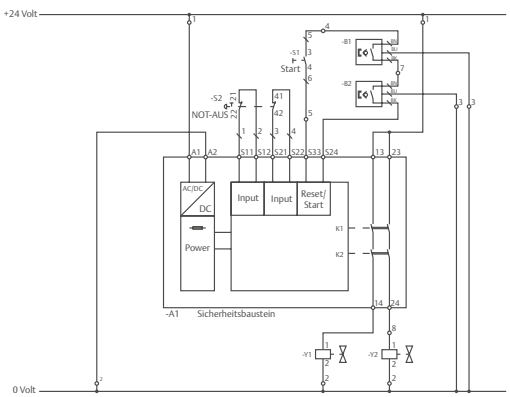
- Electronic monitoring with SB6 sensor and with 3 meter cable and M8, M12 or with open cable end
- Complies with requirements for configuring up to category 4 control circuits
- Higher diagnostic coverage (DC = 99%) for higher PL when used as system valve
- High B_{10} value: 750,000 cycles
- Components comply with basic and well-tried safety principles
- Sensor LEDs as visual indicator of switching state

The safety-related functionality of the valve is decisively influenced by the installation situation. The valve is not a safety device but can be used as part of a larger solution.

Examples of control architecture



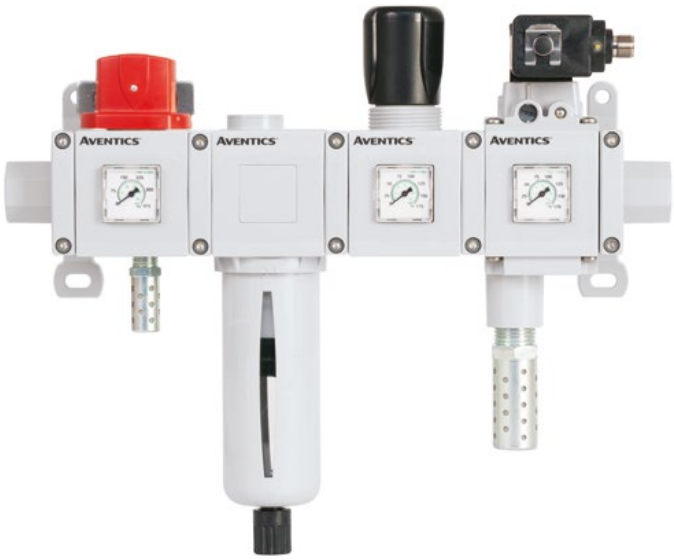
Possible category 2 control architecture, performance level c, single-channel solution



Possible category 3 control architecture, performance level d, dualchannel solution

Series 652/653 Redundant safety exhaust Valve – Reliable solution for pressurization and safe exhaust

AVENTICS Series 652/653 compressed air treatment products include filters, regulators, lubricators, emergency shut-off / soft-start valves, and accessories. Our broad line of high-flow, modular, robust and reliable products include sizes from 1/8“ to 1“ and offer the performance and flexibility to meet today‘s demanding applications. These include indoor machine safety requirements with our Redundant safe exhaust valve.



▲ Series 652 Modular assembly

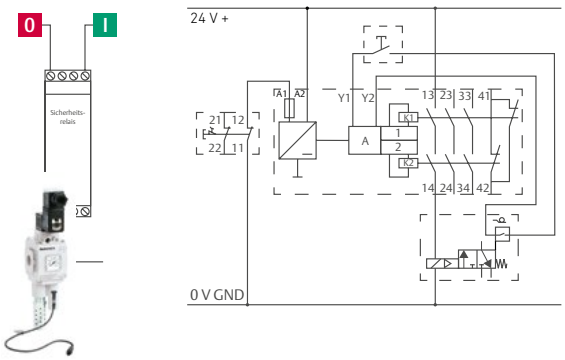
▲ Protection against unexpexted start-up and safe exhaust with Series 653

Technical features: Series 652 and 653 Redundant safety exhaust valve with position sensing

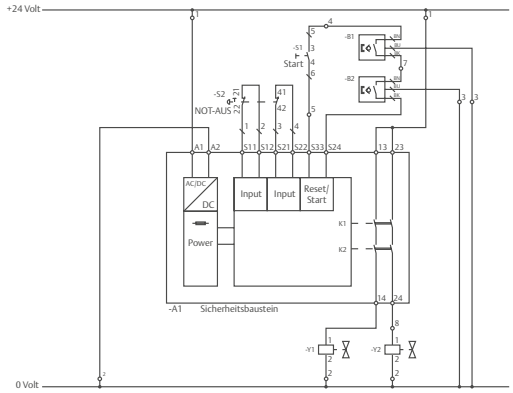
- Electronic monitoring with PNP magnetic sensors with M8 cable and 2 M8 x 1 M12 adapter. Magnetic sensors will detect close position
- Complies with requirements for configuring control circuits to performance level e
- Higher diagnostic coverage (DC = 99%) for higher PL when used as system valve
- High B_{10} value: 1 Millions cycles for 652 and 500 000 cycles for 653
- Components comply with basic and well-tried safety principles

The safety-related functionality of the valve is decisively influenced by the installation situation. The valve will be a safetydevice and it can be used as a part of a larger solution.

Examples of control architecture



Possible category 2 control architecture, performance level c, singlechannel solution



Possible category 3 control architecture, performance level d, dualchannel solution

Your advantages:

- Connection thread G3/8, G1/2, G3/4 and G1
- High flow rate performance: up to 8,200l/min
- Integration possible in 652/653 Assemblies throught our configurator
- All Series 65X mountings can be used
- High B_{10} value (Up to 1 million)

Series SV01/-03/-05 safety valves
The latest valve technology for optimized machine safety

With the new Series SV01, 03, and 05 safety valves, users can achieve category 4 safety-relevant control while realizing the maximum performance level “e” (PLe) according to ISO 13849-1. Safe exhaust and reversing – the dual valve for twice the safety.

Standard-compliant safety with minimal response times

Series SV dual valves are redundant 3/2 or 5/2 directional valves with direct monitoring that meet requirements to protect against unexpected start-up, as well as safe exhaust (3/2 directional valve) and save reversing (5/2 directional valve) in pneumatic safety controls.

The 3/2 dual valves only activate the compressed air supply when all conditions for a safe system start-up have been met, preventing potential accidents. In the event of a machine fault or emergency OFF, the valve exhausts the operating lines, ensuring a de-energized and thus safe state.

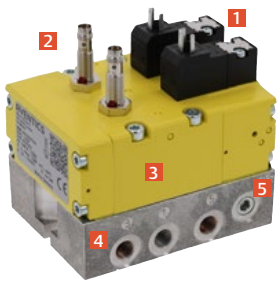
SV01/03/05 safety valves

Your advantages:

- Safe exhaust and reversing
- Protection against potential accidents
- In the event of a machine fault or emergency OFF, the valve exhausts the operating lines, ensuring a de-energized and thus safe state.

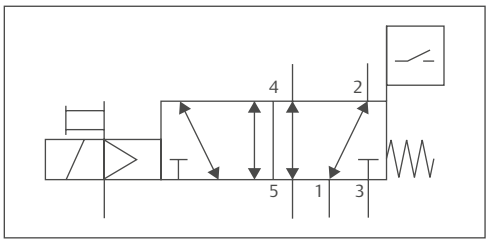
Proven valve concept with innovative safety technology

- Ultra-fast response times
- Position monitoring for feedback on availability
- Position sensors for monitoring slider positions
- Proven slider valve design
- Internal and external pilot
- Base plate assembly
- High B_{10D} values: 20 mil.
- Electronic sensors without mechanical wear
- Sensor signal, in home position (sensor LED illuminated)
- Available as a SISTEMA library
- CE mark with declaration of conformity



1. 15 mm pilot system
2. Position sensors
3. Dual valve technology
4. Base plate (5/2 version)
5. External pilot air connection

Series ISO valve IS12 – variable solution for safe exhaust and protection against unexpected start-up



IS12-PD: Valve with slider position detection

In the danger zone of machinery

- Protection against unexpected start-ups must be guaranteed and
- Safe exhaust of actuators or parts ensured.

To safely monitor the switching state of a valve and hence the safety function performance, an electronic proximity sensor queries the slider position and sends a signal with the switching state to the machine control. The valve is not a safety device but can be used as part of a larger solution.

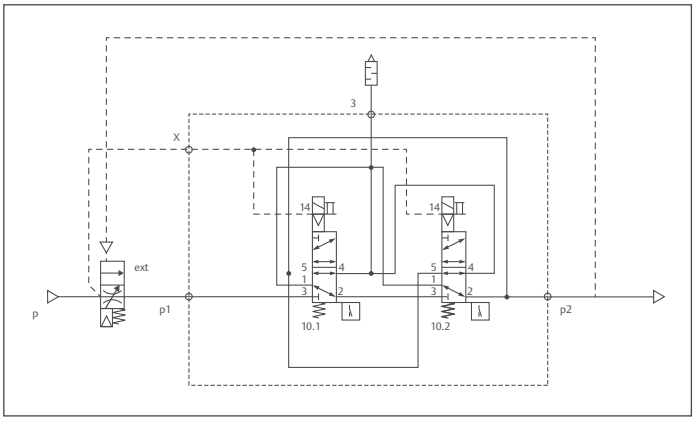
Safety-related features

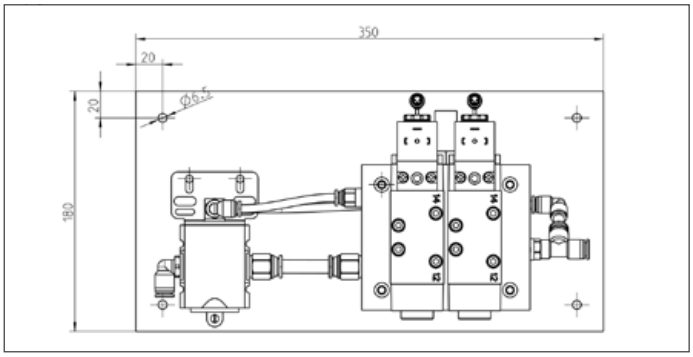
- Correct sensor mounting and positioning, including all tolerances
- Tamper-proof: the sensor is protected against tampering
- 100% functionally tested before delivery
- Can be used in the higher categories 3 and 4, max. possible performance level e
- Valve increases the diagnostic coverage of a pneumatic control (99%)
- High B_{10} value with 39.6 million switching cycles for ISO 1
- Implements basic and well-tried safety principles

ISO valve Series IS12

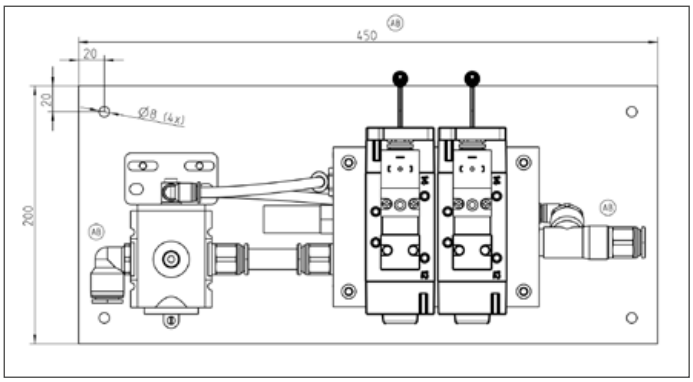
Your advantages:

- Electrically operated 5/2 directional valve with spring return according to ISO 5599-1, size 1 and size 2
- Very high B_{10} values
- Integrated slider position detection with electronic proximity sensor
- With internal or external pilot air, without or with manual override without detent
- High flow



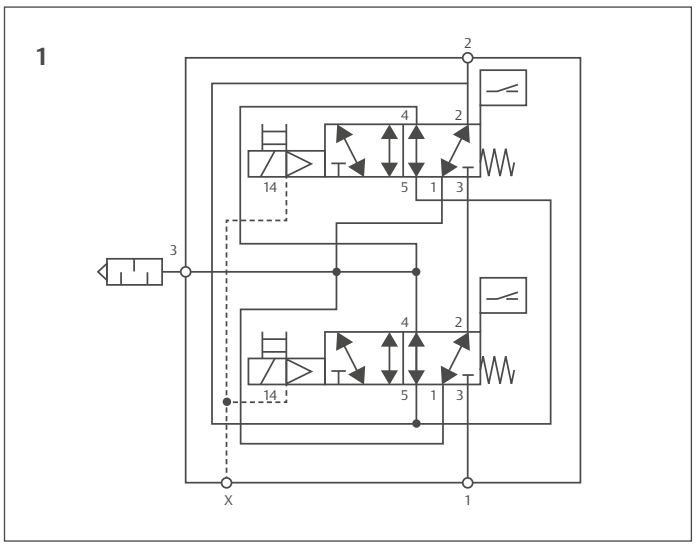


▲ ISO 1, Material-Nr.: R415018127



▲ ISO 2, Material-Nr.: R415017916

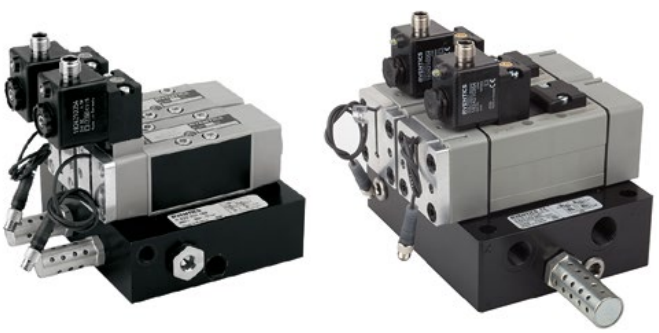
Dual valve IS12-PD



The CE-certified valve block can be used with internal or external pilot air for various safety functions. This allows the implementation of redundant control architectures (dual-channel) for use in categories 3 and 4 with a maximum performance level e.

◀ Redundant solution with internal pilot:
This solution is also available with external pilot. The system can be connected directly to working connection 2. Alternatively, an upstream startup valve can be connected to primary line 1. This startup valve is then actuated by an external pneumatic connection.

◀ Dual valve with integrated non-return valve:
Alternatively, the ISO 1 version provides you with a variant with an integrated non-return valve, in order to bridge a connected startup valve on connection 4 in the secondary line in case of exhaust. This solution is available with external or internal pilot. Additional technical data is available in our online catalog.



Series LU6:
Static locking or dynamic braking

The lock element can be used as a holding unit (blocking of a movement) or as a brake unit (emergency stop/emergency off).

LU6 locking unit application: mechanical holding function for piston rods of pneumatic cylinders according to ISO 15552 or comparable round bars; suitable for use in safety-related controls. Proper use has been tested and certified by the manufacturer.

Further exemplary safety features:

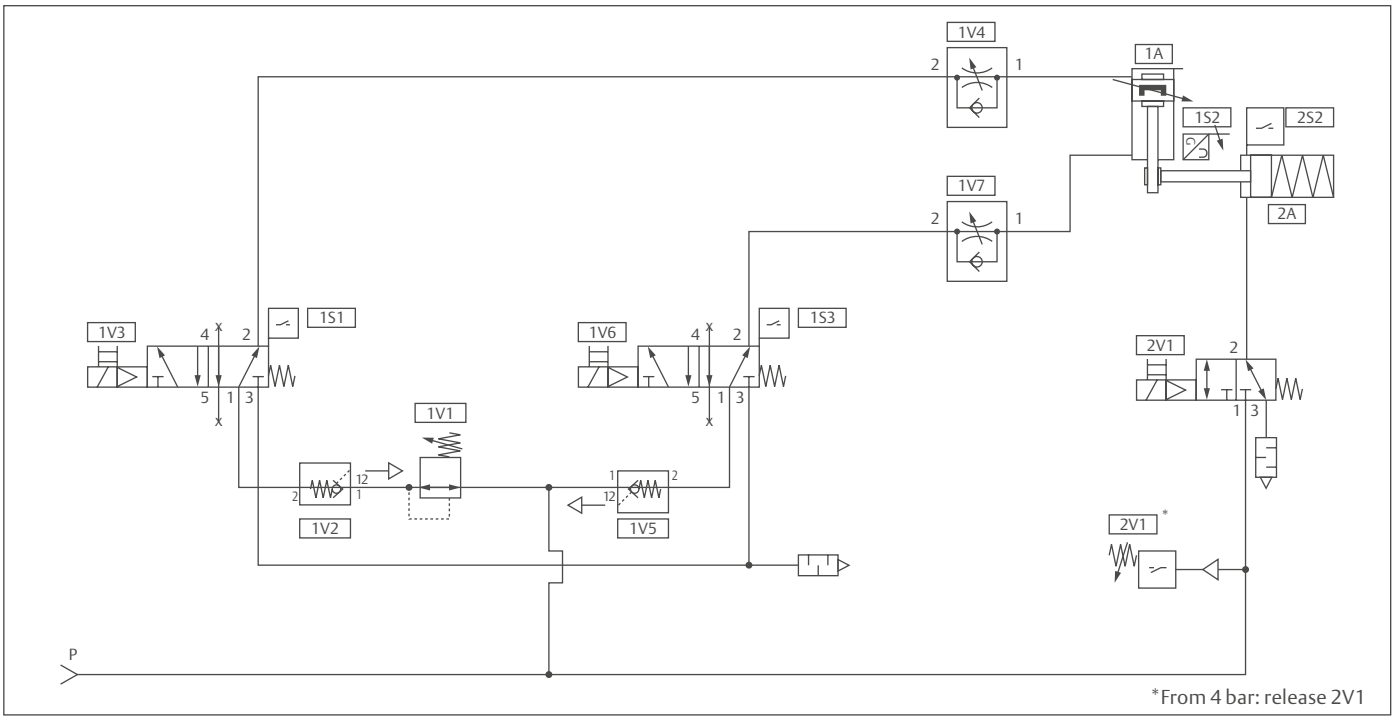
- Preventing a dangerous movement (Cat. 1 to max. PL c, “proven component”)
- Secure hold in upper end position through clamping and one-sided pressurization (up to max. PL e)
- Stopping a dangerous movement (emergency stop/ emergency off, up to max. PL e)

The locking unit can be used in controls with a maximum performance level c or Cat. 1 according to ISO 13849-1 (“proven component”), e.g. to prevent a dangerous movement. When used in controls with a higher performance level, additional control measures according to ISO 13849-1 are necessary.

On the next page you will find a circuit example that allows different cylinder mounting positions. For the safety function “preventing a dangerous movement” the example control – provided that the cylinder locking unit is not used as a dynamic brake – achieves a maximum performance level e (PL e), according to ISO 13849-1. Other components must be provided to meet the requirements for diagnostics and redundancy, as well as prevent common cause failure.

▲ Locking unit, Series LU6, max. holding force 12,000 NN

▲ Series Sensor IN1



▲ Circuit diagram for holding or braking, any cylinder mounting direction, valve normally closed in starting position

Safety-related properties of the holding device

- Permitted for use in category 3 controls up to max. performance level d in accordance with EN ISO 13849-1, for the safety function “preventing a dangerous movement”
- For use in controls with a max. performance level c, category 1, as a “well-tried component”
- High B_{10D} dynamic braking values: 2 million cycles
- High B_{10D} static holding values: 5 million cycles
- Components comply with basic and well-tried safety principles
- Optional function query directly at LU6 by sensors, which directly monitor the pneumatic control signal, helping to increase diagnostic coverage to 99%

Series LU6

Your advantages:

- Large stroke range, depending on the cylinder series (1 to 2,850 mm)
- Robust, clever design for excellent holding and braking functions
- High holding force up to 12,000 N
- Wide range of accessories for numerous combinations and application options
- Hexagonal wrench flats for easier mounting in limited installation spaces

Analog distance measuring sensors: Safe and reliable

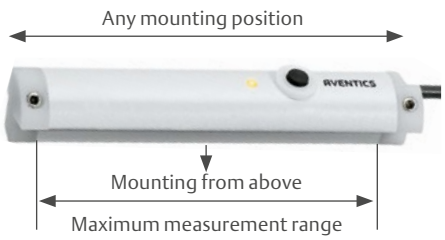
For the safety of processes, it is reassuring to know that piston position detection is highly accurate and repeatable: Feedback on the piston position allows many safety-related controls to review the cylinder position and, consequently, the switching position of the directional valve. Here, analog distance measuring sensors not only provide diagnostics, but also measure the position of the pneumatic cylinder piston with great accuracy and ease.

Thanks to simple mounting in the slot from above, flexible settings within the maximum distance measurement range and an extremely high proximity switching rate, the SM6 sensor is ideal for demanding automation solutions.

Sensor Series SM6

Your advantages:

- Suitable for 6 mm T-slot
- Zero point and measurement range settings via teach-in button
- Choice of any mounting position and cable exit
- Mounting from above in the slot (“drop-in”)
- High accuracy and linearity
- Excellent repeatability and reliability through proven Hall sensors
- Eight different sizes offered in the series to meet all required distance measurement ranges, from 32 to 256 mm



Connection variants:

The SM6-AL analog distance measuring sensor constantly records piston movement over the entire stroke.

It enables high-resolution distance measurement and exact positioning in measurement ranges from 107 to 1,007 millimeters. The distance measuring sensor is thus perfectly suited for the continuous recording of piston movements in pneumatic cylinders and is an ideal solution for cylinders with medium and long strokes.

The SM6-AL is suitable for all standard cylinders. Its universal design offers various assembly options. The robust, chemical-resistant aluminum housing, as well as a cable sleeve support, guarantee a long sensor service life and reduce maintenance costs.

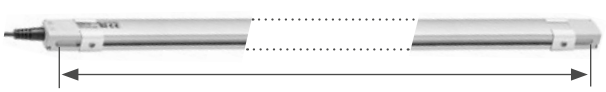
Sensor Series SM6-AL

Your advantages:

- Zero point and measurement range settings via teach-in button
- Choice of any mounting position and cable exit
- High accuracy and linearity
- Excellent repeatability and reliability through proven Hall sensors
- Flexible selection of sizes in the series to meet all required distance measurement ranges, from 107 to 1,007 mm

Free definition of a measurement range

Minimum measuring range 107 mm



Variants up to a maximum measuring range 1,007 mm

Connection variants:

SISTEMA, the software assistant

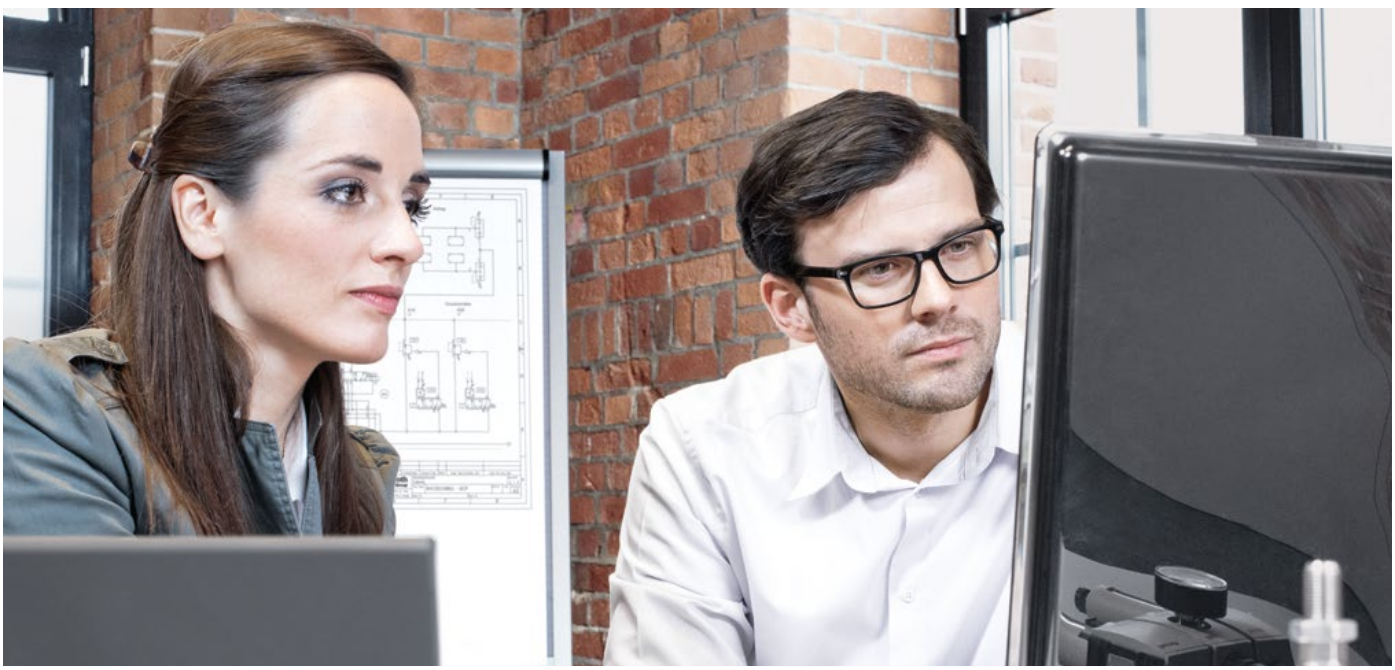
SISTEMA provides assistance in evaluating machine control safety within the scope of ISO 13849-1.

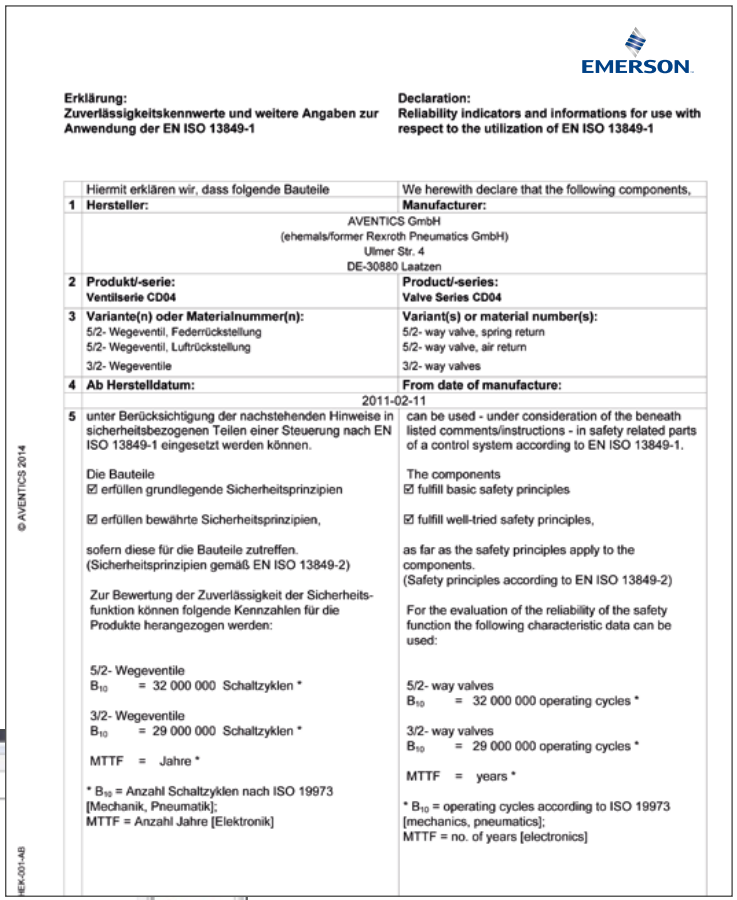
The Windows tool simulates the structure of SRP/CS (safety-related parts of a control system) based on so-called “designated architectures” and calculates reliability values at different levels of detail, including the achieved performance level (PL).

Risk parameters to determine the required performance level (PL_r), category, measures to prevent common cause failures (CCF) for multichannel systems, the mean time to dangerous failure ($MTTF_D$), and average diagnostic coverage (DC_{avg}) can be registered step by step for individual components or blocks. The effect of each parameter change on the entire system is displayed directly and can be printed as a report.

Developed by the German Institute for Occupational Safety and Health, SISTEMA has established itself as a standard. The tool is available as a free download at **www.dguv.de**.

From there you can also access the AVENTICS libraries, where you can directly incorporate all relevant products in your calculation.





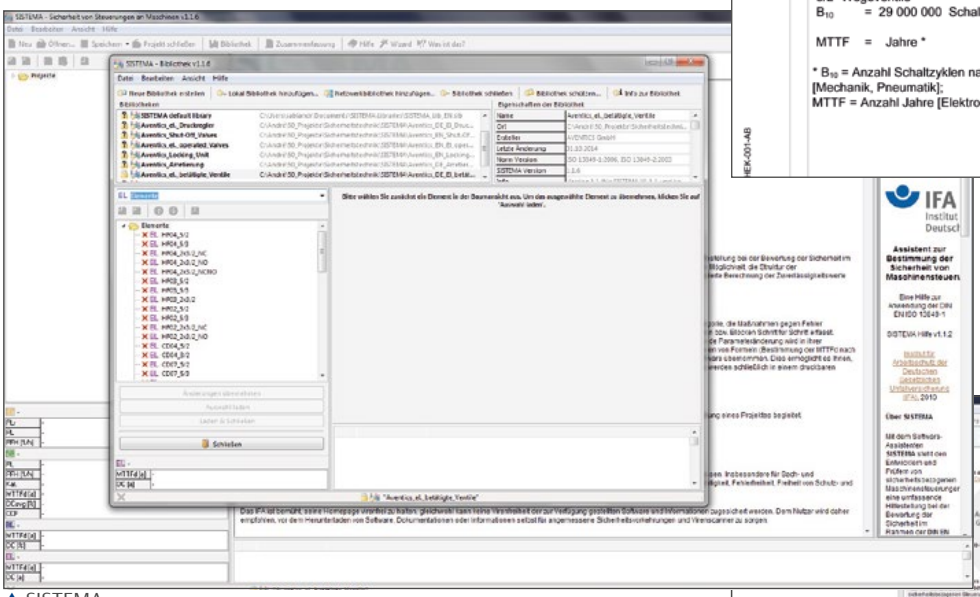
EMERSON

Erklärung:
Zuverlässigkeitskennwerte und weitere Angaben zur Anwendung der EN ISO 13849-1

Declaration:
Reliability indicators and informations for use with respect to the utilization of EN ISO 13849-1

	Hiermit erklären wir, dass folgende Bauteile	We herewith declare that the following components,
1	**Hersteller:**	**Manufacturer:**
	AVENTICS GmbH (ehemals/former Rexroth Pneumatics GmbH) Ulmer Str. 4 DE-30880 Laatzen	
2	**Produkt/-serie:** **Ventilserie CD04**	**Product/-series:** **Valve Series CD04**
3	**Variante(n) oder Materialnummer(n):** 5/2- Wegeventil, Federrückstellung 5/2- Wegeventil, Luftrückstellung 3/2- Wegeventile	**Variant(s) or material number(s):** 5/2- way valve, spring return 5/2- way valve, air return 3/2- way valves
4	**Ab Herstelldatum:**	**From date of manufacture:**
	2011-02-11	
5	unter Berücksichtigung der nachstehenden Hinweise in sicherheitsbezogenen Teilen einer Steuerung nach EN ISO 13849-1 eingesetzt werden können. Die Bauteile ☑ erfüllen grundlegende Sicherheitsprinzipien ☑ erfüllen bewährte Sicherheitsprinzipien, sofern diese für die Bauteile zutreffen. (Sicherheitsprinzipien gemäß EN ISO 13849-2) Zur Bewertung der Zuverlässigkeit der Sicherheitsfunktion können folgende Kennzahlen für die Produkte herangezogen werden: 5/2- Wegeventile B_{10} = 32 000 000 Schaltzyklen * 3/2- Wegeventile B_{10} = 29 000 000 Schaltzyklen * MTTF = Jahre * * B_{10} = Anzahl Schaltzyklen nach ISO 19973 [Mechanik, Pneumatik]; MTTF = Anzahl Jahre [Elektronik]	can be used - under consideration of the beneath listed comments/instructions - in safety related parts of a control system according to EN ISO 13849-1. The components ☑ fulfill basic safety principles ☑ fulfill well-tried safety principles, as far as the safety principles apply to the components. (Safety principles according to EN ISO 13849-2) For the evaluation of the reliability of the safety function the following characteristic data can be used: 5/2- way valves B_{10} = 32 000 000 operating cycles * 3/2- way valves B_{10} = 29 000 000 operating cycles * MTTF = years * * B_{10} = operating cycles according to ISO 19973 [mechanics, pneumatics]; MTTF = no. of years [electronics]

▲ Justificatif Emerson



▲ SISTEMA

Product overview with service life ratings

Electrically operated directional valves						
Qn		Series	Control	Connections	Function	B_{10} value in millions of cycles
300 l/min		AV03	Electric	Ø 4, Ø 6, Ø 8 Ø 1/8, Ø 1/4	5/2 AS, 5/2 AR	71
					5/3 CC, 2x3/2 CC, 2x3/2 OO, 2x3/2 OC	52.9
					2x3/2 spool valve, no close cross-over	22
700 l/min		AV05	Electric	Ø 4, Ø 6, Ø 8, Ø 1/4	5/2 AS, 5/2 AR	44.6
					5/3 CC	19.8
					2x3/2 CC, 2x3/2 OO, 2x3/2 OC	24.8
470 l/min		501	Electric	M7, Ø 4, Ø 6, Ø 1/4	5/2 AR, 5/2 SR	21.7
					5/3 CC, 5/3 EC, 2x3/2 CC, 2x3/2 OO	14.5
					5/3 PC	6.3
up to 650 l/min		502	Electric	G 1/8, 3/8, 1/2, Ø 6mm, Ø 8mm	5/2 SR	13.5
					5/2 AR, 5/3 CC, 5/3 PC, 5/3 EC, 2x3/2CC, 2x3/2 OO	35
1,400 l/min		503	Electric	G 1/8, 1/4 NPTF, Ø 8, Ø 10, Ø 3/8	5/2 AR	10
					5/2 SR, 5/3 CC, 5/3 PC, 5/3 EC, 2x3/2CC, 2x3/2 OO	10
250 l/min		2002	Electric	Ø 1/8, Ø 1/4, Ø 5/32 (4 mm), Ø 6	5/2 SR, 5/2 AS	1.3*
					2x3/2OO, 2x3/2CC	10*
560 l/min		2005	Electric	1/8 NPTF, G 1/8, Ø 1/4, Ø 6, Ø 5/16 (8 mm)	5/2 AS	16*
					5/2 SR	19.9*
					2x3/2 CC, 2x3/2 OO	13.8*
					5/3 CC	15*

*Mission time: 10 years

The values in the table reflect the current status as of the editorial deadline. This data is updated on a regular basis and can be downloaded from our website. We also provide explanations (reliability values and further information for the application of ISO 13849-1) as downloads online:

Electrically and pneumatically operated directional valves						
Qn		Series	Control	Connections	Function	B_{10} value in millions of cycles
1,200 l/min		2012		1/4 NPTF, 3/8 NPTF, 1/4G, G 3/8, Ø 3/8, Ø 8, Ø 10	5/3 CC	18.7*
					5/2 SR	11.5*
400 l/min		HF04	Electric	Ø 6	5/2 SR, 5/2 AR, 5/3 CC, 2x3/2 CC	20
					2x3/2 OO, 2x3/2 OC	10
700 l/min		HF03	Electric	G 1/8, Ø 8, NPTF 1/8	5/2 AS, 5/2 AR, 5/3 CC	26
					2x3/2 CC, 2x3/2 OO, 2x3/2 OC	24
1,400 l/min		HF02	Electric	G 1/4, Ø 10	5/2 SR, 5/2 AR, 5/3 CC	15
					2x3/2 CC, 2x3/2 OO	24
950 – 1,400 l/min		581 ISO size 1	Electric, pneumatic	G 1/8, G 1/4, Ø 6, Ø 8, 1/4“ NPT, 3/8“ NPT, (G 1/8, for direct mounting on the cylinder)	5/2 SR, 5/2 AR, 5/3 EC, 5/3 PC, 5/3 CC	20
2,100 – 2,700 l/min		581 ISO size 2		G 1/4, G 3/8, Ø 8, 3/8” NPT, 1/2” NPT, (G 3/8 for direct mounting on the cylinder)		
4,100 – 4,800 l/min		581 ISO size 3	Electric, pneumatic	G 3/8, G 1/2, 1/2“ NPT, 3/4“ NPT	5/2 SR, 5/2 AR, 5/3 CC, 5/3 EC, 5/3 PC	6.1
5,000 – 6,000 l/min		581 ISO size 4	Electric, pneumatic	G 1/2, G 3/4, G 1, 1” NPT	5/2 SR, 5/2 AR, 5/3 EC, 5/3 PC, 5/3 CC	6.2
1,100 l/min		CD01-PA/PI	Electric, pneumatic	G 1/8, G 1/4, NPTF, Ø 4, Ø 6, Ø 8, Ø 10, Ø 3/8“	5/2 AS, 5/2 AR	20
					2x3/2 CC, 2x3/2 OO, 2x3/2 OC	32
					5/3 CC, 5/3 EC, 5/3 PC	14.9

Product overview with service life ratings

Electrically and pneumatic operated valves						
Qn		Series	Control	Connections	Function	B_{10} value in millions of cycles
900 l/min		CD04	Electric, pneumatic	G 1/8, NPTF 1/8	3/2 SR	29
					5/2 SR, 5/2 AR	32
					5/3	12.9
900 – 1,400 l/min		CD07	Electric, pneumatic	G 1/4, M14 x 1.5	3/2 SR	21
					5/2 SR, 5/2 AR	24
					5/3 CC, 5/3 EC, 5/3 PC	24.8
3,800 – 4,100 l/min		CD12	Electric, pneumatic	G 1/2, M22 x 1.5	3/2	28
					5/2 SR, 5/2 AR	14
					5/3 CC, 5/3 EC, 5/3 PC	10
800 l/min		TC08	Electric, pneumatic	G 1/8, NPTF 1/8	5/2 AS, 5/2 AR, 5/3 CC, 5/3 EC, 5/3 PC	20
					2x3/2 CC, 2x3/2 OO, 2x3/2 OC	15
1,500 l/min		TC15	Electric, pneumatic	G 1/4, NPTF 1/4	5/2 SR, 5/2 AR	17
					5/3 EC, 5/3 PC, 5/3 CC	26
					2x3/2 CC, 2x3/2 OO, 2x3/2 OC	29.7
1,000 l/min		L1	Pneumatic	1/8 & 1/4 NPTF	5/2 SR	60
			Electric		DC 5/2 SR	28
					AC 5/2 SR	20
1,700 l/min		L2	Pneumatic	1/4 & 3/8 NPTF	5/2 SR	60
			Electric		DC 5/2 SR	28
					AC 5/2 SR	7
175 l/min		519	Electric	M5	5/2 SR	80
600 l/min		520	Electric	G 1/8	5/2 SR & 3/2 SR	80
1050 l/min		521	Electric	G 1/4	5/2 SR	80

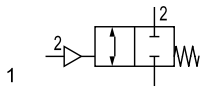
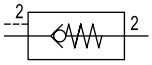
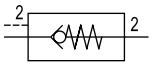
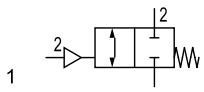
The values in the table reflect the current status as of the editorial deadline. This data is updated on a regular basis and can be downloaded from our website. We also provide explanations (reliability values and further information for the application of ISO 13849-1) as downloads online:

Electrically and mechanically operated directional valves						
Qn		Series	Control	Connections	Function	B_{10} value in millions of cycles
1,060 l/min		IS12-PD ISO1	Electric	G 1/8, G 1/4, Ø 6, Ø 8, 1/4“ NPT, 3/8“ NPT, (G 1/8, for direct mounting on the cylinder)	5/2 SR	39.6
2,500 l/min		IS12-PD ISO2	Electric	G 1/4, G 3/8, Ø 8, 3/8“ NPT, 1/2“ NPT, (G 3/8 for direct mounting on the cylinder)	5/2 SR	7
700 – 1,000 l/mn		Double valve IS12-PD ISO1	Electric	1/4 ISO1	5/2 SR	21 (with NRV) 7.5 (without NRV)
1950 – 3,000 l/min		Double valve IS12-PD ISO2	Electric	1/2 ISO2	5/2 SR	8
700 – 7,000 l/min		SV01, SV03, SV05	Electric	G 1/8, AS2 Adaption	3/2, 5/2	10
175 – 310 l/min		LS04-AF	Electric	Ø 4, Ø 6	2x3/2 spool valve, no close cross-over	2
		LS04-PD			5/2 SR & 3/2 SR	5
		LS04-XS			5/2 SR	17
280 l/min		ST	Mechanical	G 1/8	5/2 plunger SR, 3/2 plunger SR, 5/2 roller SR, 3/2 roller SR, 5/2 roller with one-way trip SR, 3/2 roller with one-way trip SR	5
1,600 – 2,400 l/min		VL/VT	Mechanical	G 3/8, G 1/2, G 3/4, G 1, G 1 1/4, G 1 1/2, G 2	3/2	

5/2 SR Single solenoid with spring return
5/2 AR Single solenoid with air return
5/2 AS Single solenoid with combined spring/air return
5/2 DS Double solenoid (bistable)
5/3 CC Closed center
5/3 EC Exhausted center
5/3 PC Pressurized center
2x3/2 CC 2x 3/2 closed in home position
2x3/2 OO 2x 3/2 open in home position
2x3/2 OC 3/2 1x closed, 1x open in home position
NRV Non-return valve

Product overview with service life ratings

Blocking valves

Qn		Series	Connections	Function	B_{10} value in millions of cycles
340 l/min		Stop valve G 1/8 (0821003075)	G 1/8 1		20
340 l/min		Pilot-operated non-return valve NR02 G 1/8 (0821003050)	G 1/8 1 1		59
680 l/min		Pilot-operated non-return valve NR02 G 1/4 (0821003051)	G 1/4 1 1		39
680 l/min		Stop valve G 1/4 (0821003076)	G 1/4 1		10

Shut-off module

Qn		Series	Control	Connections	Function	B_{10} value in millions of cycles
400 l/min		AV Shut-off	Electric, pneumatic	AV, Ø4, Ø6, Ø8, G1/4	4/2 SR	5

The values in the table reflect the current status as of the editorial deadline. This data is updated on a regular basis and can be downloaded from our website. We also provide explanations (reliability values and further information for the application of ISO 13849-1) as downloads online:

Pressure sensors and sensor technology					
Switching pressure range / switching current / measurement range		Series	Connections	B_{10} value in millions of cycles	MTTF in years
-0.9 – 16 bar		PM1 (new)	G 1/4, flange with O-ring, Ø 5x1.5, CNOMO	15	-
-1 – 12 bar		PE5	G 1/4, Ø 4	-	243 – 261
-1 – 10		PE6	Flange with O-ring, Ø 1.2x1	10	20
0.1 A, DC max.		ST4	M8, M12, and open cable ends	-	915
0.15 A DC max.		ST4-2P	M8 and open cable ends	-	1,832
0.07 – 0.1 A DC max.		ST6	M8, M12, and open cable ends	-	1,629
107 – 1,007 mm		SM6-AL	M8	-	76 – 221
32 – 256 mm		SM6	M8, open cable ends	-	180 – 379

In accordance with ISO 13849-1, service life ratings (B_{10}/MTTF) are not required for components used exclusively for diagnosis. (Exception: category 2 controls).

Product overview with service life ratings

Locking unit

Cylinder Ø		Series	Static holding force	Connections	Function	B_{10D} value in million cycles
32, 40, 50, 63, 80, 100, 125		LU6	760 – 12,000 N	G 1/8, G 1/4	Static	5
					Dynamic	2

FRL

Qn		Series	Control	Connections	Function	B_{10} value in million cycles
1,000 – 14,500 l/min		AS and NL	Electric, pneumatic, mechanical	G 1/4 – G 1 1/4 NPT – 1 NPT	SOV, SSV, SSU	0.75
			Mechanical		RGS, FRE, RGP	20 (AS1) 30 (NL6, AS5) 40 (NL1, NL2, NL4, AS2, AS3)
800 – 11,500 l/min		651, 652, 653	Electric, pneumatic	1/8 – 1 NPT, G, Rc	SOV, SSV	0.5
					RGS	20

Redundant safe exhaust valve

Qn		Series	Control	Connections	Function	B_{10} value in million cycles
1500-8230 l/min		652	Electric	G1/4, G3/8, G1/2, G3/4, G1	3/2 SR	1
		653				0.5

SOV 3/2 directional valve
SSV Filling valve
SSU Filling unit
RGS Regulator
FRE Filter regulator
RGP Precision pressure regulator

The values in the table reflect the current status as of the editorial deadline. This data is updated on a regular basis and can be downloaded from our website. We also provide explanations (reliability values and further information for the application of ISO 13849-1) as downloads online:

E/P pressure regulators							
Qn		Series	Control	Connections	Hysteresis	B_{10} value in millions of cycles	MTTF in years
150 l/min		ED02	mA and V	G 1/8, 1/8 NPT	< 0.05 bar	10	30
1,000 l/min		ED05	mA, V, and bus	G 1/4	< 0.06 bar	10	26
1,300 – 2,600 l/min		ED07/12	mA, V, and bus	G 3/8, Ø 12, G 3/4	< 0.03 bar	10	25
800 l/min		EV07	mA and V	G 1/4	0.03 bar	10	25
300-600 l/min		EV03	mA, V, and bus	G 1/4	0.05 – 0.2 bar	20	195
300-600 l/min		AV03-EP	mA, V, and bus	via Valvesystem	0.05 – 0.2 bar	20	195
300-600 l/min		AV05-EP	mA, V, and bus	via Valvesystem	0.05 – 0.2 bar	20	195

Product overview with service life ratings

Fieldbus technology				
	Series	Fieldbus protocol	Can be combined with valve series	MTTF in years
	BDC-B-CanOpen	CANopen	HF, CD01-PI	107
	BDC-B-DevNet	DeviceNet	HF, CD01-PI	107
	BDC-B-DP	PROFIBUS DP	HF, CD01-PI	119
	BDC-B-Sercos	SERCOS III	HF, CD01-PI	92
	BDC-B-EtherCat	EtherCat	HF, CD01-PI	92
	CMS-B-Ethernet IP	Ethernet IP	HF, CD01-PI	69
	AES	PROFIBUS, CANopen, DeviceNet	AV	125
	AES Generation 1	EtherNet/IP, PROFINET IO, EtherCAT, POWERLINK	AV	75
	AES Generation 2			106
	AV	IO-Link	AV	196

The values in the table reflect the current status as of the editorial deadline. This data is updated on a regular basis and can be downloaded from our website. We also provide explanations (reliability values and further information for the application of ISO 13849-1) as downloads online:

Fieldbus technology

	Series	Module type	Can be combined with valve series	MTTF in years
	AV	Valve driver 2x	AV	920
	AV	Valve driver 3x	AV	730
	AV	Valve driver 4x	AV	630
	AV	Electrical supply plate	AV	854
	AV	Pneumatic supply plate with switch-off voltage monitoring UAoff	AV	1094
	AES	Digital input module (8DI), M8/M12 Digital output module (8DO), M8/M12	AV	513
	AES	Digital input module (16DI), M12/spring clamp connection Digital output module (16DO), M12/spring clamp connection	AV	346
	AES	Digital output module (24DO), D-Sub	AV	306
	AES	Digital combination module (8DIDO), M8/M12	AV	203
	AES	Analog input module (2AI), M12 Analog output module (2AO), M12	AV	91
	AES	Analog combination module (2AI2AO), M12	AV	74
	AES	Pressure measurement module with 4 compressed air connections (4P4D4)	AV	93

Glossary

a, b, c, d, e	Performance level designation
B, 1, 2, 3, 4	Category designation
B_{10}	Quality descriptor (for wear); number of cycles until failure occurs in 10% of components (including for pneumatic and electromechanical components). Unit: millions of cycles
B_{10D}	Quality descriptor (for wear); number of cycles until a dangerous failure occurs in 10% of components (including for pneumatic and electromechanical components). Unit: millions of cycles
BGIA	BG Institute for Occupational Safety and Health, since January 1, 2010 renamed Institute for Occupational Safety and Health (IFA) of the German Social Accident Insurance (DGUV)
Cat.	Category
CCF	Common cause failure [ISO 13849-1]
DC	Diagnostic coverage [ISO 13849-1: Diagnostic effectiveness that can be described as the ratio between detected dangerous failures and all dangerous failures.] Unit: percent
DC_{avg}	Average diagnostic coverage Unit: percent
F, F1, F2	Frequency and/or time of exposure to the hazard
FMEA	Failure mode and effects analysis
Functional safety	When the safety of a machine depends on the correct function of the control, the term “functional safety” applies, along with special demands on the availability of the safety function.
Dangerous failure	Failure that potentially results in a dangerous state or malfunction in the SRP/CS
Hazard	Potential source of injury or ill health
Hazard area	Zone within and/or around a machine in which a person can be exposed to a hazard
I, I1, I2	Input device, e.g. sensor (failure mode and effects analysis)
I/O	Inputs/outputs
Channel	Element or group of elements that perform a function independently
L, L1, L2	Logic
MTBF	Mean operating time between failures
MTTF	Mean time to failure Unit: year
$MTTF_D$	Mean time to dangerous failure Unit: year
Protective device (not guard)	Mechanical or electrical devices that prevent the execution of hazardous machine functions under specified conditions
n_{op}	Number of operations Unit: cycles/year
Emergency OFF	Power cut-out in emergency cases [ISO 13849-1: Manually operated control unit that disconnects the electrical power supply to all or part of an installation in an emergency]
Emergency stop	Stops machine in an emergency
O, O1, O2	Output device, e.g. actuator
P, P1, P2	Possibility of avoiding the hazard

PFD	Average probability of failure to perform its design function on demand
PFH	Probability of failure per hour. Unit: per hour
PFH_D	Probability of a dangerous failure per hour. Unit: per hour
PL	Performance level [ISO 13849-1: Discrete level which specifies the capability of safety-related parts of control systems to perform a safety function under foreseeable conditions]
PL_r	Required performance level [ISO 13849-1: Applied performance level necessary to achieve the required risk reduction for each safety function]
Redundancy	Presence of multiple functionally identical or comparable technical resources (mainly for safety reasons) that are not needed for trouble-free normal operation
Residual risk	Risk that remains after a preventive measure is executed
Risk	Combined probability
Risk estimation	Determines likely extent of damage and probability of its occurrence
Risk analysis	Combines the limits of a machine, identified hazards, and estimates risks
Risk assessment	Overall process comprising risk analysis and risk evaluation
Risk evaluation	Assessment of whether risk reduction objectives have been met based on risk analysis
S, S1, S2	Severity of injury
Preventive measure	Action to eliminate a hazard or to reduce a risk
SF	Safety function
Safety component	Independently marketed component that performs a safety function which in the event of failure and/or malfunction would endanger the safety of persons. The component's function is not necessary for machine operation and can be replaced by other conventional components
Safety function	For normal machine operation, a safety function is an additional function that maintains or recovers safe operation in the event of malfunctions or critical operating conditions. A failure or an error in this function would increase the safety risk of the machine.
SIL	Safety integrity level
SRP/CS	Safety-related part of a control system Part of a control system that responds to safety-related input signals and generates safety-related output signals
T_{10D}	Wear-related indicator: Mean time until 10% of the components fail dangerously. Unit: year
TE	Test equipment
Technical safeguards	Protection measures involving protection devices to protect people against hazards that cannot be appropriately eliminated through inherently safe design, or to protect against risks that cannot be sufficiently mitigated.
TM	Mission time Unit: year
Guard	Protective physical barrier designed as part of the machine

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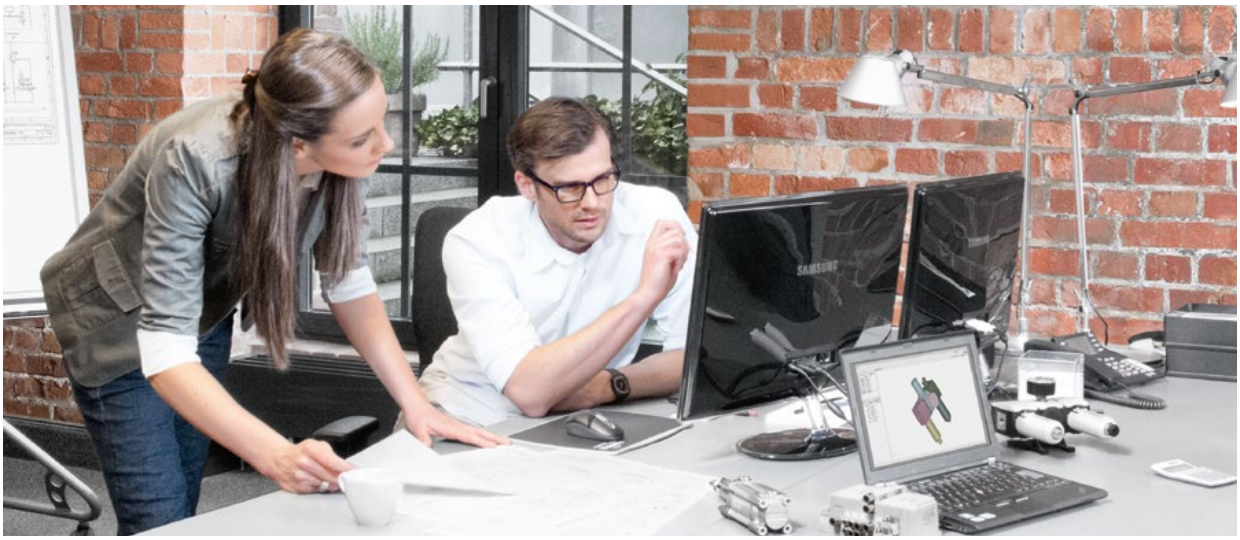

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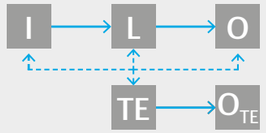
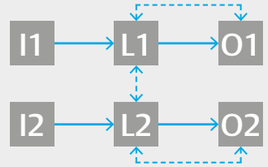
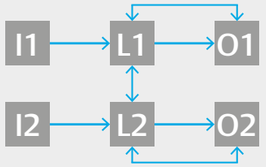
Control category properties

		Category B	Category 1	Category 2	Category 3	Category 4
	Structure					
Features	Redundancy (2 chanels)	No	No	No	Yes	Yes
	Failure resistance / failure cumulation	0 -	0 -	0 ⚡	1 ⚡	1 ✓
Requirements	Safety principles	Basic	Basic & Well tried	Basic & Well tried	Basic & Well tried	Basic & Well tried
	Well-tried components	-	Yes	-	-	-
	Component – $MTTF_D$ (service life)	Low-medium	High	Low-high	Low-high	High
	Monitoring (DC)	None	None	Low-medium	Low-medium	High
	Observation CCF	No	No	Yes	Yes	Yes
	PL (possible)	a–b	b–c	a–d	a–e	e

I Input
L Logic
O Output
TE Test equipment

O_{TE} Test equipment output
⚡ Safety function failure
----- Monitoring
——— Connection

Assessment	$MTTF_D$
Low	3 years ≤ $MTTF_D$ < 10 years
Medium	10 years ≤ $MTTF_D$ < 30 years
High	30 years ≤ $MTTF_D$ < 100 years (resp. < 2.500 years in Cat. 4)

▲ Source: ISO 13849

Assessment	DC range
None	DC < 60 %
Low	60 % ≤ DC < 90 %
Medium	90 % ≤ DC < 99 %
High	99 % ≤ DC

▲ Four DC classes in the simplified approach from ISO 13849-1

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