Functional Safety of Machines and Systems

Easy Implementation of the European Machinery Directive

EN 954-1
EN ISO 13849-1

EN 62061

Safety Integrated

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SIEMENS

New Standards Support Mechanical Engineers

Global standards, far-ranging directives

Contents

As a partner for all safety requirements, we do not only support you with the respective safety-related products and systems, but also consistently provide you with the most current know-how on international standards and regulations. Machine manufacturers and plant managers are offered a comprehensive training portfolio as well as services for the entire lifecycle of safety-related systems and machines.

To keep the residual risk in machine construction within tolerable limits, a comprehensive risk assessment and, if required, risk reduction are essential. Risk assessment provides, on the one hand, the gradual optimization of machine safety, and on the other "proof" in case of damage. The corresponding documentation describes the assessment principles and the resulting measures in order to minimize hazard. This documentation also lays the foundation for safe operation of a machine. At the same time, the industrial safety regulations require the machine operator to comprehensively train his staff on safe operation of a machine. If the operator combines individual machines into a system, effects machine modifications or expands machine functions, he himself acts as a mechanical engineer.

Compliance with the machinery directive can be ensured in different ways: within the scope of a machine acceptance performed by an authorized test body, by meeting the requirements of harmonized standards – or by providing a proof of safety, which is connected with increased test and documentation expenditures. In any case, the CE marking with a respective proof of safety visually proves compliance with the machinery directive. The CE marking is a binding requirement of the EU framework directive for industrial safety.

Avoiding accidents, preventing harmful consequences

Compared to the physical and psychological consequences of machine or system accidents for humans, mechanical damage is more tolerable – even though machine failures or production downtimes cause substantial financial loss. In worst case scenarios, however, the question of guilt has to be resolved within the scope of a post-incident examination. If it is revealed that not all relevant directives were complied with, high claims for damages may result. This might also have a negative impact on the corporate image – with far-reaching consequences. If, however, it can be proven that all relevant standards were complied with, it is assumable that the requirements of the corresponding directives are also met (presumption of conformity).

This brochure will show you how to always be on the safe side with your machine.

The Safety Evaluation Tool

The Safety Evaluation Tool for the IEC 62061 and ISO 13849-1 standards takes you to your goal directly. This TÜV-tested online tool from the Safety Integrated program by Siemens supports the fast and reliable assessment of your machine's safety functions.

As a result, you are provided with a standard-compliant report, which can be integrated in the documentation as proof of safety.

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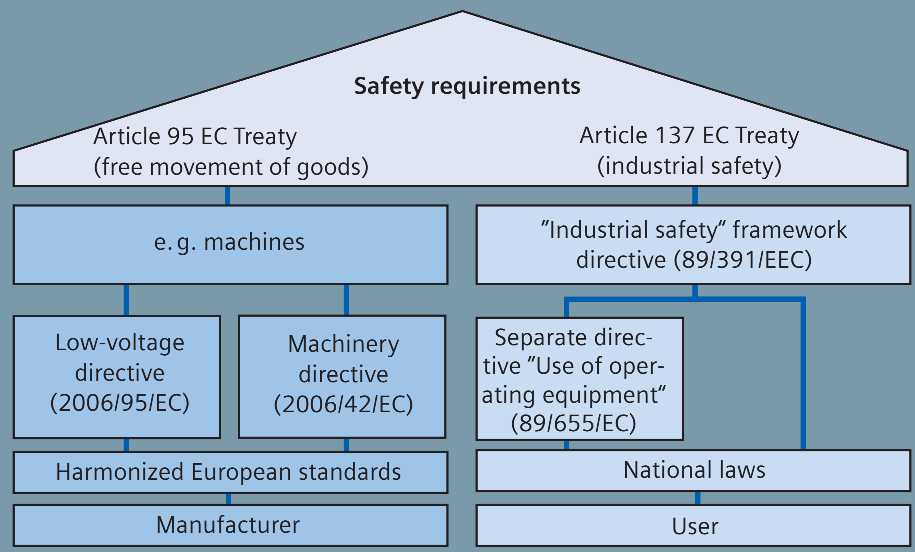
safety-evalution-tool

Basic Safety Requirements in the Production Industry

Target:
Protection of humans, machines and the environment

Result:
CE marking as proof of a "safe machine"



With the introduction of the uniform European Single Market, national standards and regulations affecting the technical realization of machines were consistently harmonized:

- Definition of basic safety requirements, which address, on the one hand, machine manufacturers in terms of the free movement of goods (Article 95) and, on the other hand, machine operators in terms of industrial safety (Article 137).
- As a consequence, the contents of the machinery directive, as a European Single Market directive, had to be transposed into national law by the individual member states. In Germany, for example, the equipment safety law (GSG) regulates the European safety requirements.

To ensure compliance with a directive, it is recommended to apply the harmonized European standards, which then confers the so-called "presumption of conformity" and provides both manufacturers and operators with legal certainty concerning compliance with national regulations such as the EC directive.

With the CE marking, the manufacturer of a machine documents the compliance with all applicable directives and regulations in the free movement of goods. As the European directives are globally approved, the CE marking is also useful for exports to EEA countries.

The following explanations are provided for mechanical engineers or machine operators who modify their machines in a way which affects safety.

Basic Standards for the Development of Control Functions

Target:
Compliance with all applicable safety requirements by sufficient risk minimization – pursuing the objective of seizing export opportunities without taking liability risks.

Result:
Realization of risk-minimizing protective measures by applying harmonized standards – thus, compliance with the safety requirements of the machinery directive on the basis of the ”presumption of conformity“.

Design and risk evaluation of the machine

EN ISO 12100	Safety of machines	Basic terms, general principles
EN **ISO 14121-1**	Safety of machines	Risk assessment, part 1: principles

Functional and safety-relevant requirements for safety-related control systems

Development and realization of safety-related controls

EN 62061:2005
Safety of machines
Functional safety of safety-related electrical, electronic and programmable electronic control systems

EN ISO 13849-1:2006
Safety of machines
Safety-related components of controls, part 1: general principles
Successor standard of EN 954-1:1996
Transition period until end of 2011

Any architectures
Safety Integrity Level (SIL)
SIL 1, SIL 2, SIL 3

Designated architectures (categories)
Performance Level (PL)
PL a, PL b, PL c, PL d, PL e

Electrical safety aspects

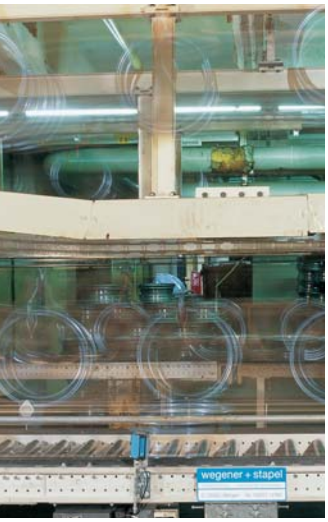
EN 60204-1	Safety of machines	Electrical equipment of machines, component 1: general requirements

Safety requires protection against various hazards. Such hazards can be eliminated as follows:

- Design on the basis of risk-minimizing principles – and risk evaluation of the machine (EN ISO 12100-1, EN ISO 14121-1)
- Technical protective measures, e. g. by using safety-related control systems (functional safety in acc. with EN 62061 or EN ISO 13849-1)
- Electrical safety (EN 60204-1)

The following section deals with **functional safety**, which refers to safety aspects of a machine or system depending on the correct functioning of control devices and guards.
Two applicable standards are:

- EN 62061:2005 – the European sector standard of the basic standard IEC 61508
- EN ISO 13849-1:2006 – the revised successor standard of EN 954-1, as the latter does not sufficiently account for the different categories



Step by step

Development and Implementation of Safety Control Systems

The EN 62061 standard

The EN 62061 standard "safety of machines – functional safety of electrical, electronic and programmable controls of machines" defines comprehensive requirements. It includes recommendations for the development, integration and validation of safety-related electrical, electronic and programmable electronic control systems (SRECS) for machines. With the implementation of EN 62061, for the first time, one standard covers the entire safety chain, from the sensor to the actuator. To attain a safety integrity level such as, for example, SIL 3, a certification of the individual components is no longer sufficient. Instead, the entire safety function must meet the defined requirements.

Requirements placed upon the capacity of non-electrical – e. g. hydraulic, pneumatic or electromechanical – safety-related control elements for machines are not specified by the standard.

Note:
If non-electrical safety-related control elements are monitored via suitable electrical feedback information, these elements are negligible for the assessment of safety when certain requirements are met.

The EN ISO 13849-1 standard

The EN ISO 13849-1 standard "safety of machines – safety-related components of controls, part 1 general principles" is based on the known categories of EN 954-1, issue 1996. It covers the entire safety function with all devices involved.

EN ISO 13849-1 not only includes the quality approach of the EN 954-1, but also discusses safety functions in terms of quantity. Based on the categories, performance levels (PL) are used. The standard describes the determination of the PL for safety-relevant control components on the basis of designated architectures for the scheduled service life. In case of deviations, EN ISO 13849-1 refers to the IEC 61508. For the combination of several safety-relevant components into a total system, the standard contains information on the determination of the resulting PL.

The standard is applicable to safety-related control components (SRP/CS) and all types of machines, irrespective of the technology and energy used (electrical, hydraulic, pneumatic, mechanical, etc.).

The transition period from EN 954-1 to EN ISO 13849-1 will end by 2011. During this period, both standards may be applied alternatively.

Safety plan in acc. with EN 62061 – guideline for the realization of a safe machine

By systematically evaluating the individual steps of the product life cycle, all safety-relevant aspects and regulations for the design and operation of a safe machine can be determined and implemented. The safety plan accompanies users through all stages – right up to modernization and upgrades. The safety plan structure as well as compliance obligation are defined by EN 62061.

The standard requires a systematic approach to safety system (SRECS) design and manufacture. This includes, amongst others, the documentation of all activities in the safety plan: from hazard analysis and risk assessment, the development and realization of the SRECS – down to validation. The safety plan has to be updated along with the implementation of the SRECS.

The following topics and activities are documented in the safety plan:

- **Planning and implementation of all activities required for the realization of an SRECS**
  For example:
  - Development of the specification of the safety-related control function (SRCF)
  - Development and integration of the SRECS
  - Validation of the SRECS
  - Preparation of an SRECS user documentation
  - Documentation of all relevant information for the realization of the SRECS (project documentation)

- **Strategy to achieve functional safety**

- **Responsibilities in terms of execution and verification of all activities**

Although the activities described above are not explicitly listed in EN ISO 13849-1:2006, they are necessary for a correct implementation of the machinery directive.

Step 1:
Strategy for risk minimization in acc. with EN ISO 12100-1, section 1

Target:
Risk minimization

Result:
Definition and determination of protective measures

The primary task of risk minimization is to detect and evaluate hazards as well as to control these hazards by means of protective measures to ensure that they will not cause any damage.

EN ISO 12100-1 suggests the following iterative process:

1. Determination of physical and temporal machine limits

2. Identification of hazards, risk estimation and evaluation

3. Estimation of the risk for every identified hazard and hazardous situation

4. Evaluation of the risk and determination of decisions for risk minimization

5. Elimination of hazards or prevention of the risk connected to the hazard by means of the ”3-step method“ – inherent design, technical protective measures as well as information for use

The EN standard EN ISO 14121-1 contains detailed information on steps 1 to 4.

The safety requirements to be met are derived from the determined risks. With the safety plan, EN 62061 supports a structured procedure:
For every identified hazard, a safety function has to be specified. This also includes the test specification – see ”Validation“ in step 4 below.

Step 2:
Risk evaluation

Target:
Determination and evaluation of the risk elements for a safety function

Result:
Determination of the required safety integrity

The risk elements (Se, Fr, Pr and Av) serve as input variables for both EN 62061 and EN ISO 13849-1. The risk elements are evaluated in different ways; according to EN 62061, a required safety integrity level (SIL) is determined, according to EN ISO 13849-1, a performance level (PL) is determined.

Risk related to identified hazard	=	Severity of damage **Se**	and	Frequency and duration of exposure to hazard	**Fr**
				Occurrence probability	**Pr**
				Probability of avoiding or limiting harm	**Av**

By way of example, consider the following: “A rotating spindle has to be safely stopped when a protective hood is opened”. Assess the risk on the basis of the two standards.

Determination of the required SIL (by SIL assignment)

Frequency and/or duration of stay **Fr**		Occurrence probability of hazardous situation **Pr**		Prevention possibilities **Av**	
≤ 1 h	5	frequently	5		
> 1 h to ≤ 1 day	5	probable	4		
> 2 weeks to ≤ 1 year	4	possible	3	impossible	5
> 2 weeks to ≤ 1 year	3	rarely	2	possible	3
> 1 year	2	negligible	1	probable	1

Effects	Severity **Se**	Class **Cl = Fr + Pr + Av** 3–4	5–7	8–10	11–13	14–15
Death, loss of eye or arm	4	SIL 2	SIL 2	SIL 2	SIL 3	SIL 3
Permanent, loss of fingers	3	Other measures		SIL 1	SIL 2	SIL 3
Reversible, medical treatment	2				SIL 1	SIL 2
Reversible, first aid	1					SIL 1

Example

Hazard	Se	Fr	Pr	Av		Cl	Safety measures	Safe
Rotating spindle	3	5	4	3	=	12	Monitoring protective hood with required **SIL 2**	Yes, with SIL 2

Procedure

1. Determination of damage severity Se:	Permanent, loss of fingers, Se = 3
2. Determination of points for frequency Fr, occurrence probability Pr and prevention Av	– Stay in hazardous area: once per day, Fr = 5 – Occurrence probability: probable, Pr = 4 – Possibility of prevention: possible, Av = 3
3. Total of points Fr + Pr + Av = class Cl	Cl = 5 + 4 + 3 = 12
4. Intersection point between severity Se and column Cl = required SIL	SIL 2

The required SIL is SIL 2

Determination of the required PL (by risk graph)

The risk is estimated on the basis of identical risk parameters

Risk parameters

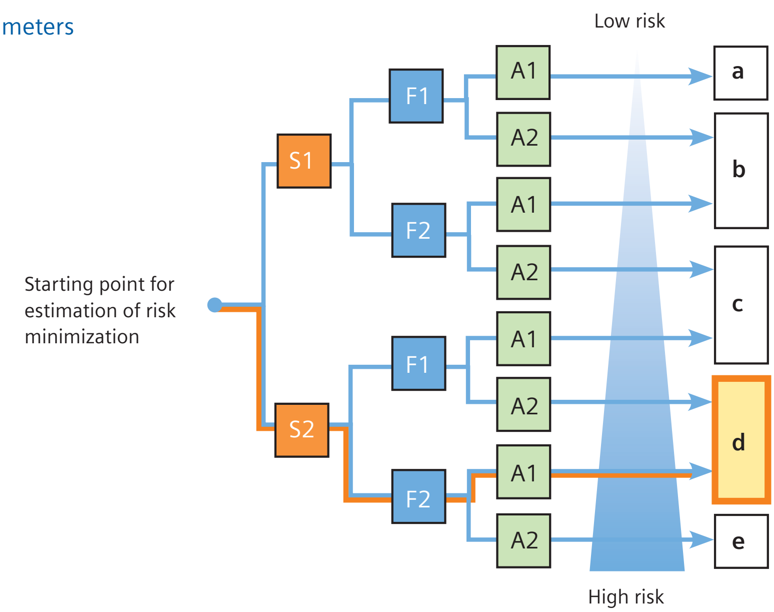
S = Severity of injury
- S1 = Slight (usually reversible) injury
- S2 = Severe (usually irreversible) injury, including death

F = Frequency and/or duration of exposure to hazard
- F1 = Rare to often and/or short exposure to hazard
- F2 = Frequent to continuous and/or long exposure to hazard

P = Probability of avoiding or limiting harm
- P1 = Possible under certain conditions
- P2 = Hardly possible

a, b, c, d, e = targets of the safety-related performance level

Required performance level PL



Procedure	**1. Determination of damage severity S:**	Se2 = severe (usually irreversible) injury, including death
	2. Determination of frequency and/or duration of exposure to hazard F:	Fr2 = frequently up to permanently and/or long exposure to hazard
	3. Determination of the possibility of hazard prevention or damage limiting P:	Av1 = possible under certain conditions
	The required performance level is PL d	

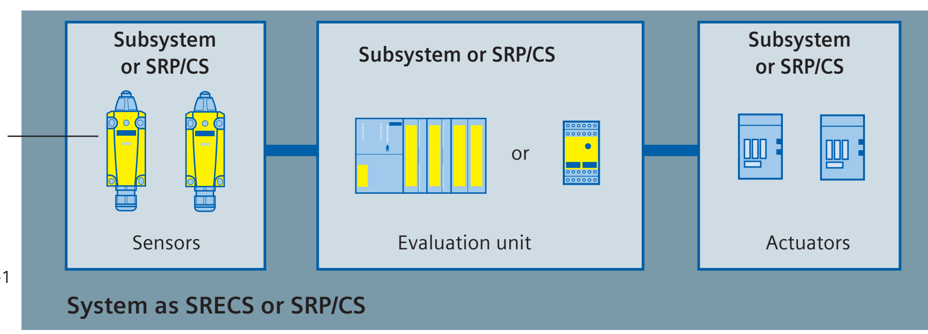
Step 3:
Structure of the safety function and determination of the safety integrity

Target:
Control function and determination of the safety integrity

Result:
Quality of the selected control function

Although the two standards use different evaluation methods for a safety function, the results are transferable. Both standards use similar terms and definitions. The approach of both standards to the entire safety chain is comparable: a safety function is described as 'system'.

Structure of a safety function



SRP/CS: Safety-related components of a control in acc. with EN ISO 13849-1
SRECS: Safety-related electrical control system in acc. with EN 62061

Example:

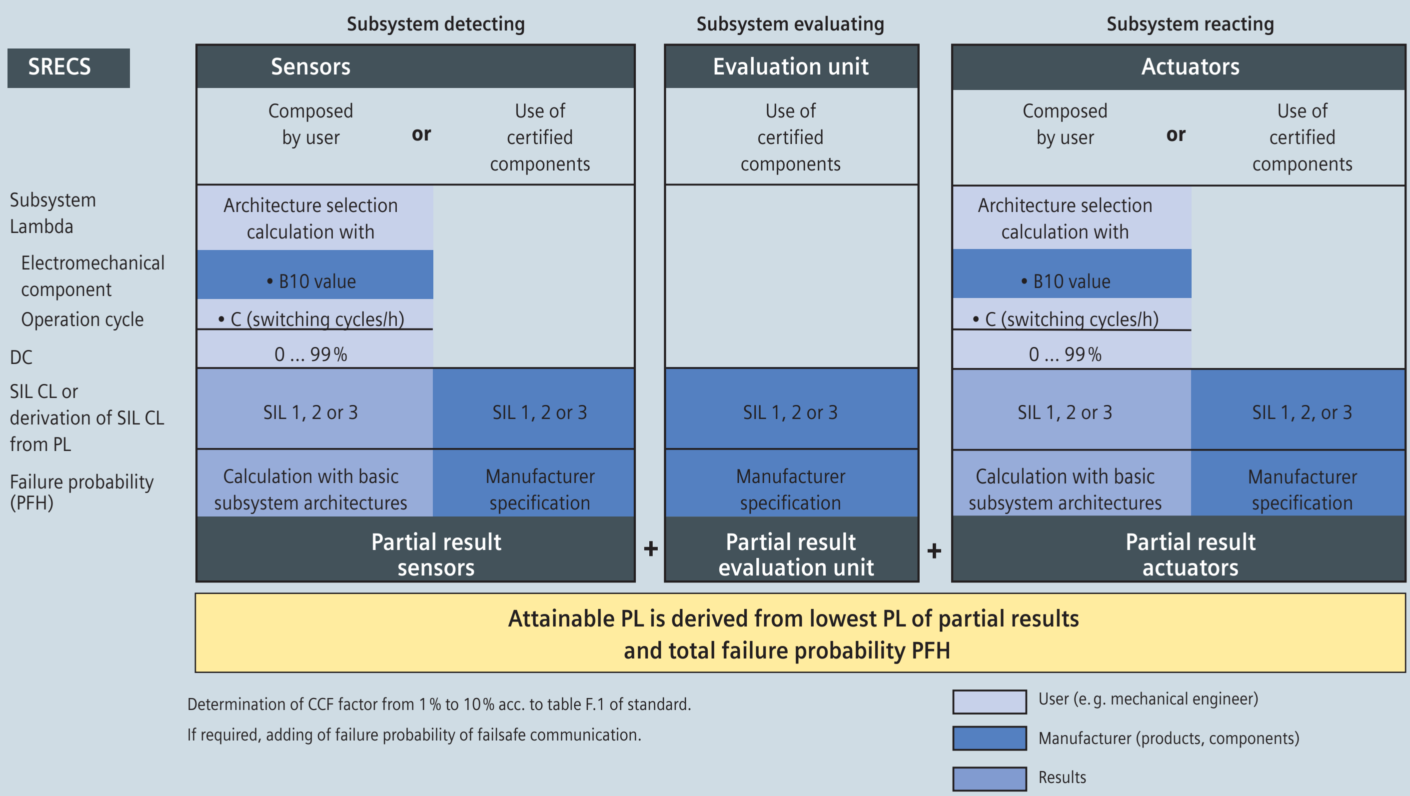
- Requirement: A rotating spindle must be reliably stopped when the protective hood is opened.
- Solution: The protective hood monitoring is realized with two position switches (sensors). The rotating spindle is stopped by two load contactors (actuators). The evaluation unit may be a failsafe control (CPU, F-DI, F-DO) or a safety relay.

The system establishing the connections between the subsystems has to be taken into account.

Joint and simplified procedure:

1. Evaluation of every subsystem or SRP/CS and derivation of "partial results". Two possibilities:
   a. Use of certified components with manufacturer data (e. g. SIL CL, PFH or PL)
   b. On the basis of the selected architecture (one- or two-channel), the rates of failure of the subsystem elements or components are calculated. Then, the failure probability of the subsystem or SRP/CS can be determined.
2. The partial results concerning the structural requirements (SIL CL or PL) have to be assessed and the probability of random hardware failure/PFH added.

Method in acc. with EN 62061



Notes:

1. The procedure to be followed for the determination of the safety integrity is described in detail in the Siemens functional example "Practical Application of IEC 62061", available for download at: http://support.automation.siemens.com/WW/view/en/23996473
2. On page 19 of this brochure you will find explanations of the abbreviations.

Subsystem "detecting" – sensors

For certified components, the manufacturer provides the required values (SIL CL and PFH). When using electromechanical components for systems composed by the user, the SIL, CL and PFH value can be determined as follows:

Determination of SIL CL

SIL CL 3 can be assumed for the example as the architecture used complies with category 4 in acc. with EN 954-1 and appropriate diagnostics are available.

Calculation of the rates of failure (λ) of the subsystem elements "position switches"

On the basis of the B10 value and the switching cycles C, the entire rate of failure λ of an electromechanical component can be determined using a formula from EN 62061, section 6.7.8.2.1:

$\lambda = (0.1 * C) / B10 = (0.1 * 1) / 10{,}000{,}000 = 10^{-8}$
C = duty cycle per hour specified by the user
B10 value = specified by the manufacturer (see Appendix page 18 – table B10 values)

The rate of failure λ consists of safe (λ_S) and dangerous (λ_D) shares:

$\lambda \ = \lambda_S + \lambda_D$
$\lambda_D = \lambda *$ share of failure to danger in %
$= 10^{-8} * 0.2 = 2 * 10^{-9}$
(see Appendix page 18 – table B10 values)

Calculation of the probability of dangerous failure per hour (PFH) in acc. with the used architecture
The EN 62061 standard defines four architectures for subsystems (basic subsystem architecture A to D). For the determination of the failure probability PFH, the standard provides calculation formulas for each architecture.

For a two-channel subsystem with diagnostics (basic subsystem architecture D) involving identical elements, the failure-to-danger rate (λ_D) for the individual subsystems can be derived as follows:

$\lambda_D = (1 - \beta)^2 * \{[\lambda_{De}{}^2 * DC * T2] + [\lambda_{De}{}^2 * (1 - DC) * T1]\} + \beta * \lambda_{De}, = \approx 2*10^{-10}$
$PFH_D = \lambda_D * 1\ h \approx 2*10^{-10}$
λ_{De} = dangerous failure rate for a subsystem element

For the calculation in this example, the following is assumed:

ß = 0.1	conservative assumption as maximum value from standard
DC = 0.99	via discrepancy and short-circuit monitoring
T2 = 1/C	via evaluation in the safety program
T1 = 87,600 h	
(10 years)	lifespan of component

Subsystem "evaluating" – evaluation unit:

For certified components, the manufacturer provides the required values:

Example values:
SIL CL = SIL 3
$PFH_D = < 10^{-9}$

Subsystem "reacting" – actuators:

For certified components, the manufacturer provides the required values.

Example values:
SIL CL = SIL 2
$PFH_D = 1.29*10^{-7}$

If the "reacting" subsystem is composed by the user, the same procedure is applied as with the subsystem "detecting".

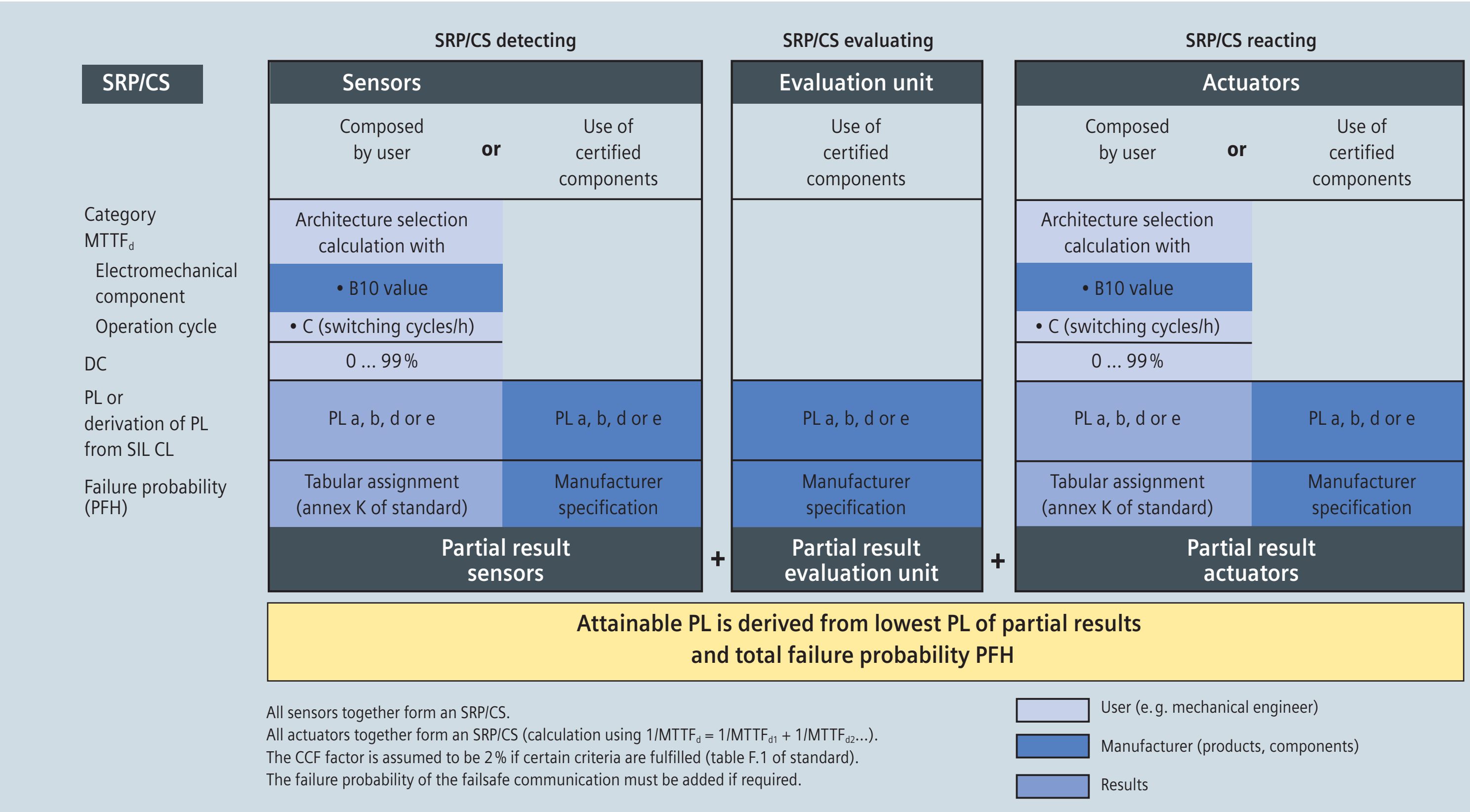
Determination of the safety integrity of the safety function
The minimum SIL limit (SIL CL) of all subsystems of the safety-related control function (SRCF) must be determined:

SIL CL Min = Minimum (SIL CL (subsystem 1) .....SIL CL (subsystem n)) =
= SIL CL 2

Total of probability of random hardware failure (PFH) of the subsystems
$PFH_D = PFH_D$ (subsystem 1) + ... + PFH_D (subsystem n) = $1.30*10^{-7}$
= $<10^{-6}$ corresponds to SIL 2

Result: The safety function meets the requirements of SIL 2

Method in acc. with EN ISO 13849-1



SRP/CS "detecting" – sensors

For certified components, the manufacturer provides the required values (PL, SIL CL or PHF). The SIL CL and the PL can be mutually transferred on the basis of probability of random hardware failure, see point "Transfer of SIL and PL".
When using electromechanical components for systems composed by the user, the PL and PFH value can be determined as follows.

Calculation of the rates of failure of the SRP/CS elements "position switches"
On the basis of the B10 value and the switching cycle n_{op} the rate of failure $MTTF_d$ of an electromechanical component can be determined by the user as follows:

$MTTF_d = B10_d/0.1 * n_{op} = 0.2 * 10^8$ hours = 2,300 years corresponds to $MTTF_d$ = high with n_{op} = actuations per year (number of operations: specified by the user)

$n_{op} = (d_{op} * h_{op} * 3{,}600\ s/h) / t_{cycle}$

With the following assumptions made with regard to the usage of the component:

- h_{op} is the average operating time in hours per day;
- d_{op} is the average operating time in days per year;
- t_{cycle} is the average time between the start of two successive cycles of the component (e. g. valve actuation) in seconds per cycle

For the calculation in this example, the following is assumed:

DC "high" via discrepancy and short-circuit monitoring
Category 4

Result: Performance level PL e with probability of dangerous failures of $2.47*10^{-8}$ is reached

(from Annex K of the EN ISO 13849-1:2006 standard)

SRP/CS "evaluating" – evaluation unit

For certified components, the manufacturer provides the required values.

Example values:
SIL CL = SIL 3, complies with PL e
PFH_D = < 10^{-9}

SRP/CS "reacting" – actuators

For certified components, the manufacturer supplies the required values.

Example values:
SIL CL = SIL 2, complies with PL d
PFH_D = $1.29*10^{-7}$

If the SRP/CS "reacting" is designed by the user, the same procedure is applied as with the SRP/CS "detecting".

Determination of the safety function's safety integrity
The smallest PL of all SRP/CS of the safety-related control function SRCF must be determined:

PL Mn = minimum (PL (SRP/CS 1) .....PL (SRP/CS n)) = PL d

Total of probability of random hardware failure (PFH) of SRP/CS
PFH = PFH (SRP/CS 1) + ... + PFH (SRP/CS n) = $1.74*10^{-7}$ = <10^{-6} corresponds to PL d

Result: The safety function meets the requirements for PL d


Determination of the performance level from category, DC and $MTTF_d$

Although the two standards use different evaluation methods for a safety function, the results are transferable. Simplified procedure for the evaluation of the PL reached by an SPR/CS:

Category	B	1	2	2	3	3	4
DC_{avg}	none	none	low	medium	low	medium	high
$MTTF_d$ of each channel							
low	a	not covered	a	b	b	c	not covered
medium	b	not covered	b	c	c	d	not covered
high	not covered	c	c	d	d	d	e

Comparison of SIL and PL

As already demonstrated, the safety function can be evaluated in two different ways.
SIL and PL can be compared on the basis of the probability of random hardware failure, see table below.

SIL and PL are mutually transferable

Safety integrity level SIL	Probability of dangerous failures per hour (1/h)	Performance level PL
–	$\geq 10^{-5}$ up to $< 10^{-4}$	a
SIL 1	$\geq 3 \times 10^{-6}$ up to $< 10^{-5}$	b
SIL 1	$\geq 10^{-6}$ up to $< 3 \times 10^{-6}$	c
SIL 2	$\geq 10^{-7}$ up to $< 10^{-6}$	d
SIL 3	$\geq 10^{-8}$ up to $< 10^{-7}$	e

Step 4:
Validation on the basis of the safety plan

Target:
Verification of the implementation of the specified safety requirements

Result:
Documented proof with regard to compliance with the safety requirements

The validation serves to check whether the safety system (SRECS) meets the requirements defined by the "Specification of SRCF" (from page 7). The safety plan serves as the basis for such validation.
The following validation procedure must be followed:

- Definition and documentation of responsibilities
- Documentation of all tests
- Validation of each SRCF on the basis of tests and/or analyses
- Validation of the systematic safety integrity of the SRECS

Planning

The safety plan must be prepared (as discussed on page 7), since the validation is based on this document.

Testing

All safety functions must be tested in accordance with the specification – as described in step 1.

Documentation

The documentation is a basic component of evaluation procedures in case of damage. The content of the documentation list is specified by the machinery directive. Basically, the following documents are included:

- Risk analysis
- Risk evaluation
- Specification of safety functions
- Hardware components, certificates, etc.
- Circuit diagrams
- Test results
- Software documentation, including signatures, certificates, etc.
- Information on usage, including safety instructions and restrictions for the operator

After a successful validation, the EC declaration of conformity for the risk-minimizing protective measure can be issued.

Benefits all along the line: safety from a single source

Whether detecting, commanding and signaling, evaluating or reacting: with our Safety Integrated product portfolio, we are the only supplier to cover all safety tasks in the production industry. Seamless safety technology from a single source, which follows the integrated and consistent concept of Totally Integrated Automation. For you, this implies: safe, reliable and efficient operation.

Integrating safety technology, saving costs

Safety Integrated is the consistent implementation of safety technology in accordance with Totally Integrated Automation – our unique comprehensive and integrated product and system range for the realization of automation solutions. Safety functions are consistently integrated in the standard automation to create a consistent overall system. The advantage for both mechanical engineers and plant operators: considerable cost savings over the entire service life.

No matter which safety tasks you want to complete: the Safety Integrated product portfolio offers everything for detecting, commanding and signaling, evaluating or reacting – from sensors and evaluation units down to the actuator.

Regardless of whether:

- you decide in favor of a conventional, bus-based or control- or drive-based solution (**degree of flexibility**) and/or
- you require a simple EMERGENCY-STOP function, a simple linking of safety circuits or highly dynamic processes (**degree of complexity**)

SIRIUS – normal B10 values of electromechanical components

The table below lists the normal B10 values and the percentage of dangerous failures for SIRIUS products (operating in high or continuous demand mode).

Siemens SIRIUS product group (electromechanical components)	Normal B10 value (switching cycles)	Ratio of dangerous failures
EMERGENCY-STOP control devices (with positive opening contacts) • Pull-to-release • Turn-to-release (also with lock)	 30,000 100,000	 20 % 20 %
Cable-operated switches for EMERGENCY-STOP function (with positive opening contacts)	1,000,000	20 %
Standard position switches (with positive opening contacts)	10,000,000	20 %
Position switches with separate actuator (with positive opening contacts)	1,000,000	20 %
Position switches with solenoid interlocking (with positive opening contacts)	1,000,000	20 %
Hinge switches (with positive opening contacts)	1,000,000	20 %
Pushbuttons (non-latching, with positive opening contacts)	10,000,000	20 %
Contactor/motor starter (with positively driven contacts with 3RH/3TH and mirror contacts with 3RT/3TF)	1,000,000	75 %

Terms related to functional safety

Failure
Termination of a unit's capability of fulfilling a required function.

β, Beta
Factor of failure due to common cause
CCF faktor: common cause failure factor β
(0.1 – 0.05 – 0.02 – 0.01)

B10
The B10 value for components subject to wear is expressed in the number of switching cycles, which is the number of switching cycles during which 10 % of specimens failed during a lifetime test. The rate of failure for electromechanical components can be calculated with the B10 value and the operation cycle.

B10d
B10d = B10 / ratio of dangerous failures

CCF (common cause failure)
Failure due to common cause (e. g. short circuit). Failures of various units due to a single event not based on mutual causes.

DC (diagnostic coverage)
Reduced probability of hazardous hardware failures resulting from the execution of automatic diagnostic tests.

Fault tolerance
Capability of an SRECS (safety-related electrical control system), a subsystem or subsystem element to further execute a required function in case of faults or failures (resistance to faults).

Functional safety
Component of the overall safety, related to the machine and the machine control system, which depends on the correct functioning of the SRECS (safety-related electrical control system), safety-related systems of other technologies and external equipment for risk minimization.

Failure to danger
Any malfunction inside the machine or its power supply which increases the risk.

Categories B, 1, 2, 3 or 4
(designated architectures)
In addition to qualitative, the categories also contain quantifiable aspects (e. g. $MTTF_d$, DC and CCF). Using a simplified procedure on the basis of the categories as "designated architectures", the attained PL (Performance Level) can be assessed.

λ, Lambda
Statistical rate of failure derived from rate of safe failures (λ_S) and the rate of failure to danger (λ_D). FIT (failure in time) represents the Lambda unit.

MTTF / $MTTF_d$
(Mean Time To Failure/Mean Time To Failure dangerous)
Mean time to a failure or failure to danger. The MTTF can be implemented for components by the analysis of field data or forecasts. With a constant rate of failure, the mean value of the failure-free operation time is MTTF = 1 / λ, with Lambda λ being the rate of failure of the device. (Statistically, it can be assumed that 63.2 % of the affected components failed after expiry of the MTTF.)

PL (Performance Level)
Discrete level which specifies the capability of safety-related control components of executing a safety function under foreseeable conditions: from PL "a" (highest failure probability) to PL "e" (lowest failure probability.)

PFH_D (Probability of dangerous failure per hour)
Probability of a dangerous failure per hour.

Proof test interval or lifetime (T1)
Repetitive test for the detection of faults or deteriorations of an SREC and its subsystems in order to be able to restore the SREC and its subsystems to an "as new" state or as closely as practically possible to this state if required.

SFF (safe failure fraction)
Share of safe failures in the total rate of failure of a subsystem which does not lead to a failure to danger.

SIL (Safety Integrity Level)
Discrete level (one of three possible) for the determination of the safety integrity requirements of safety-related control functions, which is assigned to the SRECS. Safety Integrity Level 3 represents the highest and Safety Integrity Level 1 the lowest safety integrity level.

SIL CL (Claim Limit)
Maximum SIL which can be utilized for an SRECS subsystem with regard to structural limitations and systematic safety integrity.

Safety function
Function of a machine whose failure may lead to a direct increase of the risk(s).

SRCF (Safety-Related Control Function)
Safety-related control function with a specified integrity level executed by the SRECS in order to maintain the machine's safe state or to prevent a direct increase of risks.

SRECS (Safety-Related Electrical Control System)
Safety-related electrical control system of a machine whose failure leads to a direct increase of risks.

SRP/CS (Safety-Related Parts of Control System)
Safety-related component of a control which responds to safety-related input signals and generates safety-related output signals.

Subsystem
Unit of the SRECS architecture draft on the topmost level. The failure of any subsystem leads to a failure of the safety-related control function.

Subsystem element
Part of a subsystem which comprises an individual component or any group of components.

Detecting

Products / **Approval (max.)**	**SIRIUS position switches, hinge switches, short-stroke switches, magnetically operated switches (contactless)**	**SIRIUS commanding and signaling devices, EMERGENCY-STOP, cable-operated switches, two-hand operation consoles, foot-operated switches, signaling columns and integrated signal lamps**	**DP/AS-i F-Link (ASIsafe solution PROFIsafe)**	**SIMATIC mobile panel 277F IWLAN**
IEC 62061 (IEC 61508)	Up to SIL 3	Up to SIL 3	Up to SIL 3	Up to SIL 3
ISO 13849-1	Up to PL 3	Up to PL e	Up to PL e	Up to PL e
EN 954-1 or IEC/EN 61496	Up to Cat. 4	Up to Cat. 4	Up to Cat. 4	Up to Cat. 4
Others			NFPA 79, NRTL-listed	
Application/ safety function	For the mechanical monitoring of protective equipment and protective door interlockings	EMERGENCY-STOP applications in the production and process industry; state signaling on machines and systems	Safe gateway for transfer of ASIsafe signals to the PROFIsafe telegram for safety applications in production automation	Machine-level operation and monitoring of production systems with safety-critical applications, realization of safety-relevant tasks, e.g. troubleshooting in running systems Safety functions: • EMERGENCY-STOP button • Two acknowledgement buttons (right/left) • Transponder identification and distance measuring for safe registration and operation
Fail-safe communication options	AS-Interface (ASIsafe)	AS-Interface (ASIsafe)	AS-Interface (ASIsafe) and PROFIBUS with PROFIsafe profile	PROFINET with PROFIsafe profile, IWLAN with PROFIsafe

Evaluating

SIRIUS 3TK28 safety relays	**ASIsafe** **1) Safe input modules** **2) Safety monitor (ASIsafe Solution local)** **3) Safe AS-i outputs**	**SIRIUS 3RK3 modular safety system**	**SIMATIC controllers**	**SIMATIC I/O**
Up to SIL 3	Up to SIL 3	Up to SIL 3	Up to SIL 3	Up to SIL 3
Up to PL e	Up to PL e	Up to PL e	Up to PL e	Up to PL e
Up to Cat. 4	Up to Cat. 4	Up to Cat. 4	Up to Cat. 4	Up to Cat. 4
NFPA 79, NRTL-listed	NFPA 79, NRTL-listed		NFPA 79, NFPA 85, NRTL-listed, IEC 61511	NFPA 79, NFPA 85, NRTL-listed, IEC 61511
• Monitoring of protective equipment, e.g. EMERGENCY-STOP commanding devices, position switches and contact-free sensors • Safe standstill monitoring: Standstill monitoring of motors without sensors • Safe speed monitoring: Three parameterizable limit values for standstill, setup speed and automatic speed, Connection option for various sensors and encoders, integrated protective door monitoring	1) Safe connection and networking of safety switches and electronic safety sensors 2) All safety applications in production automation: • Monitoring and evaluation of safe signals via AS-Interface, incl. disconnection on 1-2 enabling circuits • Optional control of safe AS-i outputs for the disconnection of motors or for the control of e.g. safe valves • Safe coupling of ASIsafe networks	Modular, parameterizable safety system for all safety applications in production automation: • Safe evaluation of mechanical and contactless protective equipment • Integrated diagnostic function • Integrated signal test and discrepancy time monitoring	Scalable, fail-safe controllers • Modular controllers: CPU315F/317F/319F CPU 414F/416F ET 200F-CPU for ET 200S and ET 200pro • Technology controllers with motion control: CPU 317TF-2DP • PC-based automation: Software controllers, embedded controllers, IPC Safety functions: • Integrated diagnostics function • Coexistence of standard and fail-safe programs on a CPU • Pre-fabricated, TÜV-certified safety modules, also for presses and burner applications • Software: S7 Distributed Safety with F-FBD and F-LAD as well as integrated library with TÜV-certified safety blocks. Optional: Library with function blocks for presses and burners	Scalable and redundant I/O systems • ET 200eco • ET 200M • ET 200iSP • ET 200S • ET 200pro Safety functions: • Integrated signal test and discrepancy time monitoring • One distributed I/O system with standard and fail-safe input and output modules • Configuration of signal test and discrepancy time visualization with STEP 7
	1) AS-Interface (ASIsafe) 2) AS-Interface (ASIsafe solution local)	Diagnostics via PROFIBUS	• PROFINET with PROFIsafe, IWLAN with PROFIsafe	• PROFIBUS with PROFIsafe profile: all systems • PROFINET with PROFIsafe profile: ET 200S, ET 200M, ET 200pro (IWLAN interface module available)

Reacting

Motor starters for **• ET 200S (IP20)** **• ET 200pro (IP65)**	**Frequency converters for:** **• ET 200S** **• ET 200pro FC**	**Frequency inverters** **1) SINAMICS G120** **2) SINAMICS G120D**	**Frequency converters** **SINAMICS G130** **SINAMICS G150**
Up to SIL 3	Up to SIL 2	Up to SIL 2	Up to SIL 2
	Up to PL d	Up to PL d	Up to PL d
Up to Cat. 4	Up to Cat. 3	Up to Cat. 3	Up to Cat. 3
NFPA 79, NRTL-listed			
All safety applications in production automation and distributed drive tasks as in conveyor technology or lifting drives • Starting and safe disconnection with conventional and electronic switching technology • Integrated motor protection • Safe selective disconnection (ET 200S) • All advantages of the systems SIMATIC ET 200S and SIMATIC ET 200pro Integrated, autonomous safety functions: • Safe torque off	System-integrated, central drive (frequency converter) on standard asynchronous motors without encoders Integrated, autonomous safety functions: • Safe torque off • Safe stop 1 • Safely limited speed	1) Modular, central, safe frequency inverter for applications from 0.37 to 250 kW 2) Distributed frequency inverter without encoder on standard induction motors Integrated, autonomous safety functions: • Safe torque off • Safe stop 1 • Safely limited speed • G120: Safe direction of rotation (in preparation) • G120: Safe brake control	Frequency converters for speed-variable individual drives from 75 to 1500 kW, e.g. pumps, fans, compressors, conveyor belts, extruders, agitators, mills Integrated safety functions: • Safe torque off • Safe stop 1
• Solution PROFIsafe: PROFIBUS/PROFINET with PROFIsafe profile • Solution local: on-site safety application	PROFIBUS/PROFINET with PROFIsafe profile	PROFIBUS/PROFINET with PROFIsafe profile	PROFIBUS/PROFINET with PROFIsafe profile

Reacting

SINAMICS S110 positioning drive	**1) Drive system SINAMICS S120** **2) Cabinet device SINAMICS S150**	**SINUMERIK 840D sl CNC control for machine tools**	**SINUMERIK 828D CNC control for machine tools**
Up to SIL 2	Up to SIL 2	Up to SIL 2	Up to SIL 2
Up to PL d	Up to PL d	Up to PL d	Up to PL d
Up to Cat. 3	Up to Cat. 3	Up to Cat. 3	Up to Cat. 3
	NFPA 79, NRTL-listed*	NFPA 79, NRTL-listed	NFPA 79, NRTL-listed
Single-axis servo drive for simple positioning applications with synchronous/induction motors with power ratings from 0.12 to 90 kW Integrated, autonomous safety functions: • Safe torque off • Safe stop 1 *** and 2 • Safe operating stop • Safely limited speed *** • Safe direction of rotation (in preparation) • Safe speed monitoring • Safe brake control	1) Drive system for high-performance control tasks from 0.12 to 4500 kW in machine and system production, e.g. for packing or plastic machines, handling devices, roller mills or paper machines 2) Demanding, speed-adjustable individual drives with high power ratings (75 to 1200 kW) such as test beds, sugar centrifuges, cross- cutters, cable winches, conveyor belts Integrated, autonomous safety functions: • Safe torque off • Safe stop 1 *** and 2 • Safe operating stop • Safely limited speed *** • S120: Booksize / blocksize: Safe direction of rotation (in preparation) • Safe speed monitoring • Safe brake control**	Numeric control with integrated safety technology in the control and drive for machine tools (rotating, milling, grinding, nibbling, ...) Safety functions: • Safe torque off • Safe stop 1 and 2 • Safe acceleration monitoring • Safe operating stop • Safely limited speed • Safely limited position • Safe brake management • Safe brake control • Safe brake test • Safe software cams • Safety-related inputs/outputs • Safe programmable logics • Integrated acceptance test	Numeric control for turning and milling machines with integrated safety technology in the drive The SINUMERIK 828D is a panel-based CNC control for demanding applications on turning and milling machines, which are typically employed in workshops. Integrated safety functions: • Safe torque off • Safe stop 1 and 2 • Safe operating stop • Safely limited speed • Safe direction of rotation (in preparation) • Safe speed monitoring • Safe brake control
PROFIBUS/PROFINET with PROFIsafe profile	PROFIBUS/PROFINET with PROFIsafe profile	PROFIBUS with PROFIsafe profile	

* Only applicable to SINAMICS S120 booksize ** Not applicable to S150 and S120 chassis devices *** Functions also possible without sensors

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