Functional Safety of Machines and Systems

Easy Implementation of the European Machinery Directive

Safety Integrated

Answers for industry.
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.

www.siemens.com/safety-evaluation-tool
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.
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 2009. 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

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 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.

The EN standard EN ISO 14121-1 contains detailed information on steps 1 to 4.
Step 2: Risk evaluation

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.

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)

<table>
<thead>
<tr>
<th>Severity of damage (Se)</th>
<th>Frequency and/or duration of stay (Fr)</th>
<th>Occurrence probability (Pr)</th>
<th>Prevention possibilities (Av)</th>
<th>Class (Cl)</th>
<th>Safety measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent, loss of finger</td>
<td>≤ 1 h</td>
<td>5</td>
<td>frequently</td>
<td>5</td>
<td>12 = 5 + 4 + 3</td>
</tr>
<tr>
<td>Reversible, medical treatment</td>
<td>&gt; 1 h to ≤ 1 day</td>
<td>5</td>
<td>probable</td>
<td>4</td>
<td>SIL 1</td>
</tr>
<tr>
<td>Reversible, first aid</td>
<td>&gt; 2 weeks to ≤ 1 year</td>
<td>4</td>
<td>possible</td>
<td>3</td>
<td>SIL 2</td>
</tr>
<tr>
<td>Reversible, medical treatment</td>
<td>&gt; 2 weeks to ≤ 1 year</td>
<td>3</td>
<td>rarely</td>
<td>2</td>
<td>SIL 3</td>
</tr>
<tr>
<td>Reversible, first aid</td>
<td>&gt; 1 year</td>
<td>2</td>
<td>negligible</td>
<td>1</td>
<td>SIL 1</td>
</tr>
</tbody>
</table>

### Procedure

1. **Determination of damage severity Se:**
   - Rotating spindle, Se = 3

2. **Determination of points for frequency Fr, occurrence probability Pr and prevention Av:**
   - Rotating spindle:
     - Frequency: 5
     - Occurrence probability: 4
     - Prevention possibility: 3
     - Cl = Se + Fr + Pr + Av = 5 + 4 + 3 = 12

3. **Total of points Fr + Pr + Av = class CI:**
   - Cl = 5 + 4 + 3 = 12

4. **Intersection point between severity Se and column Cl = required SIL:**
   - SIL 2

**The required SIL is SIL 2**
Step 2: Risk evaluation

The risk is estimated on the basis of identical risk parameters.

**Risk parameters**

\[
S = \text{Severity of injury} \\
S_1 = \text{Slight (usually reversible) injury} \\
S_2 = \text{Severe (usually irreversible) injury, including death} \\
\]

\[
F = \text{Frequency and/or duration of exposure to hazard} \\
F_1 = \text{Rare to often and/or short exposure to hazard} \\
F_2 = \text{Frequent to continuous and/or long exposure to hazard} \\
\]

\[
P = \text{Probability of avoiding or limiting harm} \\
P_1 = \text{Possible under certain conditions} \\
P_2 = \text{Hardly possible} \\
\]

\[a, b, c, d, e = \text{targets of the safety-related performance level}\]

**Procedure**

1. Determination of damage severity \(S\): \(S\_2 = \text{severe (usually irreversible) injury, including death}\)

2. Determination of frequency and/or duration of exposure to hazard \(F\): \(F\_2 = \text{frequently up to permanently and/or long exposure to hazard}\)

3. Determination of the possibility of hazard prevention or damage limiting \(P\): \(P\_1 = \text{possible under certain conditions}\)

The required performance level is PL d
Step 3: Structure of the safety function and determination of the safety integrity

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

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

**Method in acc. with EN 62061**

<table>
<thead>
<tr>
<th>SRECS</th>
<th>Subsystem detecting</th>
<th>Subsystem evaluating</th>
<th>Subsystem reacting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors</td>
<td>Composed by user or Use of certified components</td>
<td>Use of certified components</td>
<td>Use of certified components</td>
</tr>
<tr>
<td></td>
<td>Architecture selection calculation with</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• B10 value</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• C (switching cycles/h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 ... 99%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SIL 1, 2 or 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SIL 1, 2 or 3</td>
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<tr>
<td></td>
<td>Calculation with basic subsystem architectures</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Manufacturer specification</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Partial result sensors</td>
<td></td>
<td></td>
</tr>
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<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Partial result evaluation unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Partial result actuators</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The attainable SIL is derived from the lowest SIL of the partial results and the total failure probability PFH.

**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](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 section 6.7.8.2.1 of EN 62061:

\[
λ = 0.1 \times C / B10 = 0.1 \times 1/10,000,000 = 10^{-8}
\]

\[C \text{ duty cycle per hour specified by the user}
\]

\[B10 \text{ value = specified by the manufacturer (see Appendix page 18 – table B10 values)}\]

The rate of failure λ consists of safe (λs) and dangerous (λD) shares:

\[
λ = λ_s + λ_D \\
λ_D = λ^* \text{ share of failure to danger in } \% \\
= 10^{-8} \times 0.2 = 2 \times 10^{-9}
\]

(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 ($\lambda_{D}$) for the individual subsystems can be derived as follows:

$$\lambda_D = (1 - \beta)^2 \ast [(\lambda_{De})^2 \ast DC \ast T2] + [\lambda_{De}^2 \ast (1 - DC) \ast T1] + \beta \ast \lambda_{De}, = 2 \ast 10^{-10}$$

$$PFH_D = \lambda_D \ast 1 \text{ h} = 2 \ast 10^{-10}$$

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

- $\beta = 0.1$ 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
- $T1 = 87,600 \text{ h}$ 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
  - $PFH_D = 1.29 \ast 10^{-7}$

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:

$$SIL CL Mn = Minimum (SIL CL (subsystem 1) \ldots SIL CL (subsystem n)) = SIL CL 2$$

Total of probability of random hardware failure (PFH) of the subsystems

$$PFH_D = PFH_D (subsystem 1) + \ldots + PFH_D (subsystem n) = 1.30 \ast 10^{-7}$$

$$= <10^{-6} \text{ corresponds to SIL 2}$$

Result: The safety function meets the requirements of SIL 2
Step 3: Structure of the safety function and determination of the safety integrity

**Method in acc. with EN ISO 13849-1**

**SRP/CS detecting**

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Evaluation unit</th>
<th>Actuators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composed by user or Use of certified components</td>
<td>Use of certified components</td>
<td>Composed by user or Use of certified components</td>
</tr>
</tbody>
</table>

| Architecture selection calculation with | | |
| - B10 value | - C (switching cycles/h) | - B10 value |
| 0 ... 99% | PL a, b, d or e | PL a, b, d or e |
| Tabular assignment (annex K of standard) | Manufacturer specification | Tabular assignment (annex K of standard) |

**SRP/CS evaluating**

<table>
<thead>
<tr>
<th>Evaluation unit</th>
<th>Actuators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of certified components</td>
<td>Use of certified components</td>
</tr>
</tbody>
</table>

| Architecture selection calculation with | |
| - B10 value | - C (switching cycles/h) |
| 0 ... 99% | PL a, b, d or e |
| Manufacturer specification | Manufacturer specification |

**SRP/CS reacting**

<table>
<thead>
<tr>
<th>Actuators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of certified components</td>
</tr>
</tbody>
</table>

| Architecture selection calculation with | |
| - B10 value | - C (switching cycles/h) |
| 0 ... 99% | PL a, b, d or e |
| Manufacturer specification | Manufacturer specification |

The attainable PL is derived from the lowest PL of the partial results and the total failure probability PFH.

All sensors together form an SRP/CS.
All actuators together form an SRP/CS (calculation using 1/MTTFd = 1/MTTFd1 + 1/MTTFd2...).
The CCF factor is assumed to be 2% if certain criteria are fulfilled (table F.1 of standard).
The failure probability of the failsafe communication must be added if required.

**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 \( \text{MTTF}_d \) of an electromechanical component can be determined by the user as follows:

\[
\text{MTTF}_d = 810 \times 0.1 \times n_{op} = 0.2 \times 10^8 \text{ hours} = 2,300 \text{ years} \text{ corresponds to MTTF}_d = \text{high with } n_{op} = \text{actuations per year (specified by the user)}
\]

\[

n_{op} = \left( d_{op} \times h_{op} \times 3,600 \text{ s/h} \right) / 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.
Step 3: Structure of the safety function and determination of the safety integrity

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

<table>
<thead>
<tr>
<th>DC “high” via discrepancy and short-circuit monitoring</th>
<th>Category 4</th>
</tr>
</thead>
</table>

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

<table>
<thead>
<tr>
<th>Example values:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SIL CL = SIL 3, complies with PL e</td>
<td></td>
</tr>
<tr>
<td>$PFH_0 = &lt; 10^{-6}$</td>
<td></td>
</tr>
</tbody>
</table>

**SRP/CS “reacting” – actuators**

For certified components, the manufacturer supplies the required values.

<table>
<thead>
<tr>
<th>Example values:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SIL CL = SIL 2, complies with PL d</td>
<td></td>
</tr>
<tr>
<td>$PFH_0 = 1.29 \times 10^{-7}$</td>
<td></td>
</tr>
</tbody>
</table>

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:

\[
PL_{Mn} = \text{minimum}\ (PL\ (\text{SRP/CS} \ 1) \ldots \ldots PL\ (\text{SRP/CS} \ n)) = PL\ d
\]

\[
\text{Total of probability of random hardware failure (PFH) of SRP/CS}
PFH = PFH\ (\text{SRP/CS} \ 1) + \ldots + PFH\ (\text{SRP/CS} \ n) = 1.74 \times 10^{-7} = <10^{-6}\ \text{corresponds to PL } d
\]

**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:

<table>
<thead>
<tr>
<th>Category</th>
<th>B</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC_avg</td>
<td>none</td>
<td>none</td>
<td>low</td>
<td>medium</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td>MTTF_d of each channel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>low</td>
<td>a</td>
<td>not covered</td>
<td>a</td>
<td>b</td>
<td>b</td>
<td>c</td>
</tr>
<tr>
<td>medium</td>
<td>b</td>
<td>not covered</td>
<td>b</td>
<td>c</td>
<td>c</td>
<td>d</td>
</tr>
<tr>
<td>high</td>
<td>not covered</td>
<td>c</td>
<td>c</td>
<td>d</td>
<td>d</td>
<td>d</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>SIL and PL are mutually transferable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety integrity level</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>~</td>
</tr>
<tr>
<td>SIL 1</td>
</tr>
<tr>
<td>SIL 1</td>
</tr>
<tr>
<td>SIL 2</td>
</tr>
<tr>
<td>SIL 3</td>
</tr>
</tbody>
</table>
Step 4: Validation

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)

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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).

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

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

\( \beta \), Beta
Factor of failure due to common cause (CCF faktor: common cause failure factor \( \beta \)) (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.

\( B10d \)
\( B10d = B10 / \text{ratio of dangerous failures} \)

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. \( MTTF \), DC and CCF). Using a simplified procedure on the basis of the categories as “designated architectures”, the attained PL (Performance Level) can be assessed.

\( \lambda \), Lambda
Rate of failure derived from rate of safe failures (\( \lambda_s \)) and the rate of failure to danger (\( \lambda_d \)).

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 \( MTTF = 1 / \lambda \), with \( \lambda_d \) 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\(_e\) (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.

SRPICS (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.
## Products

<table>
<thead>
<tr>
<th>Products</th>
<th>SIMATIC sensors light barriers</th>
<th>SIMATIC sensors light curtains</th>
<th>SIMATIC sensors laser scanners</th>
<th>SIRIUS position switches, hinge switches, short-stroke switches, magnetically operated switches (contactless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approval</td>
<td>Cat. 2 and 4 in acc. with EN 954-1 or type 2 and 4 in acc. with IEC/EN 61496</td>
<td>Cat. 2 and 4 in acc. with EN 954-1 or type 2 and 4 in acc. with IEC/EN 61496</td>
<td>Up to cat. 3 in acc. with EN 954-1 or type 3 in acc. with IEC/EN 61496-1, -3, SIL 2 acc. to IEC 61508, PL d and e acc. to ISO 13849-1, NRTL-listed</td>
<td>Up to cat. 4 in acc. with EN 954-1, Up to SIL 3 in acc. with IEC 61508, Up to PL e in acc. with EN ISO 13849-1</td>
</tr>
<tr>
<td>Application/safety function</td>
<td>Electro-sensitive protective equipment for the protection of hazardous areas, hazardous locations and access points</td>
<td>Electro-sensitive protective equipment for the protection of hazardous areas</td>
<td>Electro-sensitive protective equipment for the protection of hazardous areas in mobile and stationary systems</td>
<td>For the mechanical monitoring of protective equipment and protective door interlockings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Particularly fail-safe and highly available due to specifically developed, integrated circuits (ASICs) and intelligent evaluation method</td>
<td>• Vertical and horizontal protection</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Extended functionalities: blanking, muting, clock control</td>
<td>• Flexible protection field parameterization</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Additional versions for</td>
<td>• Ranges of up to 6.25 m</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• Small protection zones</td>
<td>• Up to 8 different protection fields</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Motion monitoring of transfer carriages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail-safe communication options</td>
<td>AS-Interface (ASIsafe) and PROFIBUS with PROFIsafe profile</td>
<td>AS-Interface (ASIsafe) and PROFIBUS with PROFIsafe profile</td>
<td>AS-Interface (ASIsafe)</td>
<td></td>
</tr>
<tr>
<td>Product</td>
<td>Description</td>
<td>Compliance</td>
<td>Features</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
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<td></td>
</tr>
<tr>
<td>SIRIUS EMERGENCY-STOP switches, cable-operated switches, two-hand operation consoles, foot switches, signaling columns and integrated signal lamps</td>
<td>Up to cat. 4 in acc. with EN 954-1; Up to SIL 3 in acc. with IEC 61508; Up to PL e in acc. with EN ISO 13849-1</td>
<td>Safe gateway for transfer of ASIsafe signals to the PROFIsafe telegram for safety applications in production automation</td>
<td>EMERGENCY-STOP applications in the production and process industry; state signaling on machines and systems</td>
<td></td>
</tr>
<tr>
<td>DP/AS-i F-Link (ASIsafe solution PROFIsafe)</td>
<td>Up to cat. 4 in acc. with EN 954-1; Up to SIL 3 in acc. with IEC 61508; Up to PL e in acc. with EN ISO 13849-1</td>
<td>Machine-level operation and monitoring of production systems with safety-critical applications, realization of safety-relevant tasks, e.g. troubleshooting in running systems</td>
<td>Machine-level operation and monitoring of production systems with safety-critical applications, realization of safety-relevant tasks, e.g. troubleshooting in running systems</td>
<td></td>
</tr>
<tr>
<td>SIMATIC mobile panel 277F IWLAN</td>
<td>Up to cat. 4 in acc. with EN 954-1; Up to SIL 3 in acc. with IEC 61508; Up to PL e in acc. with EN ISO 13849-1</td>
<td>Monitoring of protective equipment, e.g. EMERGENCY-STOP commanding devices, position switches and non-contact sensors; safe motion monitoring (e.g. safe standstill monitoring)</td>
<td>Monitoring of protective equipment, e.g. EMERGENCY-STOP commanding devices, position switches and non-contact sensors; safe motion monitoring (e.g. safe standstill monitoring)</td>
<td></td>
</tr>
<tr>
<td>SIRIUS 3TK28 safety relays</td>
<td>Up to cat. 4 in acc. with EN 954-1; Up to SIL 3 in acc. with IEC 61508; Up to PL e in acc. with EN ISO 13849-1</td>
<td>Safe connection of safety switches and electronic safety sensors such as light curtains</td>
<td>Safe connection of safety switches and electronic safety sensors such as light curtains</td>
<td></td>
</tr>
<tr>
<td>ASIsafe 1) safe modules 2) safety monitor (ASIsafe solution local)</td>
<td>Up to cat. 4 in acc. with EN 954-1; Up to SIL 3 in acc. with IEC 61508; Up to PL e in acc. with EN ISO 13849-1</td>
<td>Safe connection of safety switches and electronic safety sensors such as light curtains</td>
<td>Safe connection of safety switches and electronic safety sensors such as light curtains</td>
<td></td>
</tr>
</tbody>
</table>

**AS-Interface (ASIsafe)**

- AS-Interface (ASIsafe) and PROFIBUS with PROFIsafe profile
- PROFINET with PROFIsafe profile
- 1) AS-Interface (ASIsafe)
- 2) AS-Interface (ASIsafe Solution local)
### Evaluating

**SIRIUS 3RK3 modular safety system**

- **SIMATIC controllers**
  - Up to cat. 4 in acc. with EN 954-1
  - Up to SIL 3 in acc. with IEC 61508/62061
  - Up to PL e in acc. with EN ISO 13849-1

- **SIMATIC I/O**
  - Up to cat. 4 in acc. with EN 954-1
  - Up to SIL 3 in acc. with IEC 61508/62061
  - Up to PL e in acc. with EN ISO 13849-1

- **Motor starters for:**
  - ET 200S (IP20)
  - ET 200pro (IP65)

- **Frequency converters for:**
  - ET 200S
  - ET 200pro FC

---

**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
- Embedded automation*
- PC-based controllers*

**Safety functions:**
- Integrated diagnostics function and self-test routine
- The application can be flexibly and safely switched to and maintained in a safe state upon fault occurrence
- Coexistence of standard and fail-safe programs on a CPU
- Pre-fabricated, TÜV-certified safety modules, also for presses and burner applications
- Software: STEP 7 FUP, KOP, S7 Distributed Safety

**Scalable and redundant I/O systems**
- ET 200eco
- ET 200M
- 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

**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

**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

**Diagnostics via PROFIBUS**
- PROFIBUS with PROFlsafe
- PROFINET with PROFlsafe, IWLAN with PROFlsafe

**Solution PROFlsafe:**
- PROFIBUS/PROFINET with PROFlsafe profile
- Solution local: on-site safety application

**PROFIBUS/PROFINET with PROFlsafe profile**

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* TÜV concept approval
### Frequency Converters

<table>
<thead>
<tr>
<th>Models</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) SINAMICS G120</td>
<td>Modular, central, safe frequency converter for applications from 0.37 to 90 kW</td>
</tr>
<tr>
<td>2) SINAMICS G120D</td>
<td>Distributed frequency converter on standard asynchronous motors without encoders</td>
</tr>
</tbody>
</table>

#### Integrated, autonomous safety functions:
- Safe torque off
- Safe stop 1
- Safely limited speed (only with SINAMICS G120)

<table>
<thead>
<tr>
<th>Models</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) SINAMICS G130</td>
<td>Frequency converters for speed-variable individual drives from 75 to 1500 kW, e.g. pumps, fans, compressors, conveyer belts, extruders, agitators, mills</td>
</tr>
<tr>
<td>2) SINAMICS G150</td>
<td>Single-axis servo drive for simple positioning applications</td>
</tr>
</tbody>
</table>

#### Integrated safety functions:
- Safe torque off
- Safe stop 1
- Safely limited speed
- Safe speed monitoring
- Safe brake control

### Drive System for Motion Control and High-Performance Applications

<table>
<thead>
<tr>
<th>Models</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) SINAMICS S120</td>
<td>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</td>
</tr>
<tr>
<td>2) SINAMICS S150</td>
<td>Demanding, speed-adjustable individual drives with high power ratings (75 to 1200 kW) such as test beds, sugar centrifuges, crosscutters, cable winches, conveyer belts</td>
</tr>
</tbody>
</table>

#### Integrated, autonomous safety functions:
- Safe torque off
- Safe stop 1 and 2
- Safely limited speed
- Safe speed monitoring
- Safe brake control
- Safe acceleration monitoring

### SINUMERIK 840D sl CNC Control for Machine Tools

<table>
<thead>
<tr>
<th>Models</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to cat. 3 in acc. with EN 954-1 Up to SIL 2 in acc. with IEC 61508 NFPA 79 and 85, NRTL-listed</td>
<td>Numeric control with integrated safety technology in control and drive for machine tools, e.g. for protection during setup operation</td>
</tr>
<tr>
<td>Up to cat. 3 in acc. with EN 954-1; PL d in acc. with IEC 61508 Up to SIL 2 in acc. with IEC 61508 NFPA 79, NRTL-listed**</td>
<td>Safety functions:</td>
</tr>
</tbody>
</table>
- Safe torque off
- Safe stop 1 and 2
- Safely limited position
- Safe brake management
- Safe brake test
- Safe software cams
- Safety-related inputs/outputs
- Safe programmable logics
- Integrated acceptance test

#### PROFIBUS/PROFINET with PROFIsafe profile

** Only applicable to S120 booksize! **
The information provided in this brochure contains merely general descriptions or characteristics of performance which in actual case of use do not always apply as described or which may change as a result of further development of the products. An obligation to provide the respective characteristics shall only exist if expressly agreed in the terms of contract.

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Safety Integrated

Answers for industry.