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**Adjustable speed electrical power drive systems –
Part 5-3: Safety requirements – Functional, electrical and environmental
requirements for encoders**

**Entraînements électriques de puissance à vitesse variable –
Partie 5-3: Exigences de sécurité – Exigences fonctionnelle, électrique et
environnementale pour codeurs**



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IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS –**Part 5-3: Safety requirements –
Functional, electrical and environmental requirements for encoders**

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The text of this International Standard is based on the following documents:

FDIS	Report on voting
22G/431/FDIS	22G/434/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

Terms in *italics* are defined in Clause 3.

A list of all parts in the IEC 61800 series, published under the general title *Adjustable speed electrical power drive systems*, can be found on the IEC website.

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INTRODUCTION

As a result of automation, demand for increased production and reduced operator physical effort, control systems of machinery and plant items play an increasing role in the achievement of overall safety. These control systems increasingly employ complex electrical/electronic/programmable electronic devices and systems.

Prominent amongst these devices and systems are *encoder* which are for example applied to measure angle and position of machine parts for use in safety-related applications (*Encoder(SR)*). Based on the *Encoder(SR)*'s output signals, *PDS(SR)* or other *evaluation units* calculate for example speed, acceleration, absolute position, etc., to perform their safety sub-functions SLS, SLA, SLP and others (see IEC 61800-5-2:2016, Clause 4). The *signal processing* necessary to perform some of these *safety sub-functions* may also be included in the *Encoder(SR)*.

Examples of industrial applications are:

- machine tools, robots, production test equipment, test benches;
- papermaking machines, textile production machines, calendars in the rubber industry;
- plastics processing lines, chemicals or metal production lines, rolling-mills;
- cement crushing machines, cement kilns, mixers, centrifuges, extrusion machines;
- drilling machines;
- conveyors, materials handling machines, hoisting equipment (cranes, gantries, etc.);
- pumps, fans, etc.

This document can also be used as a reference for developers using *Encoder(SR)* for other applications, for example in wind power plants.

Users of this document should be aware that some type C standards for machinery currently refer to ISO 13849-1 for safety-related control systems. In this case, *Encoder(SR)* manufacturers may be requested to provide further information (e.g. category and *performance level PL*) to facilitate the integration of an *Encoder(SR)* into the safety-related control systems of such machinery. This has been considered during development of this document and corresponding indications are included where appropriate.

NOTE "Type C standards" are defined in ISO 12100 [1] as machine safety standards dealing with detailed safety requirements for a particular machine or group of machines.

There are many situations where control systems that incorporate *Encoder(SR)* are employed, for example as part of safety measures that have been provided to achieve risk reduction. A typical case is reducing the speed during start-up in order to protect personnel from hazards arising by unexpected fast movements of machine parts. This document gives a methodology to identify the contribution made by an *Encoder(SR)* to identified safety *sub-functions* and to enable the appropriate design of the *Encoder(SR)* and verification that it achieves the required performance.

Measures are given to co-ordinate the safety performance of the *Encoder(SR)* with the intended risk reduction taking into account the probabilities and consequences of its random and systematic *faults*.

ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS –

Part 5-3: Safety requirements – Functional, electrical and environmental requirements for encoders

1 Scope

This part of IEC 61800, which is a product standard, specifies requirements and makes recommendations for the design and development, integration and validation of safety-related *encoder* (*Encoder(SR)*) in terms of their *functional safety* considerations, electrical safety and environmental conditions. It applies to *Encoder(SR)*, being sensors as part of a *PDS(SR)*.

NOTE 1 The term "integration" refers to the *Encoder(SR)* itself, not to its incorporation into the safety-related application.

This document can also be referred to and used for *Encoder(SR)* in any other safety-related application, for example safety-related position monitoring.

NOTE 2 This document specifies only complementary *functional safety*, electrical safety and environmental condition requirements that are not clearly provided by other parts of the IEC 61800 series.

This document is applicable where *functional safety* of an *encoder* is claimed and the *Encoder(SR)* is operating mainly in the high demand or continuous mode.

NOTE 3 While low demand mode operation is possible for an *Encoder(SR)*, this document concentrates on high demand and continuous mode. *Safety sub-functions* implemented for high demand or continuous mode can also be used in low demand mode. Requirements for low demand mode are given in IEC 61508 (all parts) [2]. Some guidance for the estimation of average probability of *dangerous failure* on demand (PFD_{avg}) value is provided in IEC 61800-5-2:2016, Annex F.

The requirements of IEC 61800-5-2:2016 for *PDS(SR)* apply to *Encoder(SR)* as applicable. This document includes additional or different requirements for *Encoder(SR)*. It sets out safety-related considerations of *Encoder(SR)* in terms of the framework of IEC 61508 (all parts), and introduces requirements for *Encoder(SR)* as subsystems of a safety-related system. It is intended to facilitate the realisation of the electrical/electronic/programmable electronic (E/E/PE) and mechanical parts of an *Encoder(SR)* in relation to the safety performance of *safety sub-function(s)* of an *Encoder(SR)*.

Manufacturers and suppliers of *Encoder(SR)* will, by using the normative requirements of this document, indicate to users (system integrator, original equipment manufacturer) the safety performance of the *Encoder(SR)*. This will facilitate the incorporation of *Encoder(SR)* into safety-related control systems using the principles of IEC 61508 (all parts), and possibly its specific sector implementations (for example IEC 61511 (all parts) [3], IEC 61513 [4], IEC 62061 [5] or ISO 13849-1 and ISO 13849-2 (see Clause 2).

By applying the requirements from this document, the corresponding requirements of IEC 61508 (all parts) that are necessary for an *Encoder(SR)* are fulfilled.

This document does not specify requirements for:

- the functional properties of an *Encoder(SR)* without any safety relevance;
- the *hazard* and risk analysis of a particular application;
- the identification of *safety sub-functions* for that application;
- the initial allocation of *SILs* to those *safety sub-functions*;
- the driven equipment except for interface arrangements;

- secondary *hazards* (for example from failure in a production or manufacturing process);
- the *Encoder(SR)* manufacturing process;
- the validity of signals and commands to the *Encoder(SR)*; and
- security aspects (e.g. cyber security or *Encoder(SR)* security of access).

NOTE 4 The *functional safety* requirements of an *Encoder(SR)* are dependent on the application, and can be considered as a part of the overall risk assessment of the installation. Where the supplier of the *Encoder(SR)* is not responsible for the driven equipment, the installation designer is responsible for the risk assessment, and for specifying the functional and safety integrity requirements of the *Encoder(SR)*.

This document applies to *Encoder(SR)* implementing *safety sub-functions* with a *SIL* not greater than *SIL* 3.

This document provides additional information for *Encoder(SR)* claiming conformity with ISO 13849-1:2015.

Figure 1 shows the installation and the functional parts of a *PDS(SR)* including the *Encoder(SR)* (sensor) which is considered in this document.

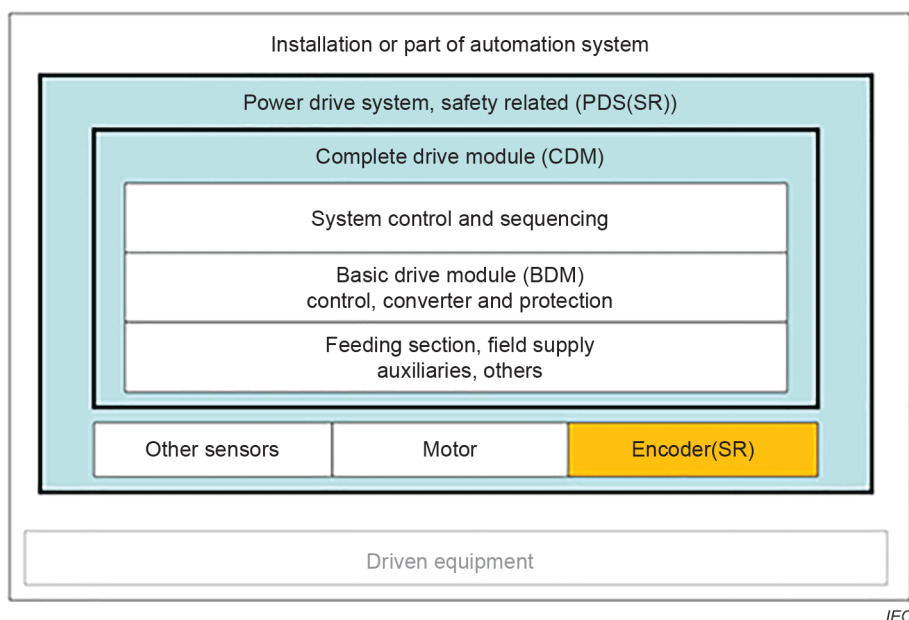


Figure 1 – Context of *Encoder(SR)*

Figure 1 shows a logical representation of a *PDS(SR)* rather than its physical description.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068-2-1, *Environmental testing – Part 2-1: Tests – Test A: Cold*

IEC 60068-2-47, *Environmental testing – Part 2-47: Tests – Mounting of specimens for vibration, impact and similar dynamic tests*

IEC 60335-1, *Household and similar electrical appliances – Safety – Part 1: General requirements*

IEC 60947-5-2:2019, *Low-voltage switchgear and controlgear – Part 5-2: Control circuit devices and switching elements – Proximity switches*

IEC 61000-6-7:2014, *Electromagnetic compatibility (EMC) – Part 6-7: Generic standards – Immunity requirements for equipment intended to perform functions in a safety-related system (functional safety) in industrial locations*

IEC 61508-2:2010, *Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 2: Requirements for electrical/electronic/programmable electronic safety-related systems*

IEC 61800-1:1997, *Adjustable speed electrical power drive systems – Part 1: General requirements – Rating specifications for low voltage adjustable speed d.c. power drive systems*

IEC 61800-5-1:2007, *Adjustable speed electrical power drive systems – Part 5-1: Safety requirements – Electrical, thermal and energy*
IEC 61800-5-1:2007/AMD1:2016

IEC 61800-5-2:2016, *Adjustable speed electrical power drive systems – Part 5-2: Safety requirements – Functional*

IEC 62368-1:2018, *Audio/video, information and communication technology equipment – Part 1: Safety requirements*

ISO 13849-1:2015, *Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design*

ISO 13849-2:2012, *Safety of machinery – Safety-related parts of control systems – Part 2: Validation*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

Table 1 shows a list of terms and definitions.

Table 1 – List of terms

3.1	<i>encoder</i>	3.19	<i>functional safety FS</i>
3.2	<i>Encoder(SR)</i>	3.20	<i>safety function</i>
3.3	<i>interface unit</i>	3.21	<i>safety sub-function</i>
3.4	<i>evaluation unit</i>	3.22	<i>fault</i>
3.5	<i>PDS(SR)</i>	3.23	<i>dangerous failure</i>
3.6	<i>tolerance range</i>	3.24	<i>hardware fault tolerance HFT</i>
3.7	<i>interpolation</i>	3.25	<i>single-fault tolerance</i>
3.8	<i>solid measure</i>	3.26	<i>safety integrity level SIL</i>
3.9	<i>mechanical fastening</i>	3.27	<i>SIL capability</i>
3.10	<i>mechanical connecting element</i>	3.28	<i>performance level PL</i>
3.11	<i>shaft-rotor coupling</i>	3.29	<i>diagnostic coverage DC</i>
3.12	<i>stator coupling</i>	3.30	<i>safe failure fraction SFF</i>
3.13	<i>bearing blockage</i>	3.31	<i>average frequency of a dangerous failure PFH</i>
3.13.1	<i>spontaneous bearing blockage</i>	3.32	<i>mean time to dangerous failure MTTF_D</i>
3.13.2	<i>gradual bearing blockage</i>	3.33	<i>process safety time</i>
3.14	<i>measurement point for working temperature</i>	3.34	<i>ideal fault detection</i>
3.15	<i>working temperature range</i>	3.35	<i>quantitative FMEDA</i>
3.16	<i>extra low voltage ELV</i>	3.36	<i>qualitative FMEDA</i>
3.17	<i>protective ELV circuit PELV circuit</i>	3.37	<i>signal evaluation</i>
3.18	<i>decisive voltage class DVC</i>	3.38	<i>signal processing</i>

3.1 encoder

electromechanical device that generates an analogue or digital output signal in response to the position of a moveable part

Note 1 to entry: Within this document, the definition of "*encoder*" includes resolvers and all types of motor feedback sensors.

Note 2 to entry: Annex A includes examples of type of *encoder*.

3.2 Encoder(SR)

encoder providing *safety sub-function(s)*

Note 1 to entry: The *safety sub-function(s)* of the *Encoder(SR)* allow(s) execution of safety sub-functions of a *PDS(SR)* or any other safety application.

Note 2 to entry: This definition has been derived from IEC 61800-5-2:2016, 3.16.

3.3 interface unit

separate electronic subassembly of the *Encoder(SR)* for signal conversion

Note 1 to entry: The functionality of the *interface unit* may be integrated in the *Encoder(SR)*.

3.4

evaluation unit

external item of equipment in which the output signal of the *Encoder(SR)* is evaluated

Note 1 to entry: Examples for *evaluation units* are *PDS(SR)*, safety elements for monitoring speed or stoppages.

Note 2 to entry: The *evaluation unit* may also perform diagnostic measures for the *Encoder(SR)*.

3.5

PDS(SR)

adjustable speed electrical power drive system providing safety sub-functions

[SOURCE: IEC 61800-5-2:2016, 3.16]

3.6

tolerance range

span between upper and lower tolerance limit

Note 1 to entry: The *tolerance range* is expressed in measuring units and is applied to *Encoder(SR)* with analogue and digital output signals.

Note 2 to entry: Tolerance range $T(R)$ is usually given in the form $T(R)$: $-X$ to $+Y$, with $T(R) = X + Y$; (e.g. -5 mm to $+5$ mm, 0° to $+10^\circ$, etc.).

Note 3 to entry: The tolerance range should take into account accuracy and resolution.

3.7

interpolation

mathematical method for resolution enhancement

EXAMPLE Forming the arc tangent of the ratio of analogue sine and cosine signal (A/B-signals).

3.8

solid measure

component providing encoded pattern used to determine a mechanical position

EXAMPLE Optical disc, magnetic strip.

Note 1 to entry: Other terms for *solid measure* are scale, disc, ring, strip.

3.9

mechanical fastening

mechanical connection for load transmission between constructional elements or attachment of constructional elements

Note 1 to entry: Load transmission can for example happen

- between stator of the motor and stator of the *Encoder(SR)*,
- between shaft of the motor and shaft of the rotary *Encoder(SR)*,
- between fixed part of the machine and fixed part of the *Encoder(SR)*, or
- between moving part of the machine and moving part of the *Encoder(SR)*.

Note 2 to entry: Load transmission can also happen within the *Encoder(SR)*.

Note 3 to entry: *Mechanical fastenings* are typically realized by bolted joints, fitting keys and key and slot joints.

3.10

mechanical connecting element

rigid or flexible mechanical part used to transmit load between *mechanical fastenings*

Note 1 to entry: *Mechanical connecting elements* are usually designated as couplings.

Note 2 to entry: Couplings may also provide compensation for mechanical tolerances during attachment or operation.

Note 3 to entry: Couplings are usually designated as *shaft-rotor coupling* or as *stator coupling*.

3.11

shaft-rotor coupling

connecting element between the shaft of a rotary *Encoder(SR)* and a driven shaft

Note 1 to entry: The *shaft-rotor coupling* is located between the ends of shafts.

Note 2 to entry: The *shaft-rotor coupling* has the task of compensating for mechanical tolerances during attachment or operation.

Note 3 to entry: The *shaft-rotor coupling* is typically realized as bellow coupling, jaw type coupling, slit type coupling, or lamina type coupling.

3.12

stator coupling

part of a rotary *Encoder(SR)* used to fix the *Encoder(SR)* with regards to a mounting point

Note 1 to entry: The *stator coupling* has the task of compensating for mechanical tolerances during attachment or operation.

Note 2 to entry: The *stator coupling* is fastened to flange or housing.

Note 3 to entry: The *stator coupling* is also known as "torque support".

Note 4 to entry: The *stator coupling* can also be located within the *Encoder(SR)*.

3.13

bearing blockage

situation where the torque necessary for the rotation of the bearing is causing the *Encoder(SR)* to be exposed to forces or torques higher than taken into account during design and development

3.13.1

spontaneous bearing blockage

suddenly occurring *bearing blockage* without any changes to the bearing properties in advance

Note 1 to entry: *Fault* detection prior to the *spontaneous bearing blockage* is not possible.

3.13.2

gradual bearing blockage

slowly occurring *bearing blockage* with preceding change in bearing properties

Note 1 to entry: It might be possible to detect the *fault* in time and set to safe state before the bearing becomes blocked.

Note 2 to entry: A *gradual bearing blockage* can be the result of wear or fatigue.

3.14

measurement point for working temperature

point on the surface of the *Encoder(SR)* for measuring the working temperature

3.15

working temperature range

temperature limits between which the measuring value does not exceed the given fault limits

3.16

extra low voltage

ELV

voltage not exceeding 50 V AC RMS and 120 V DC

Note 1 to entry: RMS ripple voltage of not more than 10 % of the DC component.

[SOURCE: IEC 61800-5-1:2007, 3.9, modified – Note 2 has been deleted.]

3.17

protective ELV circuit

PELV circuit

electrical circuit with the following characteristics:

- the voltage does not continuously exceed *ELV* under single *fault* as well as during normal conditions;
- protective separation from circuits other than *PELV* or *SELV*;
- provisions for earthing of the *PELV circuit*, or its accessible conductive parts, or both

[SOURCE: IEC 61800-5-1:2007, 3.21]

3.18

decisive voltage class

DVC

classification of voltage range used to determine the protective measures against electric shock

Note 1 to entry: According to IEC 61800-5-1:2007, Table 3, the voltage limits of *DVC A* are 25 V AC, 35,4 V AC_{peak} and 60 V DC.

[SOURCE: IEC 61800-5-1:2007, 3.7; modified – Note 1 to entry has been added.]

3.19

functional safety

FS

part of the overall safety relating to the *Encoder(SR)* which depends on the correct functioning of the *safety-related parts of the Encoder(SR)* and on external risk reduction measures

Note 1 to entry: This document only considers those aspects in the definition of *functional safety* that depend on the correct functioning of the *Encoder(SR)*.

[SOURCE: IEC 61800-5-2:2016; 3.11, modified – The abbreviated term "FS" has been added, and the word "*PDS(SR)*" has been replaced with *Encoder(SR)*.]

3.20

safety function

function to be implemented by a safety-related system or other risk reduction measures, that is intended to achieve or maintain a safe state for the equipment or machinery, in respect of a specific hazardous event

[SOURCE: IEC 61800-5-2:2016, 3.22, modified – The words "driven by the *PDS(SR)*" have been deleted.]

3.21

safety sub-function

function(s) with a specified safety performance, to be implemented in whole or in part by an *Encoder(SR)*, which is (are) intended to maintain the safety of the installation or prevent *hazardous* conditions arising at the installation

Note 1 to entry: There are only rare cases where the *safety function* of the complete application is implemented exclusively within the *Encoder(SR)*. In these cases, the *safety function* is still called a *safety sub-function* in this document.

[SOURCE: IEC 61800-5-2:2016, 3.23, modified – The words "*PDS(SR)*" have been replaced by "*Encoder(SR)*". The words "<of a *PDS(SR)*>" and the example in the Note to entry have been deleted.]

3.22**fault**

abnormal condition that may cause a reduction in, or loss of, the capability of a functional unit to perform a required function

[SOURCE: IEC 61508-4:2010, 3.6.1, modified – The note has been deleted.]

3.23**dangerous failure**

failure of a component and/or subsystem and/or system that plays a part in implementing the *safety sub-function* that:

- causes a *safety sub-function* of an *Encoder(SR)* to fail such that the equipment or machinery is put into a hazardous or potentially hazardous state; or
- decreases the probability that the *safety sub-function* operates correctly

[SOURCE: IEC 61800-5-2:2016, 3.5, modified – The word "*PDS(SR)*" has been replaced by "*Encoder(SR)*", and the words "driven by the *PDS(SR)*" have been deleted.]

3.24**hardware fault tolerance****HFT**

ability of an *Encoder(SR)* to continue to perform a required function in the presence of hardware *faults* or errors

Note 1 to entry: According to IEC 61800-5-2:2016, the *HFT* yields requirements for the diagnostic test interval. In addition, the *HFT* in 6.2.3.1 of IEC 61800-5-2:2016 is one of the attributes used for determining an upper limit for the *safety integrity level (SIL)*.

Note 2 to entry: This definition has been derived from IEC 61508-4:2020, 3.6.3.

3.25**single-fault tolerance**

ability of a functional unit to continue to perform a required function in the presence of one *fault* or error

[SOURCE: IEC 61508-4:2010, 3.6.3, modified – The word "single-" has been added in the term, and the words "*faults* or errors" have been replaced with "one *fault* or error".]

3.26**safety integrity level****SIL**

discrete level (one out of a possible three) for specifying the safety integrity requirements of a *safety sub-function* allocated (in whole or in part) to an *Encoder(SR)*

Note 1 to entry: *SIL* 3 has the highest level of safety integrity and *SIL* 1 has the lowest.

Note 2 to entry: *SIL* 4 is not considered in this document as it is not relevant to the risk reduction requirements normally associated with *Encoder(SR)*s. For requirements applicable to *SIL* 4, see IEC 61508.

Note 3 to entry: Several methods of writing are used for *SIL*x. Throughout this document *SIL* x is used.

[SOURCE: IEC 61800-5-2:2016; 3.25, modified – The word "*PDS(SR)*" has been replaced by "*Encoder(SR)*" and Note 4 to entry deleted.]

3.27**SIL capability**

maximum *SIL* that can be claimed to have been achieved by the design of an *Encoder(SR)* in terms of the systematic safety integrity and the architectural constraints on hardware safety integrity

Note 1 to entry: Each of the designated *safety sub-functions* that an *Encoder(SR)* is intended to perform can be associated with a different *SIL capability*.

Note 2 to entry: *SIL capability* includes systematic capability, the fulfilment of the architectural constraints and the hardware failure rate or *PFH* value.

[SOURCE: IEC 61800-5-2:2016, 3.28, modified: – The word "*PDS(SR)*" has been replaced by "*Encoder(SR)*".]

3.28 performance level PL

discrete level used to specify the ability of safety-related parts of control systems to perform a *safety function* under foreseeable conditions

Note 1 to entry: See ISO 13849-1:2015, 4.5.1.

[SOURCE: ISO 13849-1:2015, 3.1.23]

3.29 diagnostic coverage DC

fraction of *dangerous failures* detected by automatic diagnostic tests

Note 1 to entry: This can also be expressed as the ratio of the sum of the detected *dangerous failure* rates λ_{DD} to the sum of the total *dangerous failure* rates λ_D : $DC = \Sigma\lambda_{DD}/\Sigma\lambda_D$.

Note 2 to entry: *Diagnostic coverage* can exist for the whole or parts of a safety-related system. For example, *diagnostic coverage* can exist for sensors and/or logic *subsystems* and/or output *subsystem*.

[SOURCE: IEC 61800-5-2:2016, 3.6, modified – Note 3 to entry has been deleted.]

3.30 safe failure fraction SFF

property of a safety-related component and subsystems that is defined by the ratio of the sum of the average failure rates of safe and dangerous detected failures to the sum of safe and all *dangerous failures*

Note 1 to entry: This ratio is represented by the equation: $SFF = (\Sigma\lambda_S + \Sigma\lambda_{DD})/(\Sigma\lambda_S + \Sigma\lambda_D)$.

Note 2 to entry: See Annex C of IEC 61508-2:2010.

[SOURCE: IEC 61800-5-2:2016, 3.20, modified – Note 3 to entry has been deleted.]

3.31 average frequency of a dangerous failure PFH

average frequency of a *dangerous failure* of an *Encoder(SR)* to perform the specified *safety sub-function* over a given period of time

Note 1 to entry: In IEC 62061, the abbreviation PFH_D is used.

[SOURCE: IEC 61800-5-2:2016, 3.17, modified – The word "*PDS(SR)*" has been replaced by "*Encoder(SR)*" and Note 2 to entry deleted.]

3.32 mean time to dangerous failure MTTF_D

expectation of the mean time to dangerous failure

[SOURCE: ISO 13849-1:2015; 3.1.25]

3.33

process safety time

period of time between a failure of the *Encoder(SR)* that has the potential to cause a hazardous event and the point in time at which action has to be completed to prevent the hazardous event from occurring

[SOURCE: IEC 61508-4:2010, 3.6.20, modified – The wording has been simplified.]

3.34

ideal fault detection

detection of all *dangerous failures* and achievement of a safe state within the *process safety time*

Note 1 to entry: "*Ideal fault detection*" is a method that is applied to impart the property of *single-fault tolerance* to (sub-) systems that have a *HFT* of 0. *Single-fault tolerance* is a necessary condition for categories 3 and 4 according to ISO 13849-1. A detailed description of *ideal fault detection* is included in Annex J.

3.35

quantitative FMEDA

systematic analysis technique to obtain function block failure rates, failure modes and diagnostic capability

Note 1 to entry: The *quantitative FMEDA* (failure modes, effects and diagnostics analysis) provides the input data for quantification (calculation of *PFH*, *SFF*, *MTTF_D* (if conformity with ISO 13849-1:2015 is claimed)). It is carried out separately for each function block and divides the failure rates for all the components contained in the block separately into safe (S), dangerous (D), dangerous detectable (DD) and dangerous undetectable (DU).

3.36

qualitative FMEDA

systematic analysis technique to obtain systematic failures of function blocks

Note 1 to entry: *Qualitative FMEDA* (failure modes, effects and diagnostics analysis) is used for revealing possible systematic effects and scenarios that could impair the performance of the *safety sub-function*. For all components, it verifies that failures with a detrimental effect on the *safety sub-function* are detected and are mastered by the specified diagnostics and that, in the case in question, a certain failure can be justifiably excluded. FMEDA is used particularly for verification of the *single-fault tolerance* of an *Encoder(SR)* (see 8.4).

Note 2 to entry: In connection with static analysis (see Annex L), *qualitative FMEDA* is used for verifying that all potential *fault* scenarios are mastered by the specified diagnostics (see Clause L.7).

3.37

signal evaluation

evaluation of the output signals of the *Encoder(SR)* for the purpose of executing a *safety function*

Note 1 to entry: See also 3.38.

3.38

signal processing

signal evaluation and integrity test of the output signals for the detection of *faults* in the *Encoder(SR)* (diagnostics)

Note 1 to entry: The relationship between *signal processing*, *signal evaluation* and diagnostics is as follows: *signal processing* = *signal evaluation* + diagnostics.

4 Safety sub-functions

4.1 General

Clause 4 describes functions of an *Encoder(SR)* that may be designated as safety-related by the *Encoder(SR)* supplier. The designated *safety sub-functions* in Clause 4 are not considered to form an exhaustive list.

The technical measures required to implement these functions depend on the required *SIL capability* (and *PL capability*, if compliance with ISO 13849-1 is claimed) including the required probability of dangerous hardware failure, as indicated in the *safety requirements specification*. The technical measures are described in Clause 6.

The names of the *safety sub-functions* include the word "safe" to indicate that these functions may be used in a safety-related application on the grounds of a judgement (for example risk analysis) of that specific application, resulting in safety-relevant functions and their integrity to be performed by the *Encoder(SR)*.

The *Encoder(SR)*'s *safety sub-function(s)* may be used for implementation of the safety sub-function(s) of a *PDS(SR)*.

4.2 Safe incremental position (SIP)

This function provides an output signal that is safe in relation to the relative mechanical measurement position.

The relation of the output signal to the relative measurement position shall be within a *tolerance range* that shall be specified and included in the information for use.

4.3 Safe absolute position (SAP)

This function provides an output signal that is safe in relation to the mechanical measurement position.

The relation of the output signal to the measurement position shall be within a *tolerance range* that shall be specified and included in the information for use.

NOTE The reason for splitting the two *safety sub-functions* SIP and SAP is due to the big difference in the way these two different position values are generated and the way they are used.

4.4 Safe speed value (SSV)

This function provides an output signal that is safe in relation to the speed of the moving part.

The relation of the output signal to the speed of the moving part shall be within a *tolerance range* that shall be specified and included in the information for use.

4.5 Safe acceleration value (SAV)

This function provides an output signal that is safe in relation to the acceleration of the moving part.

The relation of the output signal to the acceleration of the moving part shall be within a *tolerance range* that shall be specified and included in the information for use.

4.6 Safety sub-functions for evaluation and signalling

Safety sub-functions providing *signal processing* within the *Encoder(SR)* and respective output signal(s) are possible, for example safely-limited speed SLS (see IEC 61800-5-2:2016, 4.2.4.5). For these *safety sub-functions*, the requirements for design and development, and verification and validation as defined by IEC 61800-5-2 shall apply.

5 Management of functional safety

The requirements of IEC 61800-5-2:2016, Clause 5, shall apply.

6 Requirements for design and development

6.1 General requirements

Table 2 indicates which parts of Clause 6 of IEC 61800-5-2:2016 shall be applied as is and which parts of Clause 6 of IEC 61800-5-2:2016 are modified for *Encoder(SR)*.

Table 3 indicates which parts of IEC 61800-5-1:2007 and IEC 61800-5-1:2007/AMD1:2016 shall be applied as is and which parts of IEC 61800-5-1:2007 and IEC 61800-5-1:2007/AMD1:2016 are modified for *Encoder(SR)*.

Encoder(SR) include diverse technologies and several hardware function blocks, needed to provide the *Encoder(SR)*'s *safety sub-functions*. The realisations of the *Encoder(SR)* are different, but they can always be structured according to the universal architecture described in Annex B. Subclauses 6.5 to 6.8 describe the additional requirements for these hardware function blocks.

**Table 2 – Applicable subclauses of IEC 61800-5-2:2016
for *Encoder(SR)* and respective modifications**

Requirements for <i>PDS(SR)</i> from IEC 61800-5-2:2016		Shall be applied for <i>Encoder(SR)</i> ?	Applicable subclause in this document
6.1	General requirements	No, replaced	6.1 General requirements
6.1.1	Change in operational status	No	
6.1.2	Design standards	No, replaced	6.2 Design standards
6.1.3	Realisation	Yes	
6.1.4	Safety integrity and fault detection	Yes	
6.1.5	Safety and non-safety sub-functions	Yes	
6.1.6	SIL for multiple safety sub-functions within one <i>PDS(SR)</i>	Yes	
6.1.7	Integrated circuits with on-chip redundancy	Yes	
6.1.8	Software requirements	Yes	6.9 Design requirements for software
6.1.9	Design documentation	Yes	
6.2	<i>PDS(SR)</i> design requirements		
6.2.1	Basic and well-tried safety principles	Yes	
6.2.2	Requirements for the estimation of the probability of dangerous random hardware failures per hour (PFH)		
6.2.2.1	General requirements		
6.2.2.1.1	PFH for each safety sub-function	Yes	
6.2.2.1.2	Estimation of PFH	Yes	

Requirements for <i>PDS(SR)</i> from IEC 61800-5-2:2016	Shall be applied for <i>Encoder(SR)</i> ?	Applicable subclause in this document
6.2.2.1.3 Failure rate data	Yes	
6.2.2.1.4 Diagnostic test interval when the hardware fault tolerance is greater than zero	Yes	
6.2.2.1.5 Diagnostic test interval when the hardware fault tolerance is zero	Yes	
6.2.3 Architectural constraints		
6.2.3.1 Limitations of SIL	Yes	
6.2.3.2 Type A and Type B subsystems		
6.2.3.2.1 General	Yes	
6.2.3.2.2 Type A	Yes	
6.2.3.2.3 Type B	Yes	
6.2.3.3 Architectural constraints	Yes	
6.2.4 Estimation of safe failure fraction (SFF)		
6.2.4.1 Methods of analysis	Yes	
6.2.5 Requirements for systematic safety integrity of a <i>PDS(SR)</i> and <i>PDS(SR)</i> subsystems		
6.2.5.1 Requirements for the avoidance of failures		
6.2.5.1.1 General	Yes	
6.2.5.1.2 Choice of design methods	Yes	
6.2.5.1.3 Design measures	Yes	
6.2.5.1.4 Test planning	Yes	
6.2.5.1.5 Design maintenance requirements	Yes	
6.2.5.2 Requirements for the control of systematic faults		
6.2.5.2.1 General	Yes	
6.2.5.2.2 Design features	Yes, with addition	6.6 Design requirements for signal generation
6.2.5.2.3 Testability and maintainability	Yes	
6.2.5.2.4 Human constraints	Yes	
6.2.5.2.5 Protection against unintentional modification	Yes	
6.2.5.2.6 Input acknowledgement and operator mistakes	No	
6.2.5.2.7 <i>PDS(SR)</i> parameterization	Yes, with addition	6.11 Parameterization
6.2.5.2.8 Loss of electrical supply	Yes	
6.2.6 Design requirements for electromagnetic (EM) immunity of a <i>PDS(SR)</i>	Yes	
6.2.7 Design requirements for thermal immunity of a <i>PDS(SR)</i>	No, replaced	6.12 Design requirements for thermal immunity
6.2.8 Design requirements for mechanical immunity of a <i>PDS(SR)</i>	No, replaced	6.13 Design requirements for mechanical immunity
6.3 Behaviour on detection of fault		
6.3.1 Fault detection	Yes, with addition	6.3 Fault detection
6.3.2 Fault tolerance greater than zero	Yes	
6.3.3 Fault tolerance zero	Yes	
6.4 Additional requirements for data communications	Yes	
6.5 <i>PDS(SR)</i> integration and testing requirements		
6.5.1 Hardware integration	Yes	

Requirements for <i>PDS(SR)</i> from IEC 61800-5-2:2016		Shall be applied for <i>Encoder(SR)</i> ?	Applicable subclause in this document
6.5.2	Software integration	Yes	
6.5.3	Modifications during integration	Yes	
6.5.4	Applicable integration tests	Yes	
6.5.5	Test documentation	Yes	

Table 3 – Applicable references of IEC 61800-5-1:2007 and IEC 61800-5-1:2007/AMD1:2016 for *Encoder(SR)* and respective modifications

Requirements for <i>PDS(SR)</i> from IEC 61800-5-1:2016 CSV		Shall be applied for <i>Encoder(SR)</i> ?	Modification for <i>Encoder(SR)</i>
4	Protection against electric shock, thermal, and energy hazards		
4.1	General	Yes	
4.2	Fault conditions	Yes	
4.3	Protection against electric shock		
4.3.1	Decisive voltage classification	Yes	Excluded are <i>Encoder(SR)</i> that are exclusively – supplied with voltage source(s) using PELV circuit(s) conforming to DVC A; and – connected to PELV circuits conforming to DVC A.
4.3.2	Protective separation	Yes	Excluded are <i>Encoder(SR)</i> that are exclusively – supplied with voltage source(s) using PELV circuit(s) conforming to DVC A; and – connected to PELV circuits conforming to DVC A.
4.3.3	Protection against direct contact	Yes	Excluded are <i>Encoder(SR)</i> that are exclusively – supplied with voltage source(s) using PELV circuit(s) conforming to DVC A; and – connected to PELV circuits conforming to DVC A.
4.3.4	Protection in case of direct contact	Yes	Excluded are <i>Encoder(SR)</i> that are exclusively – supplied with voltage source(s) using PELV circuit(s) conforming to DVC A; and – connected to PELV circuits conforming to DVC A.
4.3.5	Protection against indirect contact	Yes	Excluded are <i>Encoder(SR)</i> that are exclusively – supplied with voltage source(s) using PELV circuit(s) conforming to DVC A; and – connected to PELV circuits conforming to DVC A.

Requirements for <i>PDS(SR)</i> from IEC 61800-5-1:2016 CSV	Shall be applied for <i>Encoder(SR)</i> ?	Modification for <i>Encoder(SR)</i>
4.3.5.1 General	Yes	Excluded are <i>Encoder(SR)</i> that are exclusively – supplied with voltage source(s) using PELV circuit(s) conforming to DVC A; and – connected to PELV circuits conforming to DVC A.
4.3.5.2 Insulation between live parts and accessible conductive parts	Yes	Excluded are <i>Encoder(SR)</i> that are exclusively – supplied with voltage source(s) using PELV circuit(s) conforming to DVC A; and – connected to PELV circuits conforming to DVC A.
4.3.5.3 Protective bonding circuit	Yes	Excluded are <i>Encoder(SR)</i> that are exclusively – supplied with voltage source(s) using PELV circuit(s) conforming to DVC A; and – connected to PELV circuits conforming to DVC A.
4.3.5.4 Protective earthing conductor	Yes	Excluded are <i>Encoder(SR)</i> that are exclusively – supplied with voltage source(s) using PELV circuit(s) conforming to DVC A; and – connected to PELV circuits conforming to DVC A.
4.3.5.5 Means of connection for the protective earthing conductor	Yes	Excluded are <i>Encoder(SR)</i> that are exclusively – supplied with voltage source(s) using PELV circuit(s) conforming to DVC A; and – connected to PELV circuits conforming to DVC A.
4.3.5.6 Special features in equipment for protective class II	Yes	Excluded are <i>Encoder(SR)</i> that are exclusively – supplied with voltage source(s) using PELV circuit(s) conforming to DVC A; and – connected to PELV circuits conforming to DVC A.
4.3.6 Insulation	Yes	See Annex E for an example
4.3.7 Enclosures	Yes	
4.3.8 Wiring and connections	Yes	
4.3.9 Output short-circuit requirements	Yes	
4.3.10 Residual current-operated protective (RCD) or monitoring (RCM) device compatibility	No	
4.3.11 Capacitor discharge	No	
4.3.12 Access conditions for high-voltage PDS	No	
4.4 Protection against thermal hazards	Yes	

Requirements for <i>PDS(SR)</i> from IEC 61800-5-1:2016 CSV		Shall be applied for <i>Encoder(SR)</i> ?	Modification for <i>Encoder(SR)</i>
4.4.1	Minimizing the risk of ignition	Yes	
4.4.2	Insulating materials	Yes	
4.4.3	Flammability of enclosure materials	Yes	
4.4.4	Temperature limits		
4.4.4.1	Internal parts	Yes	
4.4.4.2	External parts of CDM	Yes	
4.4.5	Specific requirements for liquid cooled PDS	No	
4.5	Protection against energy hazards	No	
4.6	Protection against environmental stresses	Yes	

6.2 Design standards

Encoder(SR) shall be designed in accordance with IEC 61800-1, IEC 61800-5-1 and IEC 61800-5-2. This document includes additional requirements specific for *Encoder(SR)* or deviating from the requirements for *PDS(SR)*.

If requirements of this document conflict with the requirements of other applicable standards, the requirements of this document take precedence.

Additionally, the requirements of ISO 13849-1 should be complied with for *Encoder(SR)* dedicated for machinery application.

6.3 Fault detection

The necessary diagnostic measures for *Encoder(SR)* may be split into:

- diagnostic measures performed by the *Encoder(SR)*; and
- diagnostic measures performed in the *evaluation unit*.

If diagnostic measures apply within the *Encoder(SR)*, the detection of a *dangerous fault* shall be indicated to the *evaluation unit*.

If *fault* detection shall be performed in the *evaluation unit*, appropriate requirements and the specification of recommended measures for suitable *fault* detection shall be included in the information for use of the *Encoder(SR)*.

NOTE 1 See Annex I for processing *fault* detection of analogue sine and cosine signals in digital technique.

If the use of position values generated by *interpolation* of the sine and cosine *Encoder(SR)* output signal is not excluded in the instructions for use, appropriate diagnostic measures shall be applied.

EXAMPLE 1 The minimum number of samples per signal period of the *solid measure* is specified.

If *ideal fault detection* is required for the *Encoder(SR)* (see 6.4.1), the diagnostic measures applied for the *Encoder(SR)* shall be suitable for revealing all *faults* that lead to an error in any *safety sub-function* of the *Encoder(SR)* exceeding the *tolerance range* specified in the information for use. The suitability of these measures for *fault* detection shall be proven applying static analysis according to Annex L.

When a *fault* that can lead to loss of the *safety sub-function* is detected, a *fault* reaction function shall be initiated in order to prevent a hazard. Diagnostics and *fault* reaction functions shall be performed within the specified maximum *fault* reaction time.

NOTE 2 The *fault* reaction function of *Encoder(SR)* is usually limited to an indication of a *fault* to the *evaluation unit*.

The fault detection by the *Encoder(SR)* or the evaluation unit shall not be delayed or impeded by functions controlling amplitude and/or phase of analogue signals (see Annex M for examples).

NOTE 3 Analogue signals regarded here can be the output signals of an *Encoder(SR)* with sine and cosine output signals used in signal generation or signal processing of an *Encoder(SR)*.

EXAMPLE 2 Due to a component fault, the sine signal is corrupted, its amplitude is controlled and the phasor length is erroneously maintained within the specified tolerances – even during the passage of each individual period of the solid measure. Fault detection applying phasor length monitoring is impeded.

EXAMPLE 3 Controlling of the amplitudes of sine and cosine signals operates slower than the diagnostic measures apply. A dangerous failure can be detected by phasor length monitoring before the amplitude of sine or cosine signal is processed. A delay of fault detection and an increased fault reaction time is prevented.

6.4 Design requirements for specific types of *Encoder(SR)*

6.4.1 Design requirements for *Encoder(SR)* with sine and cosine output signals

For incremental *Encoder(SR)* that have independent signal generation and *signal processing* for one set of sine and cosine output signals (for example A, /A, B, /B), these signals can be considered redundant for unsigned speed information that will contribute to safety sub-function(s) (for example SLS, SSR, SLA, SS1, SS2 according to IEC 61800-5-2:2016, Clause 4). In this case, the application of *ideal fault detection* is not required and speed can be obtained redundantly by sine and cosine signals if independently evaluated.

NOTE 1 The application of quadrature decoder ICs for evaluation destroys the independency of the sine and cosine signals.

For incremental *Encoder(SR)* that do not have independent signal generation and *signal processing* or where the incremental or absolute position or direction information contributes to safety sub-function(s) (for example SOS, SDI, SCA, SLP, SSR according to IEC 61800-5-2:2016, Clause 4), the set of sine and cosine output signals (e.g. A, /A, B, /B) cannot be considered redundant. These *Encoder(SR)* shall apply *ideal fault detection* (see Annex J for more information) if category 3 or category 4 according to ISO 13849-1:2015 is claimed. If category 4 is claimed for the *Encoder(SR)*, the diagnostic measures applied to achieve *ideal fault detection* shall:

- be redundant; or
- include their own diagnostic measures with a minimum *DC* of 99 %.

Encoder(SR) which apply *ideal fault detection* shall be limited to category 3 when just one integrated circuit without on-chip redundancy according to IEC 61508-2:2010, Annex E, is used for signal generation and/or *signal processing*.

NOTE 2 If on-chip redundancy is fulfilled, the *signal processing* of the sine signal and the cosine signal is considered independent. Since the sine AND the cosine signals are necessary to achieve the safe incremental or absolute position and therefore there is no redundancy of the position information, the *HFT* is still 0.

NOTE 3 The compliance with *ideal fault detection* is necessary to fulfill the requirements for category 3 and category 4 of ISO 13849-1:2015, 6.2.6 and 6.2.7. The definitions of these categories include "...a single fault ... does not lead to the loss of the *safety function*".

NOTE 4 The *hardware fault tolerance (HFT)* is one input parameter necessary for the determination of the *SIL* limit in accordance with the architectural constraints (see H.9.2).

6.4.2 Design requirements for *Encoder(SR)* with incremental and absolute output signals

6.4.2.1 General

Encoder(SR) with incremental and absolute output signals show an architecture with two channels, one providing an incremental signal, the other providing an absolute position information.

6.4.2.2 Generation of the safe absolute position value

In the *evaluation unit*, a redundant absolute position value shall be generated from the incremental output signal of the *Encoder(SR)* and a suitable reference. To produce a safe absolute position value, the absolute position value of the *evaluation unit* and the absolute position value from *Encoder(SR)* shall be compared (cross checked) and shall comply within specified tolerances. See Figure 2 for an example of a hardware architecture.

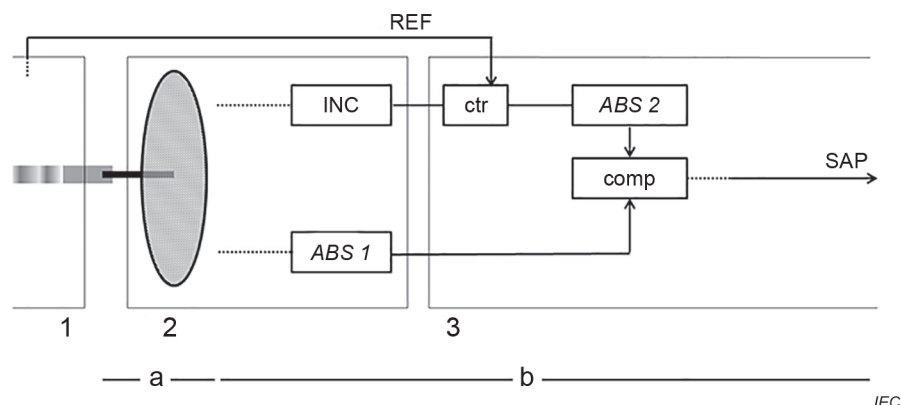
The *Encoder(SR)* shall be designed so that no undetectable dangerous *failure* can occur that causes a simultaneous change in the incremental and absolute position values which results in identical incorrect absolute position values within specified tolerances.

NOTE *Encoder(SR)* with separate, diverse *signal processing* for the incremental and absolute position values usually satisfy this requirement.

The instruction for use of the *Encoder(SR)* shall describe the process in the *evaluation unit* for generating the redundant absolute position value and for detecting *faults* in the absolute position value with the required *DC*.

If the individual channels of the *Encoder(SR)* require dedicated diagnostics performed by the *evaluation unit*, they shall be described in the instructions for use of the *Encoder(SR)*.

The reference of the *evaluation unit* for the second absolute position value shall be independent from the absolute position value of the *Encoder(SR)*.



Key

a	no redundancy, <i>fault</i> exclusion or <i>ideal fault detection</i> applied
b	redundancy, <i>fault</i> detection applied
1	machine
2	<i>Encoder(SR)</i>
3	<i>safe evaluation unit</i>
ABS 1	absolute position value provided by the <i>Encoder(SR)</i>
ABS 2	absolute position value generated by counting the incremental pulses provided by the <i>Encoder(SR)</i>
comp	comparison of ABS 1 with ABS 2
ctr	counter
INC	incremental signal provided by the <i>Encoder(SR)</i>
REF	independent signal from fixed point within the machine to run referencing procedure for ABS 2
SAP	<i>safety sub-function</i> safe absolute position

Figure 2 – Example of hardware architecture of *Encoder(SR)* with incremental and absolute output signal

The application of this type of *Encoder(SR)* provides the *safety sub-function* safe absolute position (SAP).

6.4.3 Design requirements for *Encoder(SR)* with square wave signal interface

Since square wave signal interface do not allow a sufficient diagnosis of the correct functioning of the *Encoder(SR)*, the following requirements shall be fulfilled.

The *Encoder(SR)* with square wave interface shall:

- include all necessary measures to fulfil the requirements of Clause 6 of IEC 61800-5-2:2016;
- provide a safe means to indicate any detected *fault* to the *evaluation unit*.

EXAMPLE Square wave output signals can be of the type HTL, TTL or HC-HTL.

Additionally, the requirements of ISO 13849-1 should be complied with for *Encoder(SR)* dedicated for machinery application.

6.4.4 Design requirements for Resolver

The requirements of this document shall be applied where applicable. In any case, the following requirements shall be applied:

- management of *functional safety* (see Clause 5);
- mechanics (see Clause 6.5);

- information for use (see Clause 7);
- verification and validation (see Clause 8);
- test requirements (see Clause 9); and
- modification (see Clause 10).

NOTE Resolver usually do not include electronic components, since respective functions are not included in the Resolver itself but are provided by the *evaluation unit*.

6.5 Design requirements regarding mechanics

6.5.1 General

Encoder(SR) contain a fixed and a moving part that are connected to the associated machine parts by means of *mechanical fastenings* and *mechanical connecting elements*.

6.5.2 Design requirements for *mechanical fastenings*

If a detached fastening can cause a *dangerous failure* and diagnostic measures are not available, *fault* exclusion for this fastening shall be proven according to ISO 13849-2 and/or Annex G. If a *fault* exclusion for a bolted joint is required:

- appropriate methods for the design shall be used, for example as specified in [6]; and
- additionally, the bolted joints shall be secured against loosening (because of settlement, embedding, creep or relaxation).

6.5.3 Design requirements for *mechanical connecting elements*

Fault exclusions can also be justified for *mechanical connecting elements* by suitable over-dimensioning (see ISO 13849-1:2015, 7.3 and ISO 13849-2:2012, Annex A). The necessary strength for the *mechanical connecting elements* and their durability against fatigue failure shall be proven.

NOTE 1 The calculation can be done in accordance with [7].

NOTE 2 Application to Annex G is not possible, as Table G.1 only deals with form-locked or force-locked *mechanical fastenings* and not with the material itself.

NOTE 3 *Mechanical connecting elements* are usually designated as couplings (see 3.11 and 3.12).

6.5.4 Bearings

In the case of *Encoder(SR)* with bearing(s), a *bearing blockage* can lead to a *dangerous failure*. When *fault* exclusion(s) are applied to the *mechanical connections* (for example as listed in Table G.1), the following measures shall be taken to avoid and deal with *spontaneous bearing blockage* and *gradual bearing blockage* (see Table G.2).

1) *Spontaneous bearing blockage* – appropriate measures

All measures to achieve the *fault* exclusion for *spontaneous bearing blockage* from Table G.2 shall be taken.

2) *Gradual bearing blockage* – appropriate measures

- a) a *bearing blockage* does not lead to a dangerous failure, or
- b) a *bearing blockage* is detected and action is taken to respond to the *fault* before the situation can become dangerous, or
- c) gradual bearing blockage is controlled through early detection and by taking action to respond to the fault, or

NOTE 1 Wear and fatigue alter the operating behaviour of a bearing and might become evident through:

- i) increased torque;
- ii) uneven running;

- iii) reduced operational accuracy;
 - iv) unusual noises during operation;
 - v) increase in temperature.
- d) organizational measures are taken to replace the bearing/the *Encoder(SR)* before the bearing reaches the end of its service life.

NOTE 2 Organizational measures include, for example, corresponding instructions in the information for use or precautions inside the *Encoder(SR)* with signals being sent to the higher-level control.

NOTE 3 The service life of the bearing is usually estimated in accordance with ISO/TS 16281 [8] jointly by the *Encoder(SR)* manufacturer, the bearing manufacturer, and the grease supplier, taking the mission time of the grease into account.

NOTE 4 Aging, wear, contamination, etc. will reduce the lubricity of the grease. This will lead to an increase in the forces necessary to move the bearing. This effect does not have to be taken into account during the mission time of the grease.

The *Encoder(SR)* manufacturer shall specify in the information for use the boundary conditions on the basis of which the service life of the bearing has been estimated.

NOTE 5 The boundary conditions on the basis of which the service life of the bearing is estimated include, for example, temperature, installation position, attachment conditions (alignment *faults*, coupling, forces, etc.), speed, number of revolutions, reversing operation and contamination class.

6.6 Design requirements for signal generation

6.6.1 General

The applied sensor principle of the *Encoder(SR)* shall be suitable for the intended application. Any restrictions regarding the application of the *Encoder(SR)* shall be included in the information for use (see Clause F.2 b)).

NOTE The environmental conditions at the application, like magnetic fields, shock and vibration, pollution etc. can affect the measurement.

6.6.2 Design requirements for signal generation of optical *Encoder(SR)*

On optical *Encoder(SR)*, dirt particles can be deposited in the optical path, for example *solid measure* or optical sensor, and thus cause faulty measurements that prevent the correct performance of the *safety sub-function*. Dirt particles can come, for instance, from the ambient air or arise due to bearing friction and seal abrasion. The deposition of dirt particles shall not be excluded without suitable measures. The effect of contamination could in principle be revealed with *fault*-detecting measures.

NOTE 1 Partial contamination, however, might only be detectable within a narrow position range. If measures for *fault* detection are performed at discrete times, *fault detection* is not ensured within the test interval.

NOTE 2 Measures to enhance availability are often integrated in *evaluation units* that are designed to suppress sporadically occurring *fault* signals. This is capable of additionally delaying or preventing the identification of partial contamination.

6.6.3 Design requirements for signal generation of magnetic *Encoder(SR)*

Since *Encoder(SR)* which use magnetic sensors for detecting position are susceptible to external magnetic fields also, the following specific requirements for the magnetic immunity of these *Encoder(SR)* shall be fulfilled:

- maximum value for external magnetic fields valid in any field direction for criterion A is included in the information for use;
- maximum value for external magnetic fields valid in any field direction for criterion FS is included in the information for use; and
- minimum requirement is according IEC 61000-6-7:2014, Table 2, 2.5, but criterion FS.

NOTE 1 An advice to demonstrate that the value of the external magnetic field at the *Encoder(SR)* location does not exceed the specified limits can be helpful in the information of use.

NOTE 2 In this document, criterion *FS* is used instead of criterion *DS* according to IEC 61800-5-2:2016, 9.3.3.

6.7 Design requirements for *signal processing*

The requirements of IEC 61800-5-2:2016 shall apply.

6.8 Design requirements for internal evaluation and signaling

The requirements of IEC 61800-5-2:2016 shall apply.

6.9 Design requirements for software

If software is used to perform the *safety sub-function(s)*, this software shall be developed in accordance with the requirements of IEC 61800-5-2:2016, 6.1.8.

NOTE IEC 61800-5-2:2016, 6.1.8, refers to IEC 61508-3. Accordingly, software faults as a subset of systematic faults are considered to limit the systematic capability, and the rules for the attainment of systematic capability of IEC 61508-2:2010, 7.4.3, apply. Therefore, the software systematic capability can undercut the intended *SIL* of the *safety sub-function* by one *SIL* step, if *ideal fault detection* is applied and also includes the behavior of software.

If compliance with ISO 13849-1 is claimed, the additional requirements of ISO 13849-1:2015, 4.6, shall apply.

6.10 Pre-setting

If the *Encoder(SR)* includes a position pre-setting function, it shall be designed in a way that the position pre-setting function does not compromise any of its *safety sub-functions*.

NOTE The pre-setting function is also known as "offset", "zeroing function" or "position setting function".

6.11 Parameterization

If the behaviour of a *safety sub-function* may be influenced by configuration of the respective parameters, their settings shall be considered safety related.

The requirements of IEC 61800-5-2:2016, 6.2.5.2.7 shall apply.

If compliance with ISO 13849-1 is claimed, the additional requirements of ISO 13849-1:2015, 4.6.4 shall apply.

6.12 Design requirements for thermal immunity

The *Encoder(SR)* shall be designed to have the appropriate thermal immunity for operating within the specified thermal environment.

NOTE The thermal immunity test requirements are described in 9.5.

6.13 Design requirements for mechanical immunity

The *Encoder(SR)* shall be designed to have the appropriate mechanical immunity for operating within the specified mechanical environment.

NOTE The mechanical immunity test requirements are described in 9.6.

Specific applications may cause shocks to rotary *Encoder(SR)* mounted to motors which are not covered by tests according to 9.6.5. This affects particularly shocks caused by the engagement and disengagement of mechanical brakes. To verify the resilience against these shocks, see Annex D.

6.14 Design requirements for integrated connection cables

The requirements of IEC 60947-5-2:2019, Annex C, shall apply.

7 Information for use

7.1 General

The requirements of IEC 61800-5-2:2016, Clause 7, and the following requirements shall apply.

7.2 Labels

The requirements of IEC 61800-1:1997, 8.1, shall apply as applicable.

7.3 Information and instructions for safe application of an *Encoder(SR)*

Information and instructions shall conform to Annex F.

Instructions shall be provided legibly.

NOTE A character height of 2 mm is considered readily legible.

8 Verification and validation

8.1 General

The requirements of IEC 61800-5-2:2016, Clause 8, and the following requirements (specific for *Encoder(SR)*) shall apply.

8.2 Verification of *hardware fault tolerance*

To verify the *Encoder(SR)*'s *HFT*, a breakdown of the architecture and allocation of all safety relevant components to the functional blocks of the universal architecture (see Annex B) shall be performed.

NOTE Depending on the realisation of the *Encoder(SR)*, not all function blocks are implemented.

A *qualitative FMEDA* shall be performed (see 8.4).

8.3 Additional verification for *Encoder(SR)* with sine and cosine output signals

8.3.1 Verification of diagnostic measures for *Encoder(SR)* with sine and cosine output signals with *HFT* = 0

If *ideal fault detection* is required, the effectiveness of the diagnostic measures for incremental *Encoder(SR)* with sine and cosine output signals with *HFT* = 0 shall be proven with the static analysis method according to Annex L.

8.3.2 Suitability for *interpolation*

In the application of an *Encoder(SR)* with sine and cosine output signals, the signals may have to be *interpolated* to increase the resolution. The *fault*-detecting measures shall be appropriate.

If *ideal fault detection* is required, it shall be proven that one of the three following alternatives applies:

- the *interpolation* of the sine and cosine signal for safety sub-functions is excluded in the instructions for use;
- the *fault*-detecting measures prescribed ensure *ideal fault detection* even for the higher resolution achieved with *interpolation*; or

- the instructions for use prescribe that, in the case of *interpolation*, the *fault*-detecting measures necessary to achieve *ideal fault detection* are to be defined and ensured by the user.

8.4 Qualitative FMEDA

A *qualitative FMEDA* shall be performed considering all hardware components of the *Encoder(SR)*. These also include mechanical components and electrical cables needed for operation even if they are not supplied with the *Encoder(SR)* itself.

For component *faults* for which the system behaviour described in the *qualitative FMEDA* is implausible, a *fault* shall be introduced or simulated. The *Encoder(SR)*'s response to these *faults* shall be documented.

The *Encoder(SR)* shall not contain any components with possible *faults* which may lead to a *dangerous failure* that cannot be revealed by *fault*-detecting measures. These include:

- interchanging of sine and its associated cosine signals by a multiplexer or inversion (direction of motion is incorrectly detected);
- constant output voltage of sine and/or cosine simulating stoppage (see Clause L.7 for details);
- breakage of the drive shaft in rotary *Encoder(SR)* (stoppage is erroneously identified); and
- freezing of digitised analogue values for the sine and cosine.

EXAMPLE 1 An IC digitises analogue signals and converts them after digital processing back into analogue signals.

Faults in components influencing amplitude and/or phase of analogue signals shall also be considered as dangerous failure if they impede or delay fault detection as specified in the instructions for use. See also 6.3.

EXAMPLE 2 *Encoder(SR)* with capability to control amplitude and/or phase of analogue signals include appropriate components to fulfill this function. In case of a component fault within this circuit, the amplitude(s) or phase of sine and/or cosine signal(s) are incorrectly controlled. In case of a faulty analogue signal, the phasor length is maintained within the specified tolerances and fault detection applying phasor length monitoring fails or is delayed.

NOTE 1 The aspect of *faults* in components controlling amplitude and/or phase of analogue signals are especially relevant with *Encoder(SR)* with sine and cosine output signals allowing *interpolation*.

Analysis of the components shall be based on the *fault* models included and referenced in Annex G.

If category 3 or category 4 according to ISO 13849-1:2015 is claimed, it shall be shown for all functional blocks that:

- component *faults* for physical reasons cannot occur; or
- component *faults* of the mechanics can be excluded (see 6.5); or
- *single-fault tolerance* is achieved with a redundant hardware architecture ($HFT = 1$); or
- *single-fault tolerance* is achieved without a redundant architecture by means of *ideal fault detection* (see 3.34) with the *fault*-detecting measures specified in the instructions for use.

NOTE 2 Usually, *Encoder(SR)* for machinery do not comply with $HFT = 2$ or higher.

NOTE 3 The sine and cosine output signals of incremental *Encoder(SR)* cannot be considered generally redundant channels. See Annex K for details.

NOTE 4 On incremental *Encoder(SR)* with sine and cosine output signals, the monolithic integration of the position sensors and analogue circuitry for signal generation makes FMEDA virtually impossible on the transistor level. Instead, it can be assumed that every *dangerous fault* within the IC has an impact on sine and/or cosine output signal. When *ideal fault detection* is achieved, all *dangerous faults* of these ICs are detectable.

If *fault* exclusions apply, these shall be justified in accordance with the standards given in Annex G. For *SIL* 3/*PL* e, the application of *fault* exclusion is limited (see ISO TR 23849:2010¹, 7.2.2). However, this shall not be applied to mechanical aspects – see Table G.1 and IEC 61800-5-2:2016 (exception to Table 5 of IEC 61800-5-2:2016).

8.5 Quantification

The safety reliability of the *Encoder(SR)* shall be determined with a quantitative estimate, for example according to Annex H.

9 Test requirements

9.1 General

Clause 9 replaces IEC 61800-5-2:2016, Clause 9.

9.2 Planning of tests

The requirements of IEC 61800-5-2:2016, 9.1, shall apply with the following addition:

This document contains minimum requirements. If stricter requirements are claimed, these shall be referred to when testing. If it is not obvious which requirements are the stricter ones, conformity with both requirements shall be proven.

9.3 Functional testing

Functional testing of each *safety sub-function*, including related diagnostics (*fault* insertion testing), shall be performed. During these function tests, checks shall be performed to determine whether the properties of the *Encoder(SR)* have been achieved. Deviations from the specification and indications of an incomplete specification shall be documented.

9.4 Electromagnetic (EM) and electrical immunity testing

9.4.1 Electrical tests

9.4.1.1 Impulse voltage test

Testing shall be performed in accordance with IEC 61800-5-1:2007, 5.2.3.1.

Excluded are *Encoder(SR)* whose clearances are dimensioned in accordance with IEC 61800-5-1:2007, Table 9, and that are exclusively:

- supplied with voltage source(s) using *PELV circuit(s)* conforming to *DVC* A; and
- connected to *PELV circuits* conforming to *DVC* A.

If the *Encoder(SR)* contains a potential-free contact that is not itself supplied from the same voltage source as the *Encoder(SR)*, a second electrical circuit therefore exists, and the test in accordance with IEC 61800-5-1:2007, 5.2.3.1 shall be performed.

9.4.1.2 AC or DC voltage test

Testing shall be performed in accordance with IEC 61800-5-1:2007, 5.2.3.2.

¹ This document has been withdrawn.

Excluded are *Encoder(SR)* that are exclusively:

- supplied with voltage source(s) using *PELV circuit(s)* conforming to *DVC A*; and
- connected to *PELV circuits* conforming to *DVC A*.

9.4.2 Electromagnetic (EM) immunity testing

The requirements of IEC 61800-5-2:2016, 9.3, shall apply.

9.5 Thermal immunity testing

9.5.1 General

Subclause 9.5 replaces the requirements of IEC 61800-5-2:2016, 9.4.

9.5.2 Dry cold

Testing shall be performed in accordance with IEC 60068-2-1 and the following conditions:

- the test of the *Encoder(SR)* shall be performed at the lowest permissible working temperature; the minimum temperature during the test shall not exceed $5\text{ °C} \pm 2\text{ °C}$;
- the test of the *interface unit* shall be performed at the lowest permissible ambient temperature; the minimum temperature during the test shall not exceed $5\text{ °C} \pm 2\text{ °C}$;
- the stress duration shall be at least 16 h; and
- the test shall be performed with the *Encoder(SR)* not powered and not driven.

The following acceptance criteria shall be satisfied:

- for the testing of correct function, the specimen remains in the environmental chamber, the set temperature shall not be changed and the *Encoder(SR)* is powered with minimum and maximum specified operating voltage; and

NOTE Test with maximum operating voltage is necessary due to higher currents at power on.

- the *Encoder(SR)* shall still perform its *safety sub-function(s)* according to the specification without any error indication.

9.5.3 Dry heat

Testing shall be performed in accordance with IEC 61800-5-1:2007, 5.2.6.3.1, and the following conditions shall be met during the test:

- the test of the *Encoder(SR)* shall be performed at the highest permissible working temperature, but at least $40\text{ °C} \pm 2\text{ °C}$;
- the test of the *interface unit* shall be performed at the highest permissible ambient temperature, but at least $40\text{ °C} \pm 2\text{ °C}$;
- the stress duration shall be at least 16 h; and
- the test shall be performed with the *Encoder(SR)* powered and not driven.

NOTE The testing of the *Encoder(SR)* in an environmental chamber calls for temperature control to the *measurement point for working temperature*.

The following acceptance criteria shall be satisfied:

- the *Encoder(SR)* and the *interface unit* shall work correctly during and after stressing; and
- the *Encoder(SR)* shall still perform its *safety sub-function(s)* according to the specification without any error indication.

9.5.4 Damp heat

Testing shall be performed in accordance with IEC 61800-5-1:2007, 5.2.6.3.2. Excluded are *Encoder(SR)* that are exclusively:

- supplied with voltage source(s) using *PELV circuit(s)* conforming to *DVC A*; and
- connected to *PELV circuits* conforming to *DVC A*.

The following acceptance criteria shall be satisfied:

- satisfaction of the applicable acceptance criteria of IEC 61800-5-1:2007, 5.2.6.2; and
- the *Encoder(SR)* shall still perform its *safety sub-function(s)* according to the specification without any error indication.

9.5.5 Temperature rise test

Testing shall be performed in accordance with IEC 61800-5-1:2007, 5.2.3.8, with the following modifications:

- thermal derating curves (e.g. regarding temperature versus speed) shall be tested at appropriate points of the curve;
- on rotary *Encoder(SR)*, the heating test shall be carried out at the maximum speed specified, to account for the thermal influence of bearing friction, etc.; and
- on rotary *Encoder(SR)*, the maximum working temperature shall apply instead of "design ambient temperature".

9.6 Mechanical immunity testing

9.6.1 Clearances and creepage distances

Testing shall be performed in accordance with IEC 61800-5-1:2007, 5.2.2.1.

NOTE See Annex E for more information.

9.6.2 Short-circuit testing of printed wiring boards

Testing shall be performed in accordance with IEC 61800-5-1:2007, 5.2.2.2. If the clearances and creepage distances comply with the requirements of IEC 61800-5-1:2007, Tables 9 and 10, the short-circuit testing of the printed wiring boards is not required.

9.6.3 Mechanical fastenings

Testing of *mechanical fastenings* (e.g. force-locked connections by bolted joints) shall be performed as defined by Annex G. Unfavourable environmental conditions shall be considered during the testing, for example temperature conditions for fastenings with material combinations that feature different thermal expansion coefficients.

9.6.4 Mechanical connecting elements

Mechanical connecting elements (e.g. couplings) shall be tested according to the following procedure.

- Determine the maximum static and dynamic loads (e.g. caused by displacements). The maximum loads shall be taken from the information for use.

NOTE 1 For the case of a *stator coupling*, mounting tolerances or thermal expansion effects lead typically to a static load on the coupling element, whereas axial runout deviation lead to a dynamic load on the coupling element.

- Use test equipment which applies static and dynamic loads simultaneously.
- For rotary *Encoder(SR)*, test of axial and radial loads could be done separately or in combination.

d) Test static loads with a safety factor of at least 1,0.

NOTE 2 The low safety factor 1,0 is justified by increased stress due to simultaneous application of static and dynamic loads.

e) Test dynamic loads with a safety factor of at least 1,5.

f) Select the most disadvantageous frequency or revolution speed.

g) Choose a suitable number of cycles depending on the material and safety factor.

NOTE 3 A typical procedure using the safety factor above would be to test at least 10^7 cycles for steel (body centred cubic crystal structure), and 10^8 cycles for steel (face centred cubic crystal structure) for aluminium, magnesium and copper alloy.

After the test, the following acceptance criteria shall be satisfied:

- *mechanical connecting elements* shall not have been damaged, plastically deformed, loosened or detached; and
- no damage shall occur that can influence the *safety sub-function(s)* of the *Encoder(SR)*.

An example for a suitable test of *mechanical connecting elements* is given in Annex C.

NOTE 4 The test of *mechanical connecting elements* can be done with the element alone or together with the *Encoder(SR)*.

9.6.5 Vibration and shock test

Testing shall be performed according to the requirements given in IEC 61800-5-2:2016, 9.5, except 9.5.4. If higher values are specified, they shall apply. The *Encoder(SR)* shall be powered and each *safety sub-function* shall be verified while operating.

The *Encoder(SR)*, including the possibly associated *interface unit*, shall be assembled and connected to the power supply in accordance with the assembly instructions and with reference to the requirements listed in IEC 60068-2-47.

The *Encoder(SR)* shall be mounted in accordance with its mounting instructions. The movable part of the *Encoder(SR)* shall be fixed with a fixture thus providing a constant output signal.

For *Encoder(SR)* with digital output signals, the minimum cycle time shall be chosen. For *Encoder(SR)* with analogue or square wave output signals, a sampling interval of $\leq 200 \mu\text{s}$ shall be chosen.

NOTE The sampling interval quoted here is considered sufficient for the application of *Encoder(SR)* in *safety functions*, as the time-related requirements for *safety functions* are generally less stringent than the time-related requirements for the control loop.

For vibration test, signals of *Encoder(SR)* shall be evaluated for at least one sweep (preferably the last one) in each axis.

While the *solid measure* of the *Encoder(SR)* is fixed, during each individual test the output signals shall stay within the tolerance according to the instructions for use.

After the test, the following acceptance criteria shall be satisfied:

- a) electrically live parts shall not have become touchable (see 9.6.7);
- b) parts shall not have loosened or become detached if the safety of the *Encoder(SR)* is impaired as a result;
- c) no damage shall occur that can influence the function, safety or correct fastening; and
- d) when the movable part of the *Encoder(SR)* is moved (e.g. by hand), the output signals shall be plausible.

9.6.6 Mechanical properties of integrated connecting cables

Testing shall be performed in accordance with IEC 60947-5-2:2019, Annex C.

9.6.7 Testing the non-touchability

Testing shall be performed in accordance with IEC 61800-5-1:2007, 5.2.2.3 and 5.2.2.4, and shall be carried out after vibration and shock testing.

For *Encoder(SR)* without housing, instead of testing, the instructions shall contain appropriate information to ensure the demanded protection class by installation at the place of use.

NOTE If *fault* exclusions regarding short-circuits on printed wiring boards are claimed, additional requirements apply. See IEC 61800-5-2:2016, Table D.1.

9.6.8 Deformation testing

Testing shall be performed in accordance with IEC 61800-5-1:2007, 5.2.2.5.

Excluded are built-in *Encoder(SR)* and *Encoder(SR)* that are exclusively:

- supplied with voltage source(s) using *PELV circuit(s)* conforming to *DVC A*; and
- connected to *PELV circuits* conforming to *DVC A*.

9.7 Material tests

Testing shall be performed in accordance with IEC 61800-5-1:2007, 5.2.5.

9.8 Suitability of the components and materials used

Through testing, inspection, possibly calculation and comparison with the technical documents, it shall be proven that the components and materials of the *Encoder(SR)*:

- conform to the existing standards;
- are suitable for the envisaged assignment; and
- can be operated within the defined design values.

NOTE These also include the internal wiring, connection leads, the fastening of the *solid measure* (e.g. an adhesive's temperature resistance).

To assess the suitability for the envisaged *working temperature range* of the *Encoder(SR)*, the following shall be considered:

- the heating of the *Encoder(SR)* due to electrical power uptake;
- the permissible ambient temperature range of the *Encoder(SR)*; and
- heat uptake and release at the place of assembly.

On rotary *Encoder(SR)* with the coupling of the *Encoder(SR)* shaft to the drive shaft, heat uptake and release depends largely on the thermal properties of assembly. Unless thermally insulated assembly is excluded in the instructions for use, the temperature increase due to bearing friction and friction of the shaft seal shall be determined. To this end, the *Encoder(SR)* shall be assembled with the use of thermally insulating materials, and the inherent heating within the permissible speed range shall be determined.

All safety-relevant components shall be operated within the permissible temperature range. If necessary, the instructions for use shall include the limitation in terms of the speed and/or ambient temperature range.

The effectiveness of the *solid measure* and its fastening shall remain unchanged throughout the system's service life. This shall be verified by an FMEDA. To justify *fault* exclusions regarding the detachment of the *solid measure*, the factors for over-dimensioning in Annex G shall be applied.

9.9 Contamination of *solid measure*

Durability against contamination of the *solid measure* shall be proven by:

- *fault* exclusion, or
- adequate measures to uphold the safety-relevant features, or
- adequate diagnostic measures.

9.10 Labels

The contents of labels shall be inspected regarding:

- completeness (see 7.2);
- correctness;
- consistency of the details; and
- legibility of the print.

NOTE A print height of 2 mm is considered readily legible.

The durability of labels shall be proven by:

- rubbing for 15 s with a cotton cloth soaked with water; and thereafter
- rubbing for 15 s with the chemical product "n-Hexane for Analysis" according to the test liquid defined in IEC 60335-1 and IEC 62368-1.

The labels shall be readily legible after the tests.

It shall not be possible to remove label plates easily by hand nor are they permitted to become wavy or wrinkled.

9.11 Instructions

The technical documents shall be compared to the requirements and inspected regarding completeness, correctness and consistency.

9.12 Test documentation

The requirements of IEC 61800-5-2:2016, 9.6, shall apply.

10 Modification

The requirements of IEC 61800-5-2:2016, Clause 10, shall apply.

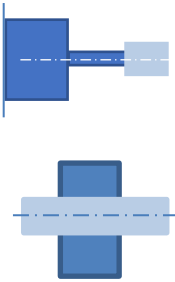
Annex A (informative)

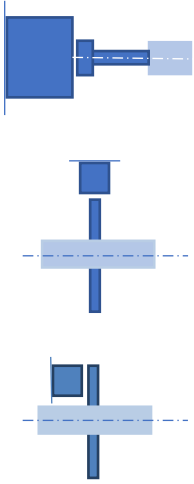
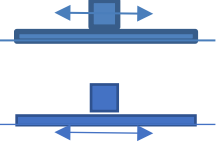
Types of *Encoder(SR)*

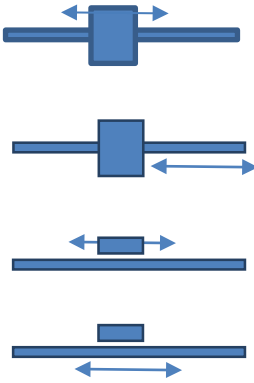
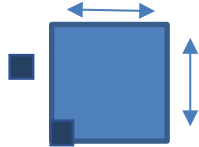
Table A.1 details the general types of *Encoder(SR)* and shows the general arrangement of different types of *Encoder(SR)*.

Light blue indicates the input shaft for the rotary *Encoder(SR)*.

Table A.1 – Types of *Encoder(SR)*

<i>Encoder(SR)</i> type	Description	Remark
Incremental <i>Encoder(SR)</i>	<i>Encoder(SR)</i> that provides analogue or digital signal(s) proportional to the change of position of a moveable part.	There can be an additional index signal. Incremental <i>Encoder(SR)</i> generate a precisely defined number of pulses per revolution or linear measurement range.
Absolute <i>Encoder(SR)</i>	<i>Encoder(SR)</i> that provides analogue or digital signal(s) indicating the position of a moveable part.	Without further referencing, it is possible to get the absolute position over the entire measuring range. The absolute <i>Encoder(SR)</i> keeps track of its position at all times, and provides a valid output signal when power is applied.
Rotary <i>Encoder(SR)</i>	<i>Encoder(SR)</i> that generates analogue or digital output signal(s) in response to the rotary position of a moveable part.	Rotary <i>encoder</i> are also known as "rotary position transducer", "speed sensor", "shaft <i>encoder</i> " or "angle <i>encoder</i> ".
Single-turn <i>Encoder(SR)</i>	Rotary <i>Encoder(SR)</i> which provides absolute position information within one revolution.	The measuring values are repeated after every complete revolution.
Multi-turn <i>Encoder(SR)</i>	Rotary <i>Encoder(SR)</i> which provides absolute position information within multiple revolutions.	
Rotary <i>Encoder(SR)</i> with integral bearing	 <i>Encoder(SR)</i> contains bearing(s), is a self-contained unit and does not rely on the host machine for the control of rotary motion. - Input shaft can be connected to host machine via a coupling. <i>Encoder(SR)</i> internal parts will generally be protected from the environment.	
Rotary <i>Encoder(SR)</i> without integral bearing	<i>Encoder(SR)</i> is in two parts.	

Encoder(SR) type	Description	Remark
	- Actuating element/<i>solid measure</i> is fixed to the host machine shaft and relies on the host machine bearings for control of rotary motion. - Actuating element/<i>solid measure</i> needs to be aligned relative to the sensor as part of the installation process. - Actuating element/<i>solid measure</i> can be protected or not protected from the environment and hence the <i>Encoder(SR)</i> function can be affected by solids or liquids. - Sensor internal parts will generally be protected from the environment.	
Bearingless <i>Encoder(SR)</i>	<i>Encoder(SR)</i> without its own bearing or guide	
Built-in <i>Encoder(SR)</i>	<i>Encoder(SR)</i> which fulfils the requirements concerning protection from environmental influences only when installed at its place of use.	
External <i>Encoder(SR)</i>	<i>Encoder(SR)</i> for attachment at the place of use	
Resolver(SR)	A Resolver(SR) is a type of rotary transformer used for measuring degrees of rotation.	
Linear <i>Encoder(SR)</i> without integral bearing, not protected from the environment 	<i>Encoder(SR)</i> is in two parts, sensor and solid measure, and relies on the host machine bearings for the control of linear motion. - The sensor is either - mechanically fastened to a fixed element of the host machine and the <i>solid measure</i> is fixed to a moving element, or - fixed to a moving element and the <i>solid measure</i> is fastened to a fixed element. <i>Encoder(SR)</i> internal parts can be protected from the environment or can be mounted in a protected area of the host machine. <i>Solid measure</i> is aligned relative to the sensor. Generally, the solid measure is not protected from the environment and hence the <i>Encoder(SR)</i> function can be affected by solids or liquids.	

Encoder(SR) type	Description	Remark
Linear <i>Encoder(SR)</i> protected from the environment 	• <i>Encoder(SR)</i> is mounted to the host machine as one unit. • The sensor and <i>solid measure</i> movement can be controlled by the host machine bearings or the <i>Encoder(SR)</i> can contain integral bearings for the control of linear motion. • The <i>solid measure</i> needs to be aligned relative to the sensor as part of the installation process. • Internal parts are protected from the environment and hence the <i>Encoder(SR)</i> function is not affected by solids or liquids.	
Linear shaft <i>Encoder(SR)</i> 	• <i>Encoder(SR)</i> is either – in one part and contains bearings to guide the movement of the sensor relative to the shaft/<i>solid measure</i>, or – in two parts and relies on the host machine bearings for the control of linear motion • Either shaft/<i>solid measure</i> or sensor is mounted to a moving part of the host machine • <i>Encoder(SR)</i> internal parts can be protected from the environment or can be mounted in a protected area of the host machine. • Generally the shaft/<i>solid measure</i> is not protected from the environment and hence the <i>Encoder(SR)</i> function can be affected by solids or liquids. • The shaft/<i>solid measure</i> can rotate.	
X-Y plate <i>Encoder(SR)</i>/ grid <i>Encoder(SR)</i> 	• <i>Encoder(SR)</i> is in three parts. • Two sensors detect simultaneous movement of the <i>solid measure</i> in two axes. • Relies on the host machine bearings for the control of linear motion. • Sensors are mounted to a fixed element of the host machine. • <i>Solid measure</i> is mounted to a moving element of the host machine.	

Annex B (informative)

Universal architecture of *Encoder(SR)*

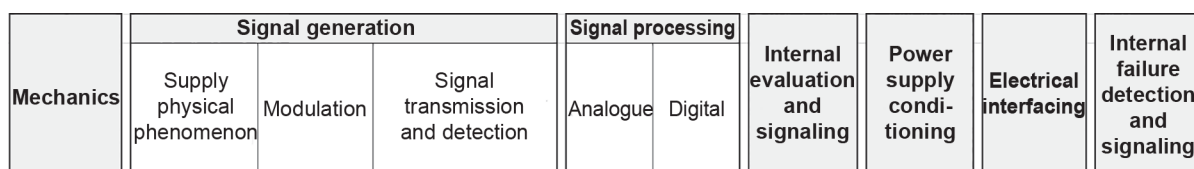
B.1 General

Encoder(SR) include diverse technologies and several hardware function blocks, needed to provide the *Encoder(SR)*'s *safety sub-functions*. The realisations of the *Encoder(SR)* are different, but they can always be structured according to the universal architecture. This is helpful to perform a breakdown to analyse *HFT* and category (if desired).

NOTE In this document, the universal architecture has also been used to structure the contents within some clauses and to allow easy enhancements of additional technologies etc. in the future.

B.2 The universal *Encoder(SR)* architecture

In Figure B.1, the universal architecture with its function blocks is shown.



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Figure B.1 – Universal *Encoder(SR)* architecture

Encoder(SR) do not necessarily include all function blocks of the universal architecture, but all hardware components of every *Encoder(SR)* can be assigned to an appropriate function block. Table B.1 gives a list of the function blocks and corresponding examples.

Table B.1 – Function blocks of the universal *Encoder(SR)* architecture

Function block	Examples
Mechanics	Flexible shaft coupling, stiff shaft coupling, <i>stator coupling</i> , fixing stator, fixing rotor, fixing <i>solid measure</i> , fixing read head, bearing, screw fitting, gluing, gearbox
Signal generation	
Supply physical phenomenon	Light, magnetic field, electromagnetic field, electrical field, electrical resistance
Modulation	<i>Solid measure</i> , code disc, gear wheel, mechanical distance
Signal transmission and detection	Fibre optic cable, light sensitive component, "magnetic conductor frame", magnetic field sensitive component, lens, coil, aperture, triangulation, measurement of transit time
Signal processing	
Analogue	Impedance converter, amplifier, linearising amplifier, analogue adder/subtractor, amplitude controller, <i>DC</i> controller
Digital	Quadrature decoder, counter, signal converter, e. g. into rectangle, determination of position, speed, acceleration, etc., <i>interpolation</i> , ADC
Internal evaluation and signalling	Position comparator (SLP), speed comparator (SLS)
Power supply conditioning	Controller, filter
Electrical interfacing	Bus-ICs, driver, analogue/digital, connector, cable
Internal <i>fault</i> detection and signalling	Phasor length monitor, signal generation monitor, signal comparator, information comparator, temperature monitor, output signals monitor

Annex C (informative)

Examples of suitable mechanical tests for rotary *Encoder(SR)*

C.1 General

In Annex G, suitable tests for justifying *fault* exclusions for mechanical connections are demanded. An example of appropriate tests for the justification of the *fault* exclusion for the mechanical connection between rotary *Encoder(SR)* and drive is provided here.

C.2 Mechanical fastening of the *Encoder(SR)*

C.2.1 Force-locked connection (e.g. by bolted joints)

According to Table G.1, a safety factor of $S \geq 4$ for force-locked connection shall be verified by testing.

Therefore, the connections:

- between stator of the motor and stator of the *Encoder(SR)*;
- between shaft of the motor and shaft of the rotary *Encoder(SR)*;
- between fixed part of the machine and fixed part of the *Encoder(SR)*;
- between moving part of the machine and moving part of the *Encoder(SR)*;

are statically loaded by:

- the maximum possible force; and
- the maximum possible torque including:
 - i) the torque resulting from angular acceleration of the inertia (angular rotating mass) of *Encoder(SR)* rotary parts;
 - ii) the bearing torque at adverse environmental conditions;
 - iii) etc.;

multiplied by at least a safety factor of $S = 4$. The connections shall withstand this force/torque and no slipping shall occur.

NOTE The signal of the *Encoder(SR)* can be used to determine slipping within the interface, when *solid measure* and shaft of the *Encoder(SR)* are fixed via a mechanical short-circuit.

C.2.2 Form-locked connection (e.g. by feather key)

According to Annex G, a high safety factor against fatigue fracture (e.g. $S \geq 2$ for steel) for form-locked connection shall be verified by testing. The acceleration for the test (and the moved inertia) is thereby adjusted to correspond to the maximum possible force/torque that may occur within the application, multiplied by the respective safety factor. To determine the maximum possible force/torque, the torque resulting from maximum acceleration of the shaft inertia, the maximum bearing torque at adverse environmental conditions, etc. shall be considered. No damage shall occur that can influence the function, safety or correct fastening.

C.3 Mechanical connecting elements of the *Encoder(SR)* – Stator coupling (torque support) or shaft-rotor coupling

C.3.1 General

The *Encoder(SR)* is assembled in accordance with the instructions for use under additional superimposed axial and radial pre-stressing (static load) of the *mechanical connecting element*. The *mechanical connecting element* is then subjected to the number of deflections according to 9.6.4 g) (dynamic load). Depending on the geometry, the deflection of the *mechanical connecting element* is performed by lateral deflection (e.g. via hydropulser) and/or by rotation with an eccentric shaft.

For the experimental set-up, the dimensioning according to C.3.2 and C.3.3 is undertaken. Thereby, the axial and radial static pre-stressing of the *mechanical connecting element* are maintained superimposed to define the initial position from where the deflection of the *mechanical connecting element* starts. Potential eigenfrequencies of the *mechanical connecting element* shall be taken in account. No damage shall occur that can influence the function, safety or correct fastening.

C.3.2 Axial loads

C.3.2.1 Static

According to the information for use, the *Encoder(SR)* is mounted with the axial offset, the maximum permissible shaft displacement, combined with the mechanical tolerances of the *Encoder(SR)*, the machine bed and the drive shaft.

NOTE Precision gauge bands can be used for shimming to maintain the static displacement.

C.3.2.2 Dynamic

If dynamic axial displacement is permissible, the *Encoder(SR)* or the shaft, respectively, is moved with the amplitude of the mechanical tolerances and the maximum permissible displacement, multiplied by the safety factor of at least $S = 1,5$, according to 9.6.4.

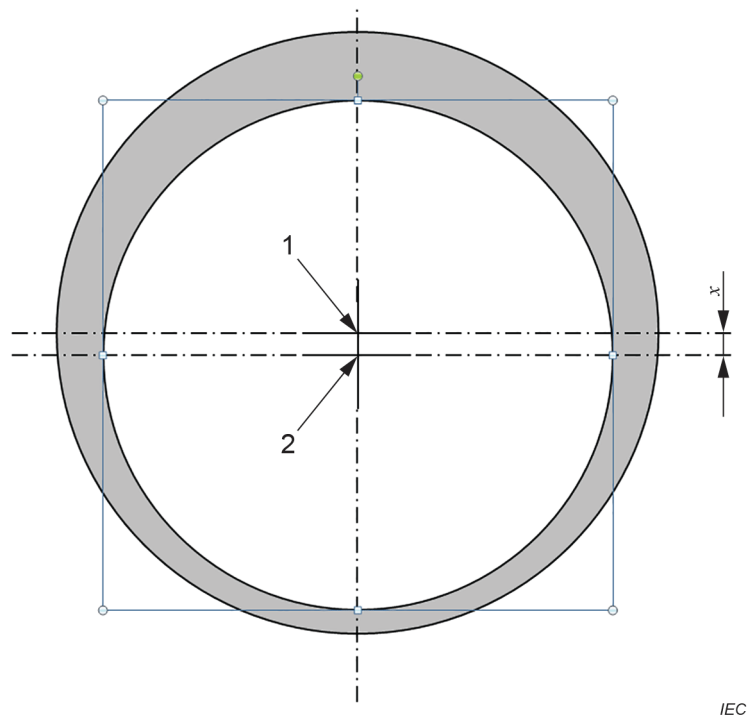
C.3.3 Radial loads

C.3.3.1 Stator coupling static/shaft-rotor coupling dynamic

The *Encoder(SR)* is assembled with the radial offset derived from the information for use on the maximum permissible radial shaft displacement. For dynamic loads (in case of *shaft-rotor coupling*), the safety factor is at least $S = 1,5$, according to 9.6.4.

C.3.3.2 Stator coupling dynamic/shaft-rotor coupling static

The drive shaft is provided with an additional eccentric ring (see Figure C.1). The degree of eccentricity depends on the mechanical tolerances and the maximum permissible radial shaft movement in accordance to the information for use and for dynamic loads (in case of *stator coupling*) multiplied by the safety factor of at least $S = 1,5$, according to 9.6.4.



Key

- 1 *Encoder(SR)* shaft centre
- 2 drive shaft centre
- x eccentricity

Figure C.1 – Example of an additional ring for assembly with eccentricity x

Annex D (informative)

Extended shock testing for rotary *Encoder(SR)* mounted to motors

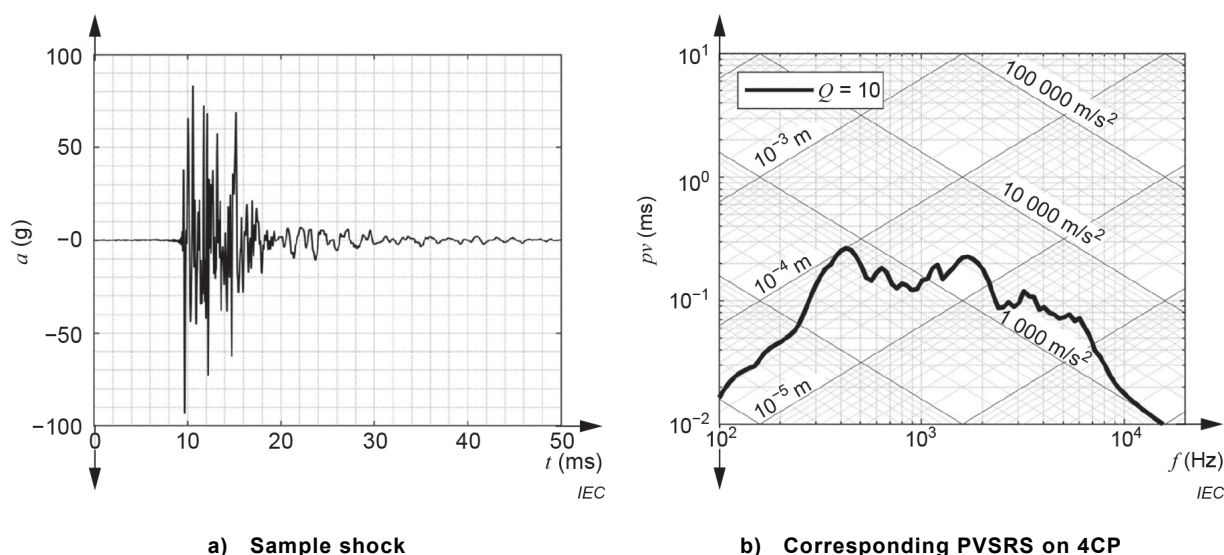
D.1 General

The engagement and disengagement of mechanical brakes (or other mechanical excitations, e.g. impacts) can cause shocks, which may damage or distort rotary *Encoder(SR)* mounted to motors. The damaging effect of these shocks typically extends over a broad frequency range and cannot be satisfactorily reproduced by testing in accordance with IEC 60068-2-27.

D.2 Pseudo-velocity shock-response spectrum (PVSRS)

A suitable method to assess the damaging effect of shocks is the pseudo-velocity shock-response spectrum (PVSRS). Figure D.1 depicts a sample shock caused by the engagement of a mechanical brake and the corresponding PVSRS on four-coordinate paper (4CP).

NOTE For detailed information regarding the PVSRS and the PVSRS on 4CP, see [9].



Key

a acceleration
 t time
 f frequency
 pv pseudo velocity
 Q Q-factor

NOTE 1 Pseudo velocity indicates the severity of the shock.

NOTE 2 The Q-factor (quality factor) describes the assumed damping of the system.

Figure D.1 – Sample shock and corresponding PVSRS on 4CP

D.3 Verification of resilience

If verification of sufficient resilience against shocks caused by brakes or other mechanical excitations is desired, it is recommended

- to perform an endurance test in the foreseeable operating environment or

- to perform a suitable test on a testing machine.

When the verification is provided by testing on a testing machine, it shall be ensured that the damaging effect of the tested shocks is at least equivalent to the damaging effect expected during operation.

The comparison of the damaging effect of shocks can be conducted by comparing the PVSRS calculated in accordance with ISO 18431-4 [10]. It is recommended to examine the frequency range from at least 100 Hz to 10 kHz, to calculate the PVSRS for a minimum of twelve frequencies per octave, and to choose a Q-factor of ten. It is only possible to compare response spectra with each other that were determined under comparable conditions (measuring point, measuring direction, etc.) and for comparable shock durations [11].

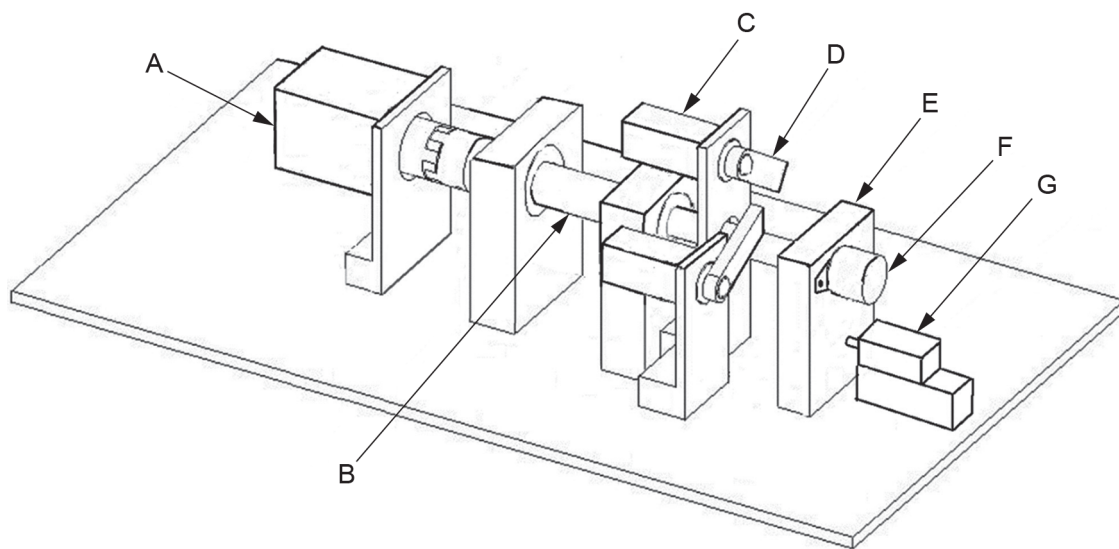
NOTE 1 For detailed information regarding the measuring techniques and shock testing machines, see [11].

NOTE 2 In order to avoid the definition of all relevant conditions in each individual case, a general definition of suitable conditions (measuring points, directions etc.) and limits for the deviation of the shock duration is currently under discussion.

D.4 Testing machine

Figure D.2 depicts a possible testing machine for verification of resilience by conducting a test on a testing machine. The testing machine is particularly suitable for simulating high frequency and multi axis shock loads as expected during use on brake motors. The testing machine enables variation of the shock load on the static as well as the rotating part of the *Encoder(SR)* virtually independently and to achieve a high rate of repetition.

NOTE The testing machine is a modification of known testing machines causing shock excitations by mechanical impact. For examples, see [11].



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Key

- A drive motor
- B shaft of testing machine
- C rotary actuator
- D impactor
- E stator of testing machine
- F rotary *Encoder(SR)*
- G linear actuator

Figure D.2 – Testing machine