International Standard

ISO 13855

Safety of machinery — Positioning of safeguards with respect to the approach of the human body

Sécurité des machines — Positionnement des moyens de protection par rapport à l'approche du corps humain

Third edition
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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 199, *Safety of machinery*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 114, *Safety of machinery*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 13855:2010), which has been technically revised.

The main changes are as follows:

— document expanded for applicable cases and partly revised to be state-of-the-art;

— figures revised for clarity and better understanding;

— scope wording improved to better focus on the document’s content;

— Clause 4 improved for better explanation of the methodology;

— document restructured from Clause 5;

— calculation of reaching distances separated for those applications which are initiating a safety function and those which are not initiating a safety function;

— dynamic separation distance calculation included for mobile applications with unknown human direction of approach;

— improvements for better distinction of different paths of approach;

— requirements for single control devices (hand- and foot-operated) and interlocking guards added;

— annexes revised in order to match with the body text of this document;

— Annexes D to G added.

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Introduction

The structure of safety standards in the field of machinery is as follows:

a) type-A standards (basic safety standards) giving basic concepts, principles for design, and general aspects that can be applied to all machinery;

b) type-B standards (generic safety standards) dealing with one safety aspect or one type of safeguard that can be used across a wide range of machinery:

  — type-B1 standards on particular safety aspects (e.g. safety distances, surface temperature, noise);

  — type-B2 standards on safeguards (e.g. two-hand control devices, interlocking devices, pressure-sensitive devices, guards);

c) type-C standards (machine safety standards) dealing with detailed safety requirements for a particular machine or group of machines.

This document is a type-B1 standard as stated in ISO 12100.

This document is of relevance, in particular, for the following stakeholder groups representing the market players with regard to machinery safety:

— machine manufacturers (small, medium and large enterprises);

— health and safety bodies (regulators, accident prevention organisations, market surveillance).

Others can be affected by the level of machinery safety achieved with the means of the document by the above-mentioned stakeholder groups:

— machine users/employers (small, medium and large enterprises);

— machine users/employees (e.g. trade unions, organizations for people with special needs);

— service providers, e.g. for maintenance (small, medium and large enterprises);

— consumers (in case of machinery intended for use by consumers).

The above-mentioned stakeholder groups have been given the possibility to participate in the drafting process of this document.

In addition, this document is intended for standardization bodies elaborating type-C standards.

The requirements of this document can be supplemented or modified by a type-C standard.

For machines which are covered by the scope of a type-C standard and which have been designed and built according to the requirements of that type-C standard, the following applies: if the requirements of that type-C standard deviate from the requirements in type-B standards, the requirements of that type-C standard take precedence over the provisions of other standards.

Correct positioning of protective devices is critical for them to be effective. In deciding on these positions, a number of aspects are taken into account, such as:

— the necessity of a risk assessment according to ISO 12100;

— the practical experience in the use of the machine;

— the time taken to achieve the intended risk reduction following operation of the safeguard, for example, to stop the machine;

— the bio-mechanical and anthropometric data;

— any intrusion by a part of the body towards the hazard zone until the protective device is actuated;

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— the path taken by the body part when moving from the detection zone towards the hazard zone;

— the possible presence of a person between the safeguard and the hazard zone;

— the possibility of undetected access to the hazard zone.

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Safety of machinery — Positioning of safeguards with respect to the approach of the human body

1 Scope

This document specifies requirements for the positioning and dimensioning of safeguards with respect to the approach of the human body or its parts towards hazard(s) within the intended span-of-control as follows:

— the position and dimension of the detection zone(s) of ESPE and pressure-sensitive mats and pressure-sensitive floors;

— the position of two-hand control devices and single control devices;

— the position of interlocking guards.

This document also specifies requirements for the positioning of safety-related manual control devices (SRMCD) with respect to the approach of the human body or its parts from within the safeguard space relative to:

— the position and dimension of the detection zone(s) of ESPE and pressure-sensitive mats and pressure-sensitive floors; and

— the position and dimension of interlocking guards.

When evaluating the ability of the human body or its parts to access SRMCD from within the intended safeguarded space, the requirements of this document are also applicable to determine the dimensions of safeguard(s). Approaches such as running, jumping or falling, are not considered in this document.

NOTE 1 The values for approach speeds (walking speed and upper limb movement) in this document are time tested and proven in practical experience.

NOTE 2 Other types of approach can result in approach speeds that are higher or lower than those defined in this document.

This document applies to safeguards used on machinery for the protection of persons 14 years and older.

Safeguards considered in this document include:

a) electro-sensitive protective equipment (ESPE) such as:

  — active opto-electronic protective devices (AOPDs) (see IEC 61496-2);

  — AOPDs responsive to diffuse reflection that have one or more detection zone(s) specified in two dimensions (AOPDDRs-2D) (see IEC 61496-3);

  — AOPDs responsive to diffuse reflection that have one or more detection zone(s) specified in three dimensions (AOPDDRs-3D) (see IEC 61496-3);

  — vision based protective devices using reference pattern techniques (VBPDPP) (see IEC/TS 61496-4-2);

  — vision based protective devices using stereo vision techniques (VBPDST) (see IEC/TS 61496-4-3);

b) pressure-sensitive mats and pressure-sensitive floors (see ISO 13856-1);

c) two-hand control devices (see ISO 13851);

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d) single control devices;

e) interlocking guards (see ISO 14120).

This document is not applicable to:

— safeguards (e.g. pendant two-hand control devices) that can be manually moved, without using tools, nearer to the hazard zone than the separation distance;

— protection against the risks from hazards arising from emissions (e.g. the ejection of solid or fluid materials, radiation, electric arcs, heat, noise, fumes, gases);

— protection against the risks arising from failure of mechanical parts of the machine or gravity falls.

The separation distances derived from this document do not apply to safeguards used solely for presence sensing function.

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.

ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction*

ISO 13857:2019, *Safety of machinery — Safety distances to prevent hazard zones being reached by upper and lower limbs*

3 Terms, definitions, symbols and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 12100 and the following apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms and definitions

3.1.1
overall system response time
DEPRECATED: overall system stopping performance
T
time interval between the actuation of the sensing function and achieving the intended risk reduction

Note 1 to entry: This time typically includes tolerance factors (e.g. due to uncertainty of measurements, consideration of environmental factor such as friction).

3.1.2
response time
t_x
maximum time between the occurrence of the event leading to the actuation of the safeguarding device and the achieving of its intended state

Note 1 to entry: This time typically includes tolerance factors (e.g. due to uncertainty of measurements, consideration of environmental factor such as friction).

[SOURCE: IEC 61496-1:2020, 3.21, modified — The wording “output signal switching devices OSSD achieving the OFF state” has been replaced by “achieving of its intended state”. The wording “sensing” has been

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replaced by “safeguarding”. The original Notes 1, 2 and 3 to entry have been deleted and a new Note 1 to entry has been added.]

3.1.3
detection capability
d
ability to detect the specified test piece(s) in the specified detection zone

[SOURCE: IEC 61496-3:2018, 3.3, modified — Notes to entry and references have been removed.]

3.1.4
effective detection capability
d_e
sensing function parameter limit set by the integrator of the device that will cause its actuation

3.1.5
electro-sensitive protective equipment
ESPE
assembly of devices and/or components working together for protective tripping or presence-sensing purposes and comprising as a minimum:

— a sensing device;

— controlling/monitoring devices;

— output signal switching devices and/or a safety-related data interface.

Note 1 to entry: ESPEs refer only to non-contact sensing devices.

[SOURCE: IEC 61496-1:2020, 3.5, modified — The original Notes 1 and 2 to entry have been deleted and a new Note 1 to entry has been added.]

3.1.6
indirect approach
approach where the shortest path to the hazard zone is obstructed by a mechanical obstacle

Note 1 to entry: The hazard zone can only be approached by going around the obstacle.

3.1.7
detection zone
zone within which a specified test piece is detected by the sensitive protective equipment

Note 1 to entry: The detection zone can also be a point, line or plane.

Note 2 to entry: ISO 13856-1 uses the term “effective sensing area” when describing pressure-sensitive mats and pressure-sensitive floors. In this document, the terms “detection zone” and “effective sensing area” are used synonymously.

[SOURCE: IEC 61496-1:2020, 3.4, modified — “electro-” has been removed before “sensitive protective equipment” and Note 2 to entry has been added.]

3.1.8
separation distance
DEPRECATED: minimum distance
S
minimum distance required between the actuation position of the protective devices and the hazard zone to prevent the human body or its parts from reaching the hazard zone before the cessation of the hazardous machine function

Note 1 to entry: Examples of protective devices are found in ISO 12100:2010, 3.28.

Note 2 to entry: The separation distance is always the shortest distance between the detection zone and the hazard zone, independent from the entry point of the person through the detection zone.

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3.1.9
reaching distance associated with a protective device
DEPRECATED: intrusion distance
D_{DS}
distance that a part of the body can move through or past the safeguard prior to actuation of the safeguard, either towards the hazard zone or towards a *safety-related manual control device (SRMCD)* (3.1.14) from within the safeguarded space

3.1.10
reference plane
level at which persons would normally stand during the use of the machine or access to the hazard zone or *safety-related manual control device (SRMCD)* (3.1.14)

Note 1 to entry: The reference plane is not necessarily the ground or the floor (e.g. a working platform can be the reference plane).

[SOURCE: ISO 13857:2019, 3.2, modified — "or safety-related manual control device (SRMCD)" and its definition reference "(3.1.14)" have been added.]

3.1.11
span-of-control
predetermined portion of the machinery under control of a specific device or safety function

Note 1 to entry: A protective device can initiate a stop function of a machine or a portion of a machine.

3.1.12
safeguarded space
area or volume enclosing a hazard zone(s) where guards and/or protective devices are intended to protect persons

3.1.13
whole body access
situation where a person can be completely inside a *safeguarded space* (3.1.12)

Note 1 to entry: The term *whole body access* is used differently in other documents to specify the opening size for ergonomic access.

3.1.14
safety-related manual control device
SRMCD
control device which requires deliberate human action and whose actuation can result in an immediate increase of the risk(s)

Note 1 to entry: Examples include actuating devices such as pushbuttons, selector switches, or foot pedals designed for functions such as reset, start/restart, unconditional guard unlocking or hold-to-run control (e.g. jog, inching).

3.1.15
single control device
control device which requires actuation by either a single hand or foot in order to initiate hazardous machine functions, thus providing a protective measure only for the person who actuates it

Note 1 to entry: Examples include actuating devices such as pushbuttons or foot pedals designed to control hazardous machine functions only during actuation, or incremental movement upon each actuation.

3.1.16
industrial environment
workplace where the public is restricted from access or not reasonably expected to be present for the intended tasks and machine applications

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3.1.17
dynamic hazard
source of harm that changes its location either by the movement of parts of the machine or the machine itself

Note 1 to entry: The dimensions and shape of the hazard zone associated with the dynamic hazard result from the range of the moving parts of the machine (operating space) or the moving range of the machine itself.

3.1.18
stopping distance
distance travelled by the hazard, hazardous point or part of the machine or the machine itself, from the initiation of the safety function until the intended risk reduction is achieved

Note 1 to entry: Situations are possible in which the intended risk reduction is achieved even if the hazardous machine parts are still moving.

Note 2 to entry: Hazards can also travel even if machine parts do not (e.g. a rotating laser beam).

3.1.19
speed and separation control
SSC
safety function that achieves the intended risk reduction by maintaining the separation distance by changing the speed and or the trajectory of the machine or its parts relative to the detected position of parts of the human body

Note 1 to entry: The separation distance depends on several parameters, e.g. the speed and approach direction of the parts of the human body; the speed, direction, and orientation of moving hazard zones; the *effective detection capability* (3.1.4) of the protective devices; the *response time* (3.1.2) of the safety-related parts of the control system involved.

3.1.20
safety-related part of a control system
SRP/CS
part of a control system that performs a safety function, starting from a safety-related input(s) to generating a safety-related output(s)

[SOURCE: ISO 13849-1:2023, 3.1.1, modified — Note 1 to entry has been deleted.]

3.2 Symbols and abbreviated terms

3.2.1 Symbols

See Annex E.

3.2.2 Abbreviated terms

AOPD	active opto-electronic protective device
AOPDDR	active opto-electronic protective device responsive to diffuse reflection (e.g. laser scanner)
VBPD	vision-based protective device
ESPE	electro-sensitive protective equipment
SPE	sensitive protective equipment (see ISO 12100:2010, 3.28.5)
SRMCD	safety-related manual control device
SRP/CS	safety-related part of a control system
SCS	safety-related control system (see IEC 62061:2021, 3.2.3)

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SSC speed and separation control

4 Methodology

4.1 General

Safeguards shall be configured and positioned such that access to the hazard zone to be safeguarded shall be detected in time to achieve the intended risk reduction.

In an application using an SPE where two or more hazard zones are present, the separation distance for each hazard zone shall be calculated. Where necessary, additional safeguards shall be provided to prevent circumventing the detection zone of the safeguard (see Figure 12).

Figure 1 provides a representation of the methodology for determining the positioning of sensing or actuating devices of safeguards in accordance with this document, which is as follows:

a) Determine if the considered safeguard is appropriate to achieve the intended risk reduction for the identified hazard (as specified in ISO 12100).

NOTE 1 Intended risk reduction can include detection of access toward a hazard zone, as well as reaching toward an SRMCD from within the safeguarded space.

b) If a type-C standard exists for the machinery, select one of the specified types of safeguards from that standard, and then use the distance specified by that standard. If no type-C standard exists, continue to Step c).

If there is no type-C standard, use the formulae in this document to calculate the separation distance for the safeguard selected.

NOTE 2 Type-C standards can specify minimum distances (referred to as separation distance in this document) directly or by reference to this document.

c) Confirm that the application of the safeguard is within the assumptions identified within this document.

d) Identify the hazard zones associated with the safeguard.

e) Determine the separation distances between the safeguard and its hazard zone(s). Then select the largest (most protective) of the separation distances. Consideration shall be given to possible circumvention of the safeguard (e.g. reaching over, through, around or under).

f) Determine if whole body access is possible. If whole body access is possible, apply additional protective measures to prevent unexpected reset/restart with person(s) inside the safeguarded space according to step g). If whole body access is not possible or is not applicable (e.g. two-hand control device), continue to step i).

NOTE 3 ISO 12895 is under preparation specifically for the topic of whole body access and its derived risks.

g) When no additional detection of persons within the safeguarded space is used, SRMCD(s) shall be identified and step h) applies. Where additional detection of persons within the safeguarded space is used for those additional detection means, the separation distances of this document do not apply, continue to step i).

h) Determine the reaching distances for each possible approach (over, through, around or under) from the safeguard toward the SRMCD(s). Then select the largest (most protective) of the reaching distances such that circumvention is prevented.

i) Determine if the separation and reaching distances are feasible for the application. If feasible, the process is completed, otherwise a design modification is required. Where this modification only applies to the considered safeguard, the process shall be repeated starting at step e). Where the modification consists of the application of a different safeguard or a modification of the machinery design (including additional safeguards), the process shall be repeated starting at step a).

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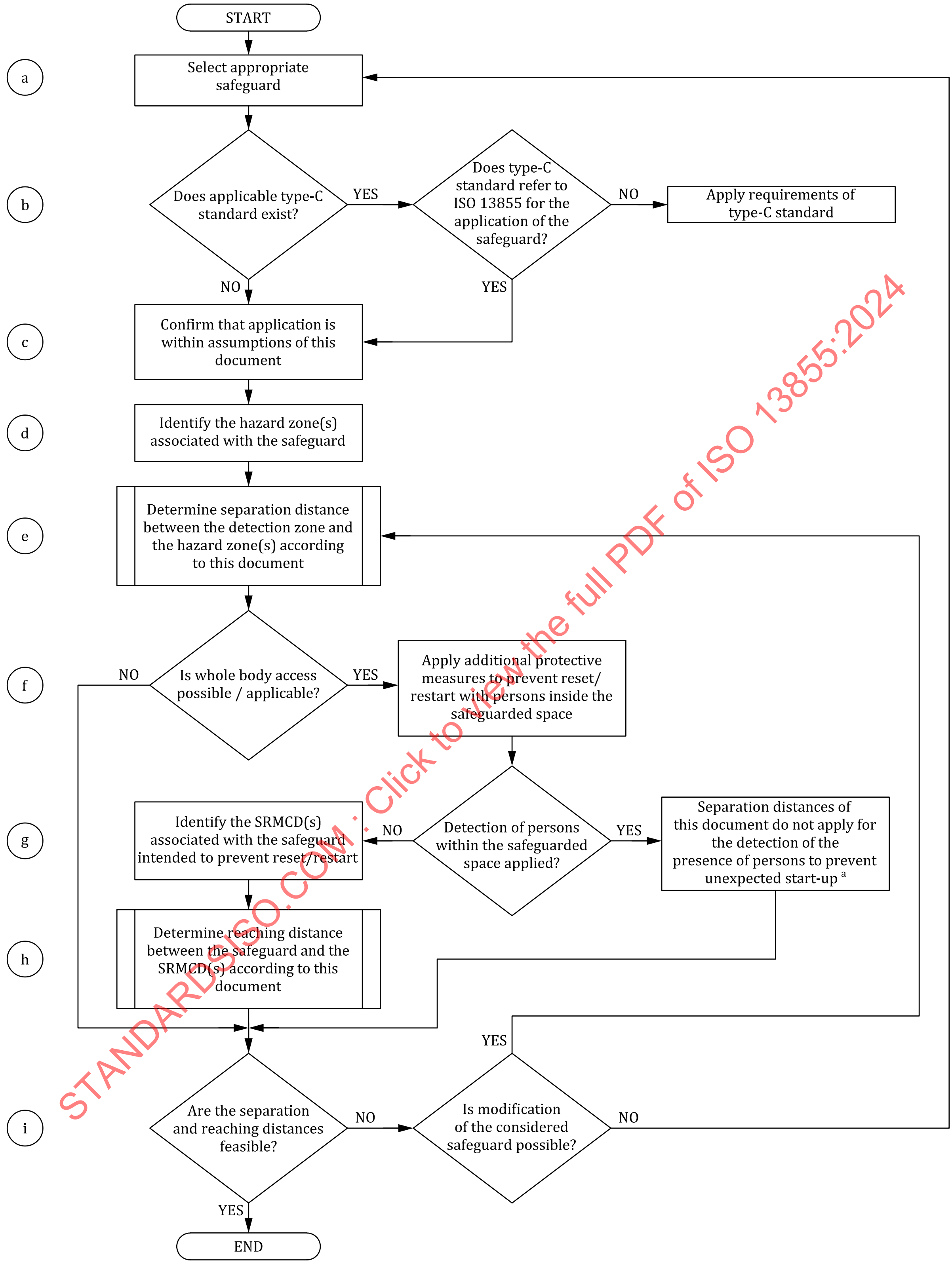
NOTE 4 Redesign of the machine or the safeguard can result in a risk reduction measure which does not require the application of this document.



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[a] This applies to the function of the detection of persons within the safeguarded space, regardless of whether this function is provided by the same device providing the trip function or a different protective device providing the detection function. See Clause 1, last paragraph.

Figure 1 — Methodology

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4.2 Static and dynamic separation distances

Two different scenarios shall be considered for machinery:

a) Static separation distance: The separation distance is determined to the maximum boundary of the hazard zone, independently of the actual position of the origin(s) of the hazard(s) within the physical limits of the machine, or the position of the machine itself.

b) Dynamic separation distance: The separation distance is determined to the boundary of the hazard zone that the origin(s) of the hazard(s) can reach according to its actual position and the change in this position during the overall system response time, T to achieve the intended risk reduction.

Clause 5 describes the calculation of the static separation distance, e.g. for the proper positioning of an AOPD (safety light curtain) away from the die of a power press. The static approach, however, can lead to large safety distances due to its worst-case approach or cannot be applicable due to the nature of the hazards to be covered by the intended safeguarding (e.g. the collision of a mobile platform with a human).

Clause 6 describes the calculation of the dynamic separation distance, e.g. for the proper sizing of the detection zone of an AOPDDR-2D (safety laser scanner) or AOPDDR-3D (safety 3D sensor) or VBPD monitoring a safeguarded space. As a basis for the dynamic separation distance calculation, the position of the hazard and the overall system response time according to the actual speed and braking capability (deceleration) of the hazard shall be known.

4.3 Reference planes

The parameters specified in this document are applicable to typical approaches of persons in the workplace. In some applications, movement near machinery requires persons to change elevation to perform expected tasks (step up or step down). Furthermore, design of machinery can present the ability for persons to change elevation while accessing the hazard zone or an SRMCD. In such cases, the level the person is using for access shall be considered when determining appropriate reaching considerations.

When a change in elevation is present (e.g. step, platform, machinery frame), the reference plane shall be determined according to Table 1 and Figure 2.

When using Table 1 and Figure 2, the direction of approach toward the hazard zone or the SRMCD shall be considered.

NOTE The situation where a person climbs and stays on the higher surface is not considered in the scenarios described in Table 1 (see 4.4).

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Table 1 — Determination of reference plane with elevated surfaces when reaching toward hazard zone or SRMCD

<table>
<tr><th rowspan="3">Direction of approach</th><th rowspan="3" colspan="2">SPE location to step</th><th rowspan="3">Height of step
H_S</th><th colspan="2">Width of step from edge to detection zone
W_S</th></tr>
<tr></tr>
<tr><th>< 50 mm [a]</th><th>≥ 50 mm [a]</th></tr>
<tr><td rowspan="4">Stepping up</td><td rowspan="2" colspan="2">In front
[see Figure 2 a)]</td><td>≥ 1 000 mm</td><td>A</td><td>A</td></tr>
<tr><td>< 1 000 mm</td><td>A</td><td>A</td></tr>
<tr><td rowspan="2" colspan="2">At or behind
[see Figure 2 b)]</td><td>≥ 1 000 mm [b]</td><td>B</td><td>B</td></tr>
<tr><td>< 1 000 mm [b]</td><td>A</td><td>C</td></tr>
<tr><td rowspan="4">Stepping down</td><td rowspan="2" colspan="2">In front
[see Figure 2 c)]</td><td>≥ 500 mm [c]</td><td>D</td><td>D</td></tr>
<tr><td>< 500 mm [c]</td><td>E</td><td>E</td></tr>
<tr><td rowspan="2" colspan="2">At or behind
[see Figure 2 d)]</td><td>≥ 500 mm [c]</td><td>D</td><td>F</td></tr>
<tr><td>< 500 mm [c]</td><td>E</td><td>G</td></tr>
<tr><td>Scenario</td><td colspan="3">Possibility of access</td><td colspan="2">Reference plane</td></tr>
<tr><td>A</td><td colspan="3">Undetected access to higher surface not possible</td><td colspan="2">Lower surface</td></tr>
<tr><td>B</td><td colspan="3">Access to higher surface not possible</td><td colspan="2">Lower surface</td></tr>
<tr><td>C</td><td colspan="3">Undetected access to higher surface possible</td><td colspan="2">Higher surface</td></tr>
<tr><td>D</td><td colspan="3">Undetected access to lower surface not possible [d]</td><td colspan="2">Higher surface</td></tr>
<tr><td>E</td><td colspan="3">Undetected access to lower surface not possible</td><td colspan="2">Higher surface</td></tr>
<tr><td>F</td><td colspan="3">Undetected access to lower surface possible [d]</td><td colspan="2">Lower surface</td></tr>
<tr><td>G</td><td colspan="3">Undetected access to lower surface possible</td><td colspan="2">Lower surface</td></tr>
<tr><td colspan="6">[a] 50 mm value derived from P5 heel width given in DIN 33402-2:2020-12, Table 60.
[b] 1 000 mm value taken from ISO 13857:2019, Table 1 (Note a) and Table 2 (Note b).
[c] 500 mm presents risk of falling; value taken from ISO 14122-2:2016, 4.2.3.
[d] See ISO 14122-2 for further information for other means to address additional falling hazards.</td></tr>
</table>

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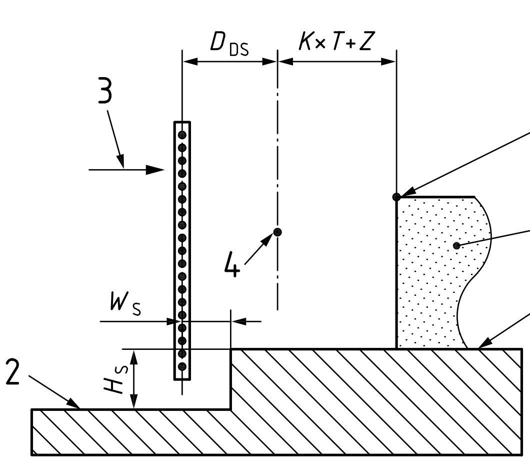
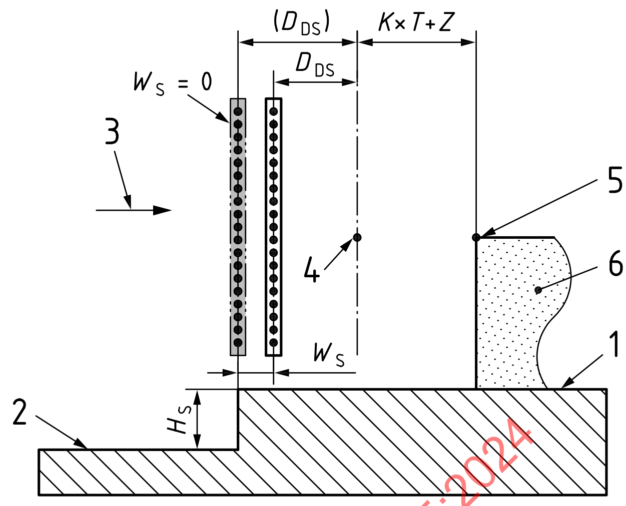
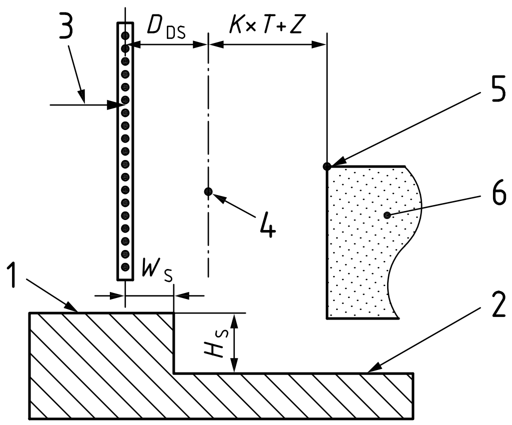


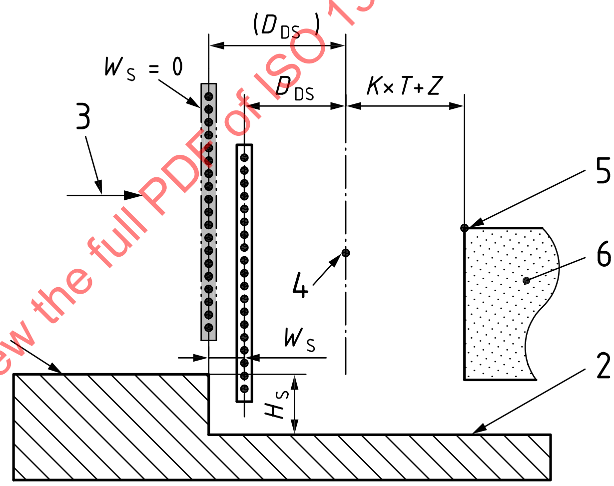
a) Stepping up (SPE in front of the step)



b) Stepping up [SPE behind (or at) the step]



c) Stepping down (SPE in front of the step)



d) Stepping down [SPE behind (or at) the step]

Key

1 higher surface
2 lower surface
3 direction of approach
4 nearest point when approaching an SRMCD
5 nearest point when approaching a hazard zone
6 hazard zone

H_S height of step
W_S width of step from edge to detection zone
D_{DS} reaching distance associated with a protective device
K approach speed
T overall system response time
Z application-dependent supplemental distance factor

Figure 2 — Representation of elevated surfaces for determining reference plane when reaching toward hazard zone or SRMCD

4.4 Assumptions

The reaching distances have been derived by making the following assumptions:

— persons reaching toward a hazard zone(s) are not inserting the head or leg over or under the safeguard in order to reach the considered area (hazard zone or SRMCD);

— anthropometric data from the 5th to the 95th percentile of persons of 14 years and older were used in the determination of the reaching distance values in the formulae;

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- data specifically for children have not been used in this document. Until specific data are available for approach speeds for children, the designer should calculate the distances taking into account that children can be quicker and that a child can be detected later;
- the largest anticipated value of d_e is used to determine D_{DS} for the application;
- the safeguards retain their position relative to the hazard zone(s) and SRMCD location(s);
- attention should be paid to the possibility that the hazard zone changes its position relative to the safeguard or reference plane during the time interval from the actuation of the safeguard or reference plane to achieving the intended risk reduction (e.g. industrial mobile robot);
- reaching distances are measured from the surface, restricting the relevant part of the body;
- persons can force parts of the body around or through openings created between safeguards and other protective structures (e.g. mounting/support structures, machine frame) in an attempt to reach the identified area (hazard zone or SRMCD);
- the reference plane is a surface on which a person would normally stand, but is not necessarily the floor (e.g. a permanent working platform or permanent means of access);
- there is some contact with the reference plane (e.g. climbing is not included);
- no aids (e.g. chairs, portable ladders) are used to change the reference plane;
- it is not possible to gain access to the identified area by stepping or climbing on the housing of the safeguards, including associated mounting structures;
- no aids (such as rods or tools) are used to extend the natural reach of the upper limbs that can reach or become engaged with the identified area.

4.5 Specific requirements for ESPE regarding whole body access

4.5.1 General

When an ESPE is used only for the detection of whole body access on an orthogonal approach, the height of the lower edge of the detection zone (e.g. beam) from the reference plane H_{DB}, to prevent access under the detection zone, shall be ≤ 200 mm. For industrial environments, a maximum height of 300 mm for the lowest edge of the detection zone is acceptable if the results of the risk assessment show this to be sufficient. See Annex C.

4.5.2 Additional requirements for detection zones mounted vertical to the reference plane

a) The height of the upper edge of the detection zone H_{DT} shall be ≥ 900 mm to prevent stepping over the detection zone. This is not applicable where a single beam is used (see Annex C) as well as where the detection zone is parallel to the direction of approach (see 9.2);

b) the beam spacing of the ESPE shall be ≤ 400 mm. See Figure 3.

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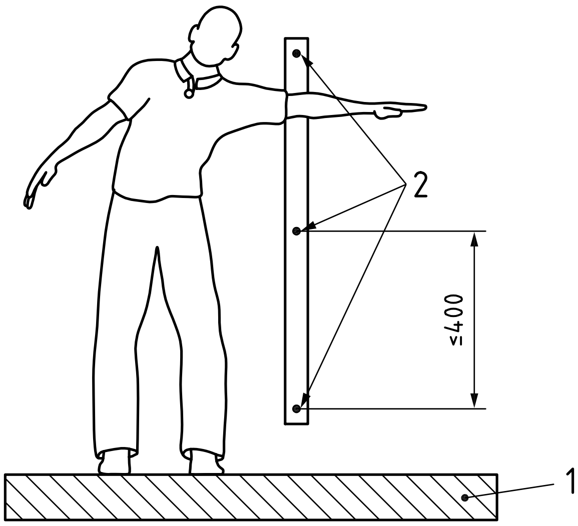
Dimensions in millimetres



Key

1 reference plane

2 ESPE beams

Figure 3 — Example of multiple beam system used for whole body access

In exceptional cases (see 8.3.5) a beam separation of 500 mm may be applied.

4.5.3 Additional requirements for single beam devices

Single beam devices mounted parallel to the reference plane shall only be used for openings with height ≤ 500 mm and shall be placed at a height of 200 mm. See Annex C.

4.6 Reaching distance to SRMCD

The concept of reaching distances has previously only been applied to distances for parts of the human body accessing a hazard zone. This document extends this concept to include accessing an SRMCD from within a safeguarded space. This concept shall be applied to positioning of any SRMCD whose actuation can result in an immediate increase of the risk.

For use with SRMCD, substitute the point defined as the nearest hazard (e.g. location, measurements) in the relevant parts of this document with the SRMCD where contact shall be prevented.

When actuation of an SRMCD can result in harm to individuals, the SRMCD shall be oriented and located at sufficient distance to prevent actuation by a person from inside the safeguarded space.

For SRMCD used in conjunction with protective structures (e.g. guards), the requirements of ISO 13857 shall apply in addition to the requirements of this document.

4.7 Direction of approach toward detection zone of SPE

The direction of approach of the person or part of the person's body shall be determined to be

a) orthogonal (at right angles or normal) to the detection zone (see Clause 8), or

b) parallel to the detection zone (see Clause 9).

Requirements are also provided for arrangements where

— an angled approach (between orthogonal and parallel) needs to be considered (see Clause 7);

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— it is necessary to address possible circumventing of the detection zone (see 8.2 and 8.4);

— the path from the detection zone to the hazard zone is restricted by obstacles (indirect approach) (see 8.3.6).

NOTE 1 These situations also appear in combination.

NOTE 2 This document is not intended to provide measures against reaching a hazard zone by climbing over.

For the use of AOPDDRs or VBPDs with a two-dimensional protection zone, the calculation of the separation distance shall be in line with Clauses 8 or 9, depending on the approach direction.

4.8 Speed and separation control (SSC)

SSC may be used to achieve the required risk reduction by maintaining the dynamic separation distance by appropriate adaptation of the speed or trajectory of the potential hazardous movements of the machine or its parts. The change of speed or trajectory of the hazardous movements of the machine or its parts can include causing a stop.

Safeguarding with SSC shall meet the requirements of 6.1, 6.2 and the following:

— Any parts of the human body intended to be detected and present in the safeguarded space shall be detected.

— Failure to track all parts of the human body intended to be detected in the safeguarded space shall result in an immediate command to achieve the intended risk reduction within the span-of-control.

— Failure to maintain the separation distance between a human or parts of the human body in the safeguarded space shall result in an immediate command to achieve the intended risk reduction within the span-of-control.

The dynamic separation distance shall be calculated according to 6.3. Where the SPE measures the approach speed of the human or parts of the human body, the measured value may be applied for the calculation. Otherwise, the approach speed according to 5.3.1 shall be applied.

The performance of the SRP/CS or SCS providing the approach speed measurement shall be such that it does not diminish the performance of the SRP/CS or SCS that provides the SSC function. The uncertainty of the measurement of the position and speed of the hazardous machine parts or the machine itself as well as the uncertainty of the measurement of the position and speed of parts of the human body shall be included in the supplemental distance factor Z. If the measurement uncertainty is known, it shall be stated as Z_M as described in 5.6. If the measurement uncertainty is unknown, then three sample standard deviations shall be added to the mean value of the measurements. See B.5 for additional information.

5 Separation distance

5.1 General

The safeguard shall be located at the separation distance from the hazards or hazard zone within the span-of-control of the safeguard to protect persons when reaching over, through or under the safeguard. See also, Annex A for information regarding achieving intended risk reduction.

Safeguards that require a separation distance include:

a) SPE (see Clauses 7, 8 and 9);

b) pressure-sensitive mats and pressure-sensitive floors (see Clause 9);

c) two-hand control devices (see Clause 10);

d) single control devices (see Clause 11);

e) interlocking guards (see Clause 12).

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NOTE The variables used to determine the separation distance for safeguards have been modified in this document to avoid confusion with other International Standards which use the same variables to represent different parameters. See Annex E.

5.2 Separation distance *S*

The separation distance shall be calculated by using Formula (1).

$$S = (K \times T) + D_{DS} + Z \quad (1)$$

where

- S is the separation distance, in millimetres (mm);
- K is a parameter, in millimetres per second (mm/s), derived from data on approach speeds of the body or parts of the body (see 5.3);
- T is the overall system response time, in seconds (s), (see 5.4);
- D_{DS} is the reaching distance associated with a protective device, in millimetres (mm), (see 5.5);
- Z is an application-dependent supplemental distance factor, in millimetres (mm), (see 5.6).

5.3 Approach speed *K*

5.3.1 Approach speed of the human body

The factor K is the speed constant which includes hand and body movements of a person(s) approaching a hazard zone.

This document considers the following factors for the determination of K:

— hand and arm movement;

— twisting of the body or shoulder, or bending at the waist;

— walking.

The speed constant of 2 000 mm/s defines the hand speed value, usually considered as the horizontal motion of the upper limbs (hand and arm, also known as reaching). For approaches to the hazard zone where this hand and arm movements are involved, a value for K = 2 000 mm/s shall be applied.

The speed constant of 1 600 mm/s defines the walking speed value. For approaches to the hazard zone where walking movement is required, a value for K = 1 600 mm/s shall be applied.

These values do not include other movements of the body, machinery or combinations which can affect the actual approach speed. Consideration of these movements shall be included when determining the speed constant for a given application.

5.3.2 Approach speed of mobile machinery

Where the hazard itself is derived from the mobility of the machine, the combined approach speed of the mobile machine and the person(s) shall be considered if it is reasonably foreseeable that a person will approach the machine at the same time the machine approaches the person.

NOTE When collision avoidance requires timely detection of the human approach, even larger sizes of the detection zone resulting from the consideration of the combined approach will not prevent the collision when the person reaches the crossing at nearly the same time the machine does.

The resulting approach speed shall be determined as the vectorial subtraction (speed value and movement direction) of the human and machine approach speeds.

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5.4 Overall system response time *T*

The overall system response time T used to determine the separation distance of a safeguard shall be determined either by calculation or by measurement (T_m).

The overall system response time T for the machinery to achieve the intended risk reduction includes portions of time that vary by machine type, the safeguard(s) applied, and the elements of the SRP/CS or SCS involved in the safety function. See Formula (2) and Figure 4.

When the overall system response time is calculated, it shall be the sum of the following factors as represented by Formula (2):

$$T \geq t_{SRP/CS} + t_{ME} + t_F \quad (2)$$

where

T	is the overall system response time used in the calculation to determine the separation distance;
$t_{SRP/CS}$	is the response time of the SRP/CS or SCS;
t_{ME}	is the response time of the machinery;
t_F	is the time related to a tolerance factor for the machinery, if necessary.

$t_{SRP/CS}$ is determined by adding the worst-case assumptions from the manufacturer of the safeguard and the related parts of the SRP/CS or SCS.

t_{ME} is estimated by the machine manufacturer during the design and includes uncertainties.

t_F is a value typically determined based on T_m and is influenced by various factors. When determining t_F, factors such as tool weight, temperature, and aging of components as well as the worst-case scenario (e.g. maximum speed of a moving part) should be considered.

The overall system response time T can be determined as the sum of these factors and may be represented by Formula (3):

$$T \geq t_I + t_L + t_O + t_D + t_R + t_M + t_F \quad (3)$$

where

T	is the overall system response time used in the calculation to determine the separation distance;
t_I	is the response time of the input (e.g. sensor, protective device);
t_L	is the response time of the SRP/CS or SCS logic;
t_O	is the response time of the SRP/CS or SCS output;
t_D	is the response time related to dissipation of source energy;
t_R	is the response time related to mechanical response;
t_M	is the response time related to mechanical inertia;
t_F	is the time related to a tolerance factor for the machinery, if necessary.

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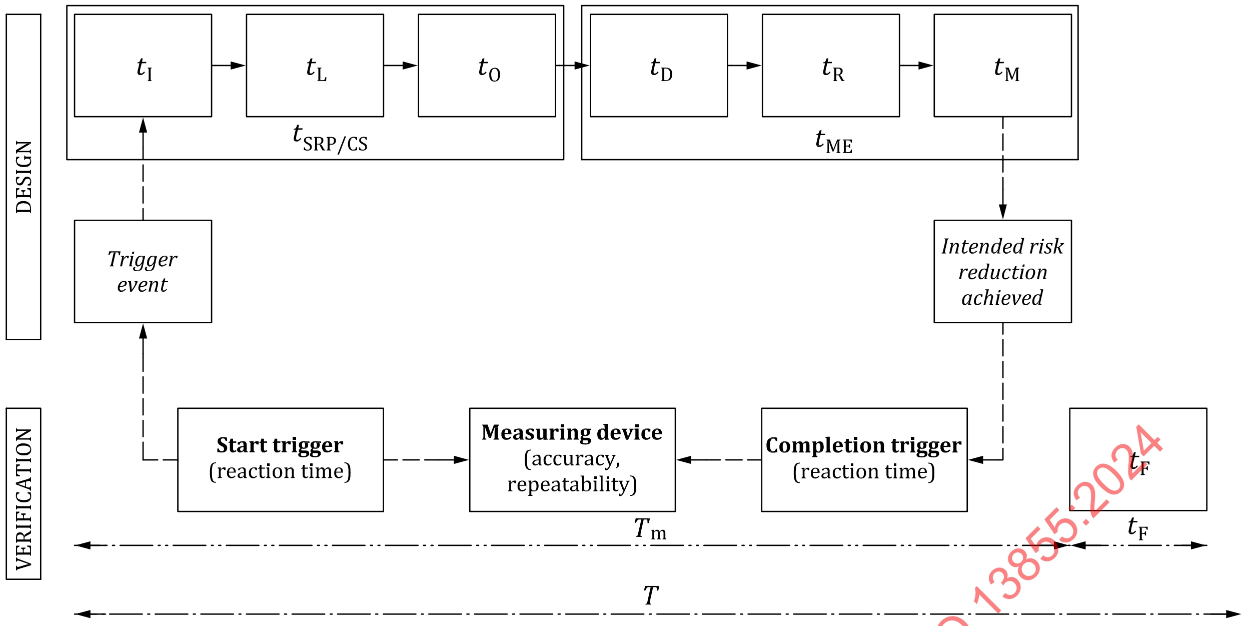

Key

T overall system response time

T_m overall system response time determined by measurement

For t_I, t_L, t_O, t_D, t_R, t_M, t_F see Key to Formula (3).

Figure 4 — Factors of T and measurement principle

NOTE 1 Each block within $t_{SRP/CS}$ and t_{ME} adds time delay from the initiation of a safety function (detection event of a potentially hazardous situation by the sensor) to the final achievement of the intended risk reduction.

NOTE 2 Not all elements of t_{ME} can affect the overall system response time in all safety functions to achieve the intended risk reduction. Elements which do not affect the overall system response time are not included in T.

When embedded safety functions prevent exceeding the time limit to achieve the stated risk reduction, the values t_{ME} and t_F in Formula (2) may be substituted with t_{SF} as shown in Formula (4).

$$T \geq t_{SRP/CS} + t_{SF} \quad (4)$$

where

T is the overall system response time used in the calculation to determine the separation distance;

$t_{SRP/CS}$ is the response time of the SRP/CS or SCS;

t_{SF} is the time delay from the initiation of a safety function.

Where the determination of $t_{SRP/CS}$ and t_{ME} is not possible, the overall system response time T shall be determined by measurement. The value T_m is the time resulting from measurements of the application. Deviations due to measurement errors shall be included based on the evaluation of multiple measurements with appropriate statistical methods. The overall system response time used within the calculation shall be greater than or equal to the sum of T_m and t_F as shown in Formula (5).

$$T \geq T_m + t_F \quad (5)$$

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where

T_m is the overall system response time determined by measurement;

t_F is the time related to a tolerance factor for the machinery, if necessary.

NOTE 3 Measurement of the time required to achieve the intended risk reduction can also be used for verification and validation of the separation distance.

NOTE 4 If a stop time measurement device is used to measure the value of T_m and start and completion triggers do not encompass all of the devices used in the logic path, the measured time can be shorter and therefore less accurate.

To determine T_m, the start and completion triggers shall be as close as possible to the trigger event of the input [presence or absence of a person(s)] and when the intended risk reduction is achieved, respectively. Manual operation of the start and completion trigger can introduce larger variables.

Determination of the time factors in the overall system response time to achieve the intended risk reduction is provided in Annex F.

5.5 Reaching distance factors associated with a protective device D_{DS}

5.5.1 General

Additional reaching distance factors are dependent upon how safeguards are applied. Safeguards allow a certain amount of reach toward the hazard zone prior to initiating a safety function; see 5.5.2. In some instances, the application can also allow reach toward the hazard zone around the safeguard without detection of a person; see 5.5.3.

5.5.2 Reaching distance in applications initiating a safety function

For the following safeguards, the associated reaching distances shall be in accordance with Clauses 7 to 12:

— SPE, including ESPE and pressure-sensitive mats and pressure-sensitive floors;

— two-hand control devices and single control devices; and

— interlocking guards.

NOTE SPE do not detect the presence of a person or parts of the human body at the detection zone until an amount of penetration into the detection zone occurs. When using two-hand control devices, single control devices, or interlocking guards, it is possible for a person to reach toward the hazard zone before initiating a safety function. This amount is the reaching distance associated with a protective device D_{DS}.

5.5.3 Reaching distance in applications where hazard zones can be reached by circumventing the safeguard

In addition to the separation distance resulting from the calculations related to the overall system response time [see Formula (1)], the hazard shall be beyond the reach of a person. Situations where a person(s) can reach a hazard which shall be prevented include

— interlocking guards where a person(s) can reach over, through or under the guard;

— reaching around the mechanical enclosure of an SPE; or

— the detection zone of an SPE is combined with a protective structure, allowing a person to reach over without detection. See also 8.2.3 and 8.4.4.

The reach by a person in such situations shall be determined in accordance with ISO 13857.

When determining the separation distance associated with a safeguard according to the provisions of this document, parameters which influence the reaching distance shall be identified and evaluated. Applicable parameters shall be included to determine the sizing, location or orientation of each safeguard or detection

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zone to achieve intended risk reduction. To determine the separation distance, the largest values according to Formula (1) and ISO 13857 shall be applied.

5.6 Supplemental distance factors

Depending on the application, machinery, and safeguard, a supplemental distance factor Z can be necessary. The manufacturer's instructions for use shall be applied when determining the supplemental distance factor(s).

NOTE The manufacturer can be the manufacturer of the safeguard or the machinery, or the integrator of the application or system.

Supplemental distance factors to be considered include, but are not limited to:

— Z_G = supplement for general device measurement errors, e.g.:

  — Z_M = supplement for position uncertainty of the machinery, resulting from the accuracy of the machinery position measurement system;

  — Z_P = supplement for position uncertainty of the person, resulting from the accuracy of the SPE.

— Z_R = supplement for reflection-based measurement errors. This supplement can be necessary if a retroreflector is in the vicinity of an SPE.

— Z_F = supplement for lack of ground clearance of moving machinery (e.g. a vehicle). This supplement can be necessary because, generally, a person is detected by an SPE above the foot, and the braking process of the machinery cannot take into account the length of the foot in front of the point of detection. A person's foot can be injured if the machinery has no ground clearance.

— Z_B = supplement for the decreasing braking torque of moving machinery (e.g. a vehicle), from the manufacturer's information for use.

By adding any applicable supplemental distance factors to Formula (1), the formula for calculating the separation distance becomes Formula (6):

$$S = (K \times T) + D_{DS} + (Z_G + Z_R + Z_F + Z_B + \ldots) \quad (6)$$

where

S	is the separation distance, in millimetres (mm);
K	is a parameter, in millimetres per second (mm/s), derived from data on approach speeds of the body or parts of the body (see 5.3);
T	is the overall system response time, in seconds (s), (see 5.4);
D_{DS}	is the reaching distance associated with a protective device, in millimetres (mm), (see 5.5);
Z_G, Z_R, Z_F, Z_B	are the supplemental distance factors as explained above.

6 Dynamic separation distance

6.1 General

The dynamic separation distance is determined to the boundary of the hazard zone that a hazard, hazardous point, parts of the machine that are the origin for the hazard or the machine itself can reach according to its actual position and the change in this position during the overall system response time T to achieve

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the intended risk reduction. The overall system response time T is analogous to that in 5.4 for the static separation distance with the addition of control system sampling interval t_S as shown in Formula (7):

$$T = t_I + t_L + t_O + t_D + t_R + t_M + t_F + t_S \tag{7}$$

where

$t_{I,}$ $t_{L,}$ $t_{O,}$ t_D $t_{R,}$ t_M and t_F	are as stated in the key to Formula (3);
t_S	is the control system sampling interval necessary to consider that the detection can occur at the very start of the following sample.

The position of the hazard at the time where the protective device is actuated and its stopping distance according to its actual speed and deceleration shall be considered for the relevant calculation.

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6.2 Dynamic separation distance for unknown human direction of approach

Where the human direction of approach is unknown, the dynamic separation distance calculation shall include the additional change in position of the hazard S_M during the overall system response time T to achieve the intended risk reduction. Therefore, the formula for the separation distance S to a dynamic hazard becomes Formula (8):

$$S = (K \times T) + S_M + D_{DS} + Z \tag{8}$$

where

K	is the approach speed (see 5.3);
T	is the overall system response time as calculated according to Formula (7);
S_M	is the change in position of the hazard (the distance travelled by the machinery until intended risk reduction is achieved);
D_{DS}	is a reaching distance factor(s) as determined according to 5.5;
Z	is an application-dependent supplemental distance factor(s) as determined according to 5.6.

If the acceleration and deceleration are known and constant, S_M shall be calculated as shown in Formula (9):

$$S_M = v_0 \times T - (d/2) \times t_M^2 + (a/2) \times t_{SRP/CS}^2 \tag{9}$$

where

S_M	is the change in position of the hazard (the distance travelled by the machinery until intended risk reduction is achieved);
v_0	is the initial speed of the machinery, in mm/s;
T	is the overall system response time as calculated according to Formula (7);
d	is the known possible deceleration (braking capability) of the machinery, in mm/s^2;
t_M	is the time related to mechanical inertia;
a	is the known possible acceleration of the machinery, in mm/s^2;
$t_{SRP/CS}$	is the response time of the SRP/CS or SCS.

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When considering the possible acceleration, the maximum speed v_{max} achievable by the machine should be taken into account.

Furthermore, if acceleration a is unknown, it can be calculated from the speed difference measured by the system, and therefore Formula (9) can be reduced to Formula (10), where a can be replaced by $\left(\frac{v_{max} - v_0}{t_{SRP/CS}}\right)$:

$$S_M = v_0 \times T - (d/2) \times t_M^2 + ((v_{max} - v_0)/2) \times t_{SRP/CS} \quad (10)$$

or, if infinite acceleration can be used, the following Formula (11) applies:

$$S_M = v_{max} \times T - (d/2) \times t_M^2 \quad (11)$$

where v_{max} is the maximum speed of the machinery.

Finally, if deceleration d is unknown, 0 mm/s^2 shall be used in all cases.

NOTE Both reductions can occur simultaneously in the case where a and d are both unknown.

Alternatively, the change in the position of the hazard S_M can be provided in accordance with a type-C standard, or, since the deceleration d can depend on several factors, S_M can be obtained by measurement. When obtained by measurement, S_M shall be determined according to Annex D. An additional application tolerance shall be added and this tolerance shall not be less than 10 % of the measured value. The calculated value of S_M shall be validated.

6.3 Dynamic separation distance for known human direction of approach

When the direction of the human approach is known, the dynamic separation distance may be calculated according to Formula 12 (see Figure 5):

$$S = S_A + D_{DS} + Z \quad (12)$$

with

$$S_A = \sqrt{S_M^2 + S_P^2 - 2S_M \times S_P \times \cos(\gamma)}$$

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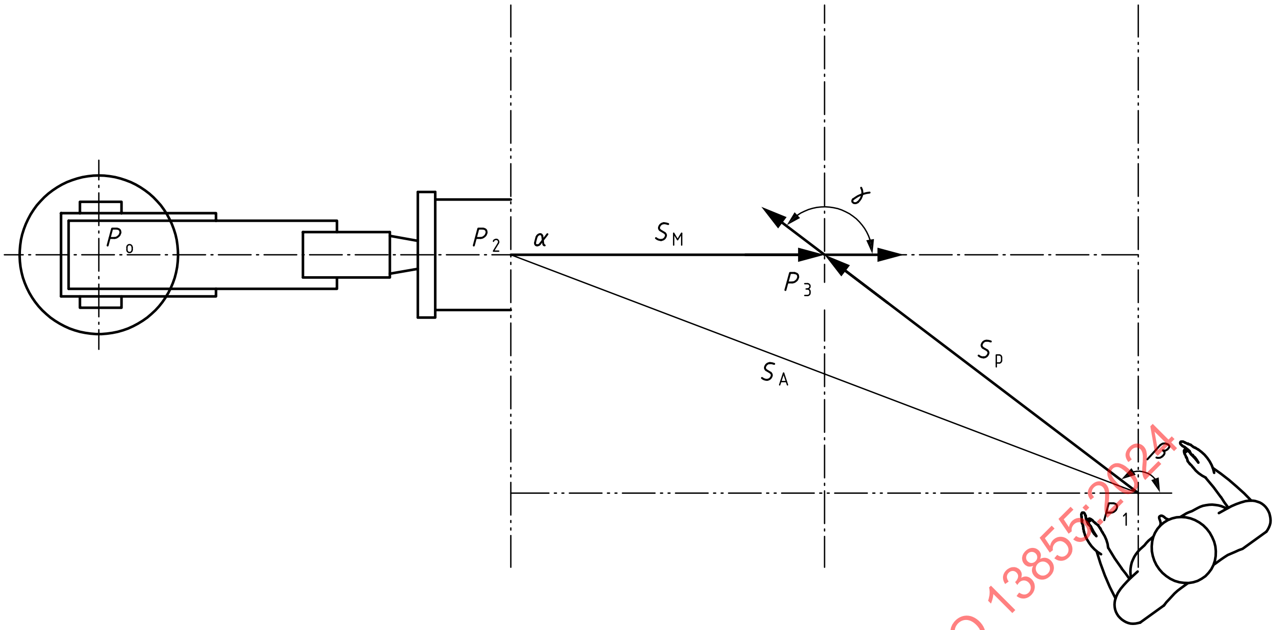

Key

S_A separation distance with dynamic approach

S_M change in position of the hazard (distance travelled by the machinery from T_0 until the intended risk reduction is achieved at T_1) from its initial speed v_0, the deceleration (braking capability) d, and the overall system response time T according to Formula (7)

S_P change in position of the person (distance travelled by the person from T_0 until contact at T_1 and the intended risk reduction is achieved), assuming a constant (maximum) speed of the person ($S_P = K \times T$)

T_0 time at which the safety function is triggered at position P_1

T_1 time at which the intended risk reduction is achieved; therefore $T = T_1 - T_0$, where T is the overall system response time

P_0 origin of coordinates

P_1 position of the person when the safety function is triggered at time T_0

P_2 position of the machine hazard when the safety function is triggered at time T_0

P_3 position of the machine hazard when the intended risk reduction is achieved (hazardous function terminated, e.g. the contact between robot and person does not lead to harm)

α approach angle of the hazard (to X-axis as reference. For simplification $\alpha = 0°$)

β approach angle of the person (to X-axis as reference)

γ angle between the movement of hazard and movement of the person

NOTE 1 The angle γ can be determined in the control system of the machine by sensing the movement direction of the hazard and detecting the approach direction of the person with an appropriate protective device.

Figure 5 — Approaching direction

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The control system sampling interval t_S between the measurements of the movement angles of the hazard α and the person β shall not exceed 0,1 s. Otherwise, the Formulae (8) to (11) in 6.2 apply.

NOTE 2 When the control system sampling interval t_s is not short enough, the expected change or variation of the angles will result in an unacceptable reduction of the dynamic separation distance which is only time related ($K \times T$).

NOTE 3 The maximum sampling interval t_s considers that human motion is unpredictable.

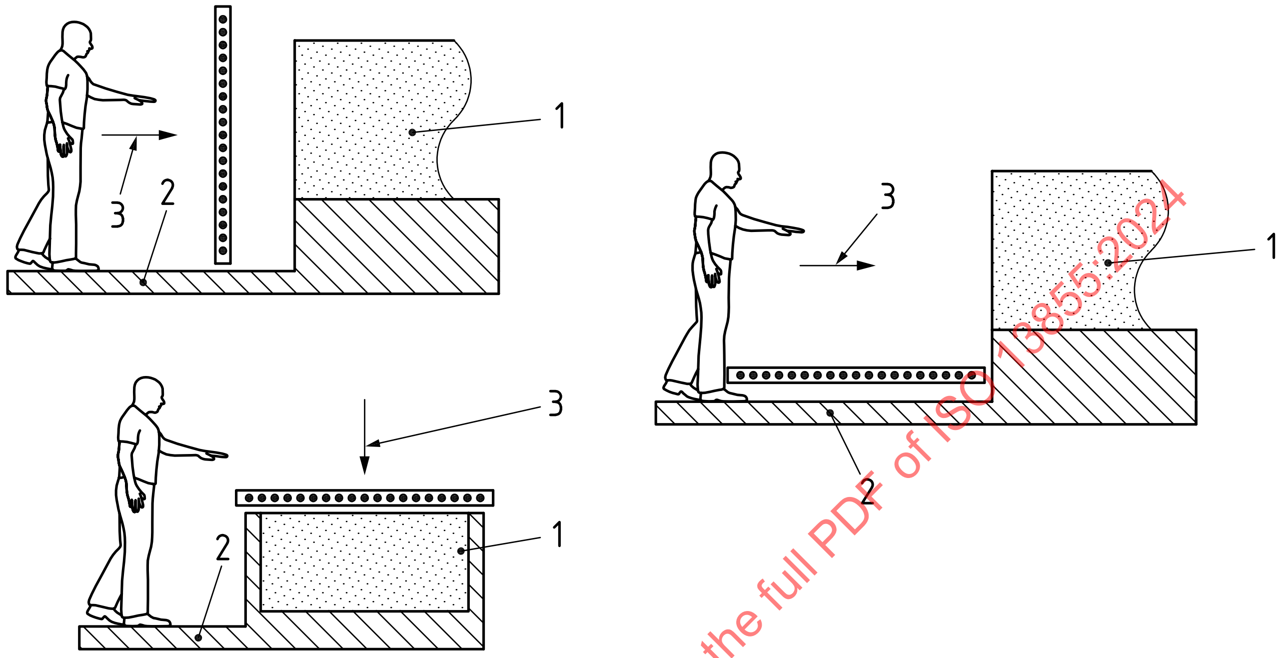
The provided example is illustrated in two dimensions for the simplicity of understanding. The principles of the calculation apply identically in three dimensions, wherein either case the calculation is performed continuously on a controller.

7 Consideration of the direction of approach to a detection zone

This document considers two different approaches to a detection zone:

— Orthogonal approach to a detection zone [see Figure 6 a) and Clause 8];

— Parallel approach to a detection zone [see Figure 6 b) and Clause 9].



a) Orthogonal approach

b) Parallel approach

Key

1 hazard zone

2 reference plane

3 direction of approach

Figure 6 — Typical directions of approach to a detection zone

If the detection zone has been installed such that it is angled 30° < Θ < 150° of the direction of approach, it shall be treated as an orthogonal approach [see Clause 8 and Figure 6 a) and Figure 8 a)]. If the detection zone has been installed such that it is angled 30° ≥ Θ or Θ ≥ 150° (up to 180°) of the direction of approach, it shall be treated as a parallel approach [see Clause 9 and Figure 6 b) and Figure 8 b)].

For the different angles to the direction of approach see Figure 7.

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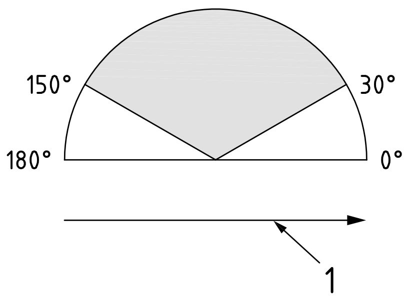
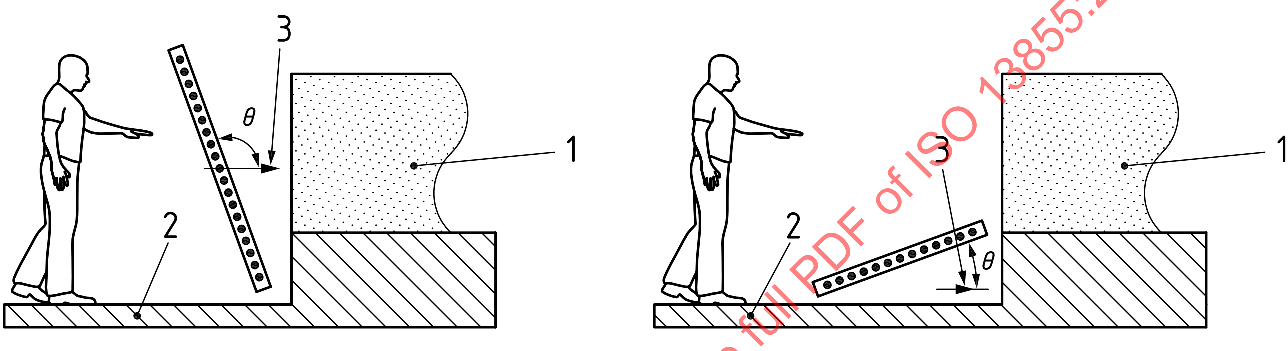


Key

1 direction of approach

Figure 7 — Different angles to the direction of approach



a) Orthogonal approaches **b) Parallel approach**

Key

1 hazard zone

2 reference plane

3 direction of approach

θ angle of detection zone relative to direction of approach

Figure 8 — Detection zone angled to the direction of approach

For SPE detecting presence of persons using volumetric detection, the direction of approach shall take into account the plane delimiting the volume at the point of detection.

8 Orthogonal approach to a detection zone

8.1 Determination of the reaching distance for an orthogonal approach to a detection zone

When determining the reaching distance D_{DS} associated with an orthogonal approach to a detection zone according to the provisions of this document, the applicable parameters shall be identified and evaluated. These parameters shall be considered and a final determination made for sizing, effective detection capability d_e and/or location of each detection zone to reduce risk to an acceptable level. Therefore, the reaching distance D_{DS} associated with an orthogonal approach to a detection zone shall be determined based upon review of all relevant application concerns:

— reaching over the detection zone resulting in D_{DO} (see 8.2);

— reaching through the detection zone resulting in D_{DT} (see 8.3);

— reaching under the detection zone resulting in D_{DU} (see 8.4).

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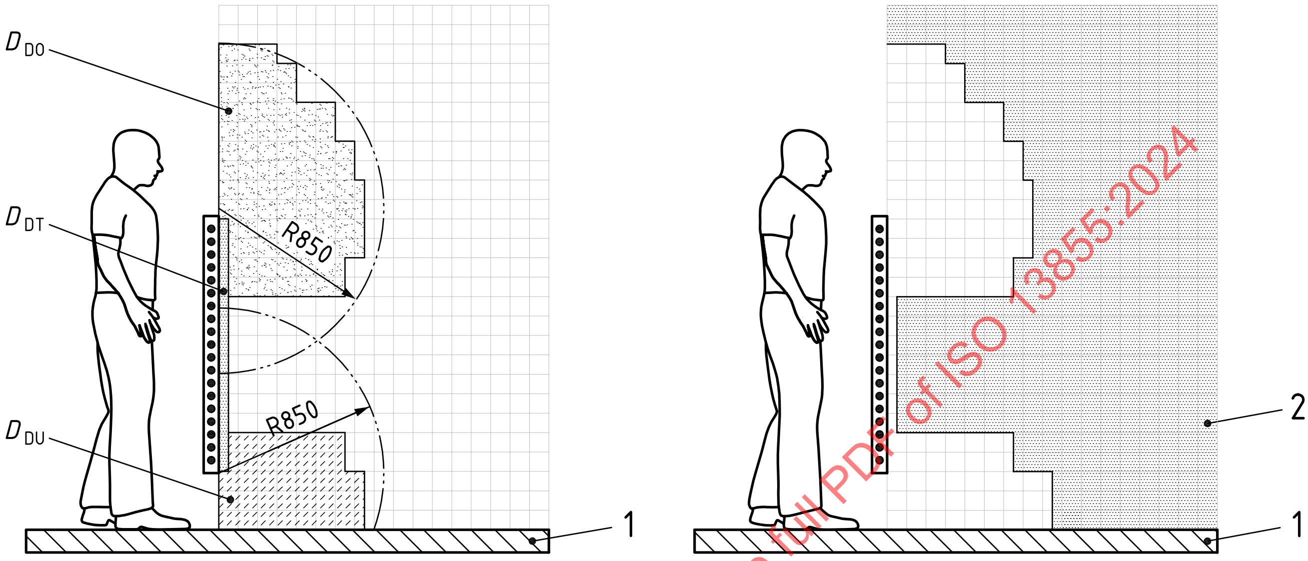
The largest value shall be applied for the reaching distance according to Formula (13) (see Figure 9).

$$D_{DS} = \max\,(D_{DO}, D_{DT}, D_{DU}) \quad (13)$$

When preventing undetected access to the hazard zone, the separation distance S shall apply from the nearest beam to the hazard zone. When preventing undetected access to an SRMCD, the reaching distance D_{DS} shall apply from the nearest beam to the SRMCD.

Dimensions in millimetres



Key

1 reference plane

2 location outside of accessible reach

D_{DO} reaching distance over a vertical detection zone

D_{DT} reaching distance through a vertical detection zone

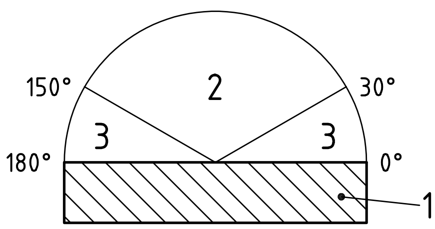
D_{DU} reaching distance under a vertical detection zone

Figure 9 — Consideration of all reaching factors for an orthogonal approach to a vertical detection zone (applies to protective devices as well as SRMCD)

Figure 9 shows an example illustrating a detection zone with effective detection capability d_e allowing access toward the hazard with the fingers.

A detection zone shall be considered vertical when the angle to the reference plane is greater than 30° and less than 150°. Otherwise the detection zone shall be considered horizontal. See Figure 10.

NOTE This document assumes that the reference plane is horizontal.



Key

1 reference plane 2 vertical 3 horizontal

Figure 10 — Angle of detection zone relative to reference plane

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8.2 Reaching over a vertical detection zone

8.2.1 General

To prevent undetected access over a vertical detection zone by

— reaching into a safeguarded space toward a hazard zone, or

— reaching out of a safeguarded space toward an SRMCD,

the separation distance shall include the reaching distance D_{DO} (see Figure 11) according to this subclause.

NOTE This can also be achieved by the provision of guards or other protective measures.

The effective detection capability d_e can change the height of the effective detection zone which will affect the reaching distance over a vertical detection zone D_{DO}.

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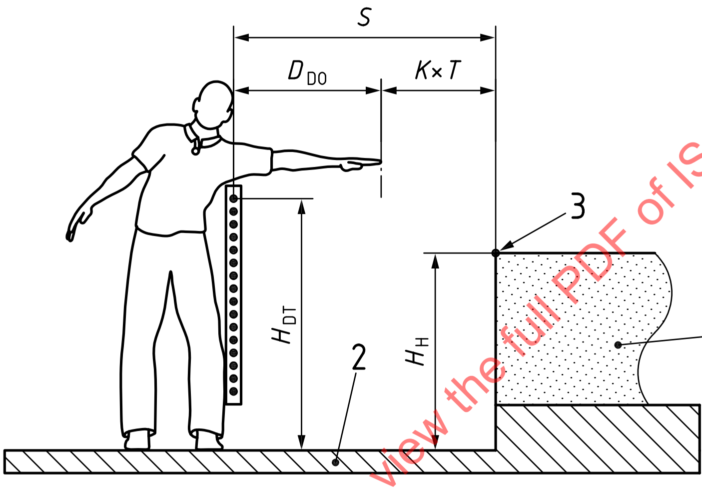

Key

1	hazard zone
2	reference plane
3	nearest point
S	separation distance
K	approach speed
T	overall system response time
H_H	height of the hazard zone from the reference plane
H_{DT}	height of the upper edge of the detection zone from the reference plane
D_{DO}	reaching distance over a vertical detection zone

Figure 11 — Reaching over a vertical detection zone

8.2.2 Vertical detection zones without additional protective structures

A distance D_{DO} is required to prevent undetected access by reaching over a vertical detection zone. See Formula (14).

For D_{DO}, the values in Table 2 shall apply. D_{DO} is given in Table 2 as the distance in millimetres, based on the distance which a part of the body (usually a hand) can move, prior to the actuation of the ESPE, towards:

— the hazard zone; or

— the SRMCD.

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Figure 11 illustrates reaching over a vertical detection zone without an additional protective structure.

Where the height of an ESPE detection zone is already fixed, Table 2 may be used to derive the separation distance S. Where the separation distance is already fixed, Table 2 may also be used to derive the required height of the ESPE detection zone.

$$S = (K \times T) + D_{DO} + Z \quad (14)$$

where K = 2 000 mm/s.

By replacing K with 2 000, Formula (14) becomes Formula (15):

$$S = (2\,000 \times T) + D_{DO} + Z \quad (15)$$

Formula (15) applies to all separation distances S up to and including 500 mm. The minimum value of S shall not be less than 100 mm. First calculate S using Formula (15).

Where the value of S exceeds 500 mm, Formula (14) may be used with an approach speed K = 1 600 mm/s to become Formula (16). The value of S shall not be less than 500 mm.

$$S = (1\,600 \times T) + D_{DO} + Z \quad (16)$$

Table 2 — Reaching over the vertical detection zone of ESPE

Dimensions in millimetres

Height of the hazard zone from the reference plane H_H	Height of the upper edge of the detection zone from the reference plane H_{DT}											
	900	**1 000**	**1 100**	**1 200**	**1 300**	**1 400**	**1 600**	**1 800**	**2 000**	**2 200**	**2 400**	**2 600**
	Reaching distance over a vertical detection zone D_{DO}											
2 600[a]	0	0	0	0	0	0	0	0	0	0	0	0
2 500	400	400	350	300	300	300	300	300	250	150	100	0
2 400	550	550	550	500	450	450	400	400	300	250	100	0
2 200	800	750	750	700	650	650	600	550	400	250	0	0
2 000	950	950	850	850	800	750	700	550	400	0	0	0
1 800	1 100	1 100	950	950	850	800	750	550	0	0	0	0
1 600	1 150	1 150	1 100	1 000	900	850	750	450	0	0	0	0
1 400	1 200	1 200	1 100	1 000	900	850	650	0	0	0	0	0
1 200	1 200	1 200	1 100	1 000	850	800	0	0	0	0	0	0
1 000	1 200	1 150	1 050	950	750	700	0	0	0	0	0	0
800	1 150	1 050	950	800	500	450	0	0	0	0	0	0
600	1 050	950	750	550	0	0	0	0	0	0	0	0
400	900	700	0	0	0	0	0	0	0	0	0	0
200	600	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0

NOTE 1 ESPE with a height of the upper edge of the detection zone below 900 mm is not included since it does not offer sufficient protection against circumventing or stepping over.

NOTE 2 Most values given in this table are lower in relation to the values of ISO 13857:2019, Tables 1 and 2, since parts of the body cannot support themselves on safeguards in case of reaching over.

[a] Approach to the hazard zone or SRMCD by reaching over is impossible.

When determining the values of Table 2 it shall not be interpolated. If the known values H_H, H_{DT} or D_{DO} are between two values of Table 2, the greater value shall be used.

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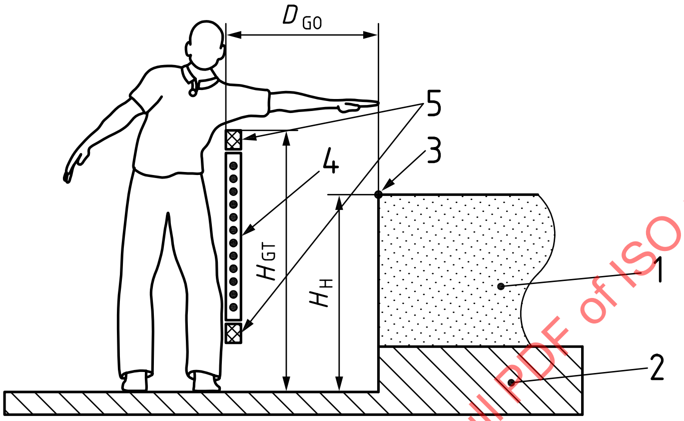
When determining an acceptable location of an SRMCD in accordance with 4.6, Table 2 applies. Instead of measuring the height of the hazard zone from the reference plane H_H, substitute the height of the SRMCD from the reference plane.

In all cases Formula (13) of 8.1 applies.

8.2.3 Vertical detection zones with additional protective structures

When a protective structure is applied above a vertical detection zone, it can be possible to gain support on the protective structure when reaching over the detection zone (see Figure 12). If access can be achieved by reaching over the protective structure, the separation distance S shall not be less than the reaching distance over a protective structure D_{GO} determined according to ISO 13857:2019, 4.2.2, Table 2.



Key

1	hazard zone	H_H	height of the hazard zone from the reference plane
2	reference plane	H_{GT}	height of the upper edge of the protective structure from the reference plane
3	nearest point	D_{GO}	reaching distance over a protective structure
4	ESPE		
5	protective structure		

Figure 12 — Example of reaching over the vertical detection zone of ESPE combined with protective structure

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When determining an acceptable location of an SRMCD in accordance with 4.6, ISO 13857:2019, Table 2 applies. Instead of measuring the height of the hazard zone from the reference plane H_H, substitute the height of the SRMCD from the reference plane.

8.3 Reaching through a vertical detection zone

8.3.1 General

If the effective detection capability can be modified (manually or automatically), the largest anticipated value of d_e shall be used, and the reaching distance through a vertical detection zone D_{DT} shall be adjusted accordingly.

The effective detection capability d_e will affect how much of the human body can reach through a detection zone without actuating the ESPE (see Figure 13).

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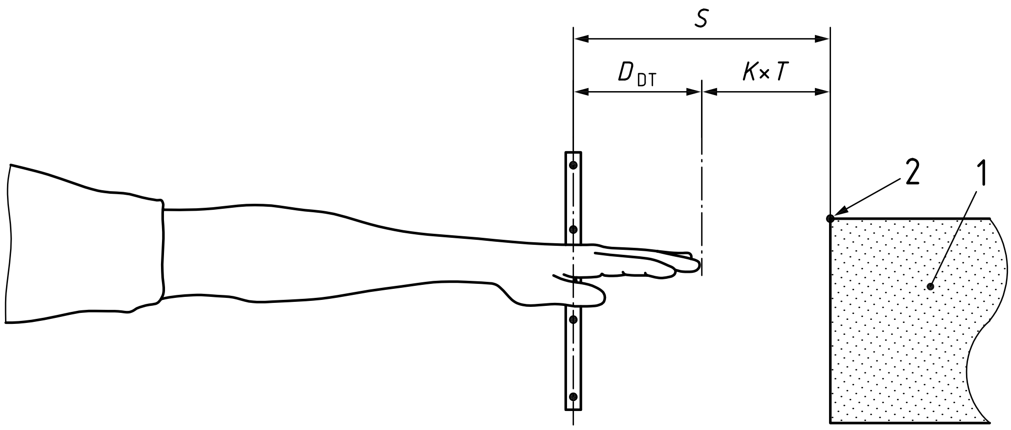

Key

1	hazard zone	K	approach speed
2	nearest point	T	overall system response time
S	separation distance	D_{DT}	reaching distance through a vertical detection zone

Z application-dependent supplemental distance factor according to 5.6

Figure 13 — Reaching through a vertical detection zone

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8.3.2 Reaching through a vertical detection zone with effective detection capability $d_e \leq 40$ mm

The separation distance S in millimetres, from the detection zone to the hazard zone shall be calculated according to Formula (17):

$$S = (K \times T) + D_{DT} + Z \qquad (17)$$

where

K is the approach speed 2 000 mm/s;

T is the overall system response time according to Formula (7);

D_{DT} is the reaching distance through a vertical detection zone, determined by Formula (18);

$$D_{DT} = 8\,(d_e - 14) \qquad (18)$$

but not less than zero.

where

d_e is the effective detection capability;

Z is an application-dependent supplemental distance factor as determined according to 5.6.

By replacing K with 2 000 and D_{DT} with Formula (18), Formula (17) becomes Formula (19):

$$S = (2\,000 \times T) + 8\,(d_e - 14) + Z \qquad (19)$$

Formula (19) applies to all separation distances of S up to and including 500 mm. The minimum value of S shall be 100 mm.

Where the value for S, calculated using Formula (19), exceeds 500 mm, Formula (17) may be used with an approach speed K = 1 600 mm/s and D_{DT} according to Formula (18) to become Formula (20). In this case, the minimum value of S shall be 500 mm.

$$S = (1\,600 \times T) + 8\,(d_e - 14) + Z \qquad (20)$$

Where it is foreseeable that ESPE will be used in non-industrial applications, the separation distance S shall be calculated with Formula (19) and be increased by at least 75 mm. In such cases, Formula (20) is not applicable.

When determining an acceptable location of an SRMCD in accordance with 4.6, Formula (18) applies.

8.3.3 Reaching through a vertical detection zone with effective detection capability 40 mm < d_e ≤ 55 mm

The separation distance S, in millimetres, from the detection zone to the hazard zone shall be calculated according to Formula (17) as given in 8.3.2,

where

K	is the approach speed 2 000 mm/s;
T	is the overall system response time according to Formula (7);
D_{DT}	is the reaching distance through a vertical detection zone, determined by Formula (21);

$$D_{DT} = 208 + 12(d_e - 40) \qquad (21)$$

where

d_e	is the effective detection capability.

NOTE The value 208 mm results from the application of Formula (18) given in 8.3.2 for the portion of effective detection capability d_e between 14 mm and 40 mm.

Formula (17) becomes Formula (22):

$$S = (2\,000 \times T) + 12\,d_e - 272 + Z \qquad (22)$$

Where the value for S calculated using Formula (22) exceeds 500 mm, Formula (17) may be used with an approach speed K = 1 600 mm/s and D_{DT} according to Formula (21) to become Formula (23). In this case, the minimum value of S shall be 500 mm.

$$S = (1\,600 \times T) + 12\,d_e - 272 + Z \qquad (23)$$

Where it is foreseeable that ESPE will be used in non-industrial applications, the separation distance S shall be calculated with Formula (22) and be increased by at least 75 mm. In such cases, Formula (23) is not applicable.

When determining an acceptable location of an SRMCD in accordance with 4.6, Formula (21) applies.

8.3.4 Reaching through a vertical detection zone with effective detection capability 55 mm < d_e ≤ 120 mm

ESPE with effective detection capability 55 mm < d_e ≤ 120 mm diameter does not always detect intrusion of the hands and, therefore, shall only be used where the risk assessment indicates that detection of intrusion of the hands is not necessary.

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The separation distance S from the detection zone shall be calculated using Formula (17) as given in 8.3.2 with an approach speed K = 1 600 mm/s and D_{DT} = 850 mm to result in Formula (24):

$$S = (1\,600 \times T) + 850 + Z \tag{24}$$

NOTE 850 mm is considered to be the standard arm length.

When determining an acceptable location of an SRMCD in accordance with 4.6, the 850 mm reaching distance applies.

8.3.5 Reaching through a vertical detection zone with effective detection capability d_e > 120 mm or undefined

Devices with multiple beams or arrangements of single beams may present an undefined effective detection capability or an effective detection capability d_e greater than 120 mm. Such devices or arrangements can be used to detect access of the whole body, but are not suitable for the detection of upper and lower limbs or small parts of the body (e.g. hand or fingers).

If only whole body access detection is required, such devices or arrangements shall be positioned at a separation distance in accordance with Formula (24). See Figure 14.

The application of devices with multiple beams or arrangements of single beams shall consider methods by which such devices can be circumvented. For example:

— crawling below the lowest beam;

— reaching over the top beam;

— reaching between two of the beams;

— whole body access by passing between two beams.

Where access to the hazard zone requires stepping up more than 300 mm from the lower surface (H_s > 300 mm) and the higher surface has a step width not greater than 50 mm, two beams with a separation equal or less than 500 mm may be used. In such a case, the lowest beam height shall be 200 mm above the higher surface and the highest beam height shall be no less than 900 mm above the lower surface.

Additional requirements are given in Annex C.

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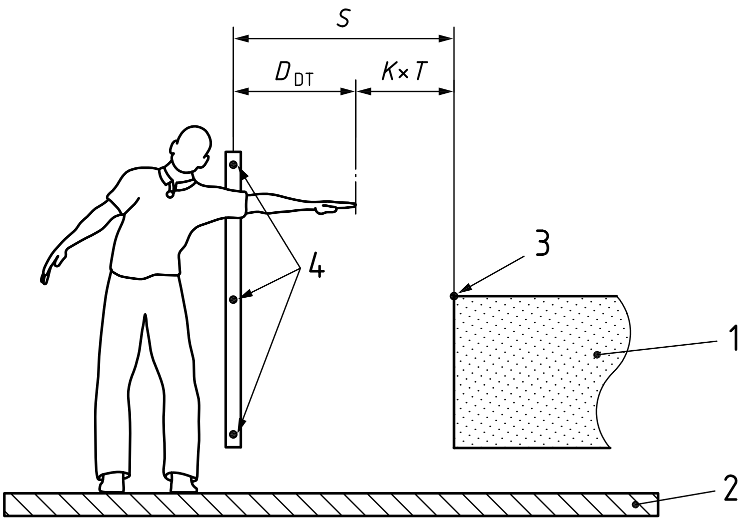

Key

1	hazard zone	S	separation distance
2	reference plane	K	approach speed
3	nearest point	T	overall system response time
4	ESPE beams	D_{DT}	reaching distance through a vertical detection zone

Figure 14 — Reaching through a vertical detection zone with effective detection capability d_e > 120 mm or undefined

When determining an acceptable location of an SRMCD in accordance with 4.6, the 850 mm reaching distance applies.

8.3.6 Indirect approach — Path restricted by obstacles

When the access by the upper limbs is hindered by obstacles that are permanently fixed, the separation distance can be the shortest path around these obstacles (see Figure 15 for indirect approach). In this case, the approach speed differs from the speed of the direct approach and, therefore, it may be reduced to 1 600 mm/s.

For *S*, the greater value resulting from the comparison of all the separation distances shall be applied.

Obstacles can result from the functional design of the machine, but shall not be applied with the sole purpose to reduce the approach speed of the upper limbs.

NOTE 1 Obstacles are parts of the machine, such as housings, covers, impeding devices, or ancillary equipment that prevent direct approach to the hazard.

NOTE 2 It can be acceptable to use a lower approach speed for certain infrequent operations where only indirect approach is possible. As an example, research has shown that for two obstacles with a distance of 1 m or less and a minimum height of 500 mm, a reduction factor of 0,8 can be applicable (see Reference [28]).

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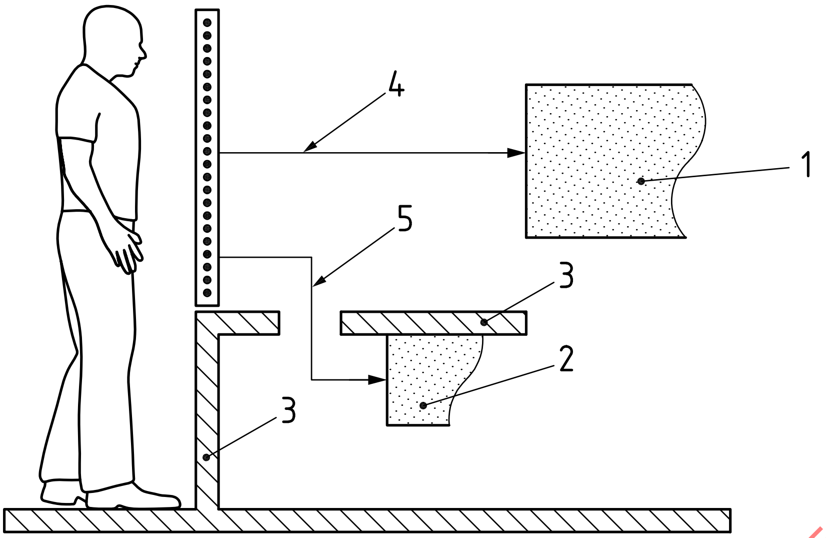

Key
1 hazard zone 1
2 hazard zone 2
3 obstacle
4 direct approach
5 indirect approach

Figure 15 — Example of direct and indirect approach

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For the indirect approach, the actual distance travelled upon approach S^* is the shortest path from the ESPE to the hazard zone around the obstacle(s) and shall be calculated according to Formula (25), see Figure (16).

$$S^* = l_1 + l_2 \ldots + l_n \qquad (25)$$

where

$l_1, l_2, \ldots l_n$	are the shortest individual distances of each section of the path around the obstacles;
$S^* \geq S$	with S calculated according to the relevant subclauses 8.3.1 to 8.3.5.

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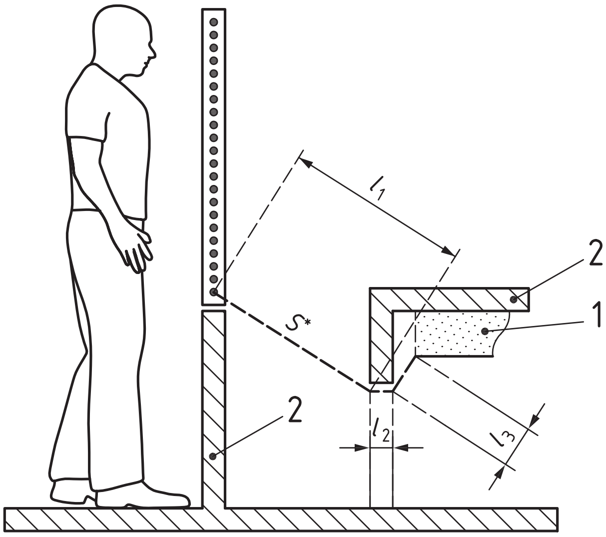

Key

1	hazard zone
2	obstacle
l_1, l_2, l_3	shortest distance around obstacles
S*	actual distance travelled upon approach

Figure 16 — Illustration of calculating the actual distance travelled

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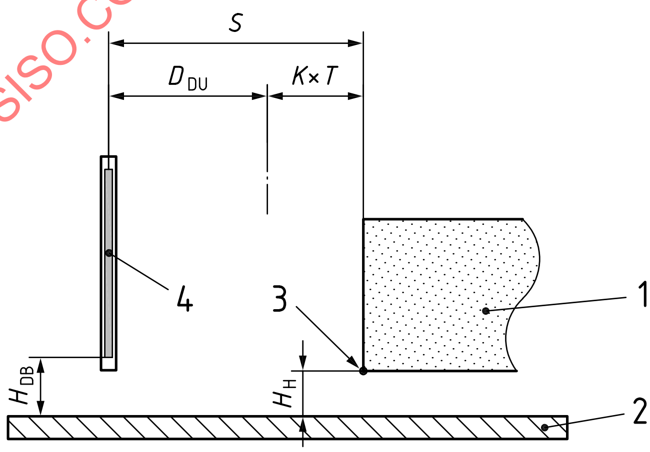
8.4 Reaching under a vertical detection zone

8.4.1 General

The following values are considered to prevent undetected access to hazard zones when reaching under a detection zone in an orthogonal approach.

The maximum height of the lower edge of the detection zone from the reference plane H_{DB} shall not exceed 300 mm. Therefore, this clause only addresses applications where $H_{DB} \leq 300$ mm. See Figure 17.



Key

1 hazard zone

2 reference plane

3 nearest point

4 detection zone

S separation distance

K approach speed
T overall system response time
H_H height of the hazard zone from the reference plane
H_{DB} height of the lower edge of the detection zone from the reference plane
D_{DU} reaching distance under a vertical detection zone

Figure 17 — Reaching under a detection zone with orthogonal approach

8.4.2 Reaching under a vertical detection zone with (d_e + H_{DB}) ≤ 40 mm

The separation distance S, in millimetres, from the detection zone to the hazard zone shall be calculated according to Formula (26):

$$S = (K \times T) + D_{DU} + Z \quad (26)$$

where K = 1 600 mm/s

K is the approach speed 1 600 mm/s;

T is the overall system response time as calculated according to Formula (7)

and the reaching distance under a vertical detection zone, D_{DU}, becomes Formula (27):

$$D_{DU} = 8\ (d_e + H_{DB} - 14) \quad (27)$$

but not less than 0 mm

where

d_e is the effective detection capability;

H_{DB} is the height of the lower edge of the detection zone from the reference plane;

Z is an application-dependent supplemental distance factor as determine according to 5.6

By replacing K with 1 600 and D_{DU} with 8 (d_e + H_{DB} − 14), Formula (26) becomes Formula (28):

$$S = (1\ 600 \times T) + 8\ (d_e + H_{DB} - 14) + Z \quad (28)$$

When determining an acceptable location of an SRMCD in accordance with 4.6, Formula (27) applies.

8.4.3 Reaching under a vertical detection zone with height of the lower edge from the reference plane 40 mm < d_e + H_{DB} and H_{DB} ≤ 300 mm

Table 3 shall be used to determine the reaching distance under a vertical detection zone D_{DU} when the effective detection capability d_e plus the height of the lower edge of the detection zone from the reference plane H_{DB} is greater than 40 mm and H_{DB} is less than or equal to 300 mm.

NOTE If the reference plane is above the hazard, such as when the reference plane is an elevated platform or the hazard zone is in a recessed pit, the reference plane can be considered as a physical protective structure.

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Table 3 — Horizontal projection of the reaching distance D_{DU} when accessing with upper limbs under a vertical detection zone with 40 mm < $d_e + H_{DB}$ and $H_{DB} \leq 300$ mm

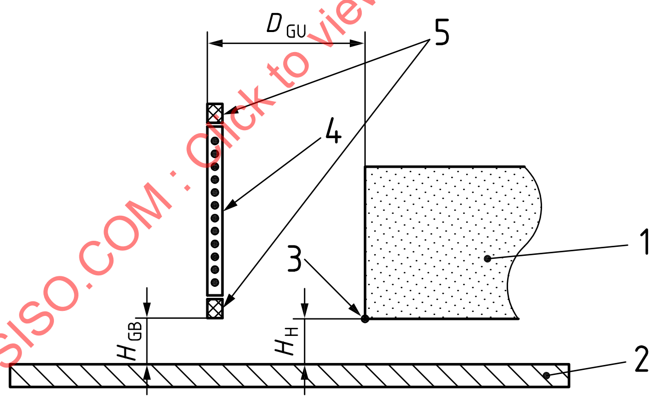
Height of the hazard zone from the reference plane H_H mm	Horizontal projection of the reaching distance under a vertical detection zone D_{DU} mm
0	850
300	850
500	800
700	700
900	450
1 100	0

When determining an acceptable location of an SRMCD in accordance with 4.6, Table 3 applies. Instead of measuring the height of the hazard zone from the reference plane H_H, substitute the height of the SRMCD from the reference plane.

8.4.4 Reaching under a vertical detection zone with additional protective structures

When the hazard zone can be approached by reaching under the protective structure, the separation distance S shall not be less than the horizontal projection of the reaching distance to the hazard zone D_{GU} shall not be less than the values according to ISO 13857:2019, Table 4, when $H_{GB} \leq 120$ mm, and Table 4 of this document when 120 mm < $H_{GB} \leq 180$ mm (see Figure 18).

NOTE According to ISO 13857:2019, Table 7, Note, slot openings with e > 180mm will allow access for the whole body. In 8.4.3 of this document, H_{GB} is equivalent to this value e.



Key

1 hazard zone
2 reference plane
3 nearest point
4 ESPE
5 protective structure

H_H height of the hazard zone from the reference plane
H_{GB} height of the lower edge of the protective structure from the reference plane
D_{GU} reaching distance under a protective structure

Figure 18 — Reaching under a vertical detection zone with an additional protective structure

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Table 4 — Horizontal projection of the reaching distance D_{GU} when accessing with upper limbs under a protective structure with 120 mm < H_{GB} ≤ 180 mm

Height of the hazard zone from the reference plane H_H mm	Horizontal projection of the reaching distance under a protective structure D_{GU} mm
0	900
200	900
400	900
600	900
800	800
1 000	600
1 200	0

When determining an acceptable location of an SRMCD in accordance with 4.6, the values according to ISO 13857:2019, Table 4 apply when H_{GB} ≤ 120 mm. When 120 mm < H_{GB} ≤ 180 mm, the values according to Table 4 of this document apply. Instead of measuring the height of the hazard zone from the reference plane H_H, substitute the height of the SRMCD from the reference plane.

8.5 Single beam applications

Where only a single beam is used to detect the approach of a person, the separation distance S, in millimetres, from the detection zone to the hazard zone shall be calculated according to Formula (1) as given in 5.2.

Using Formula (1) with an approach speed K = 1 600 mm/s and D_{DS} = 1 200 mm, the separation distance S becomes Formula (29):

$$S = (1\,600 \times T) + 1\,200 + Z \quad (29)$$

NOTE 1 When a single beam is applied, the resulting approach is always orthogonal. See Annex C.

NOTE 2 The value 1 200 mm for D_{DS} considers all possible approaches of the human body (reaching over, through or under the single beam).

The single beam shall be positioned according to Annex C.

When determining an acceptable location of an SRMCD in accordance with 4.6, the 1 200 mm reaching distance applies.

8.6 Cycle re-initiation of machine operation employing active opto-electronic protective devices (AOPDs) with control function

Where AOPDs are used for cycle re-initiation of a machine:

— the effective detection capability d_e shall be ≤ 30 mm;

— Formula (19) (see 8.3.2) shall apply;

— the separation distance S shall be > 150 mm.

If the effective detection capability d_e is ≤ 14 mm:

— Formula (19) (see 8.3.2) shall apply;

— the separation distance S shall be > 100 mm.

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NOTE 1 Conditions for using AOPDs in cycle initiation of machine operation are given in ISO 12100:2010, 6.3.2.5.3, and IEC 62046:2018, 5.8.

NOTE 2 Additional requirements for AOPD are given in IEC 61496-1.

NOTE 3 It is possible for AOPD with an effective detection capability d_e > 30 mm diameter to not detect the wrist or the lower arm after the hand has been detected. An unexpected cycle re-initiation can occur.

9 Parallel approach to a detection zone

9.1 General

If the effective detection capability d_e can be modified (manually or automatically), the largest anticipated value of d_e shall be applied for the calculation of the separation distance, or it shall be ensured that the associated reaching distance D_{DS} resulting from each modification is added accordingly.

Detection zones used in parallel approach are realized using SPE, including:

— AOPD;

— AOPDDR;

— VBPD;

— pressure-sensitive mats and pressure-sensitive floors.

For ESPE, the part(s) of the human body which can be detected by the detection zone is a function of the effective detection capability d_e. This effective detection capability is defined by the design of the ESPE, or can be configurable within the ESPE (e.g. detection zone switching, blanking of the detection zone).

When a detection zone is used in parallel approach, the parameters addressed in 9.2 to 9.4 shall be identified and evaluated.

9.2 Height of a detection zone for a parallel approach

For a safeguard where the direction of approach is parallel to the detection zone, the height of the detection zone from the reference plane H_D shall not be greater than 1 000 mm. However, if the height of the detection zone from the reference plane H_D is greater than 200 mm, there is the possibility of inadvertent undetected access beneath the detection zone. This shall be taken into account in the risk assessment and additional protective measures applied, if necessary.

The minimum allowable height of the detection zone from the reference plane H_D is directly related to the effective detection capability d_e of the ESPE. A formula to determine the minimum allowable height of a (horizontal) detection zone from the reference plane H_D may be represented by Formula (30). See also, Figure 19 and Figure 20.

$$H_D \geq 15 \times (d_e - 50) \text{, but neither less than zero nor greater than 1 000 mm} \quad (30)$$

When an angled approach is considered as parallel approach [see Clause 7 and Figures 7 and 8b)], then Formula (30) linking H_D and d_e shall apply to the edge of the detection zone furthest from the hazard zone (see Figure 19).

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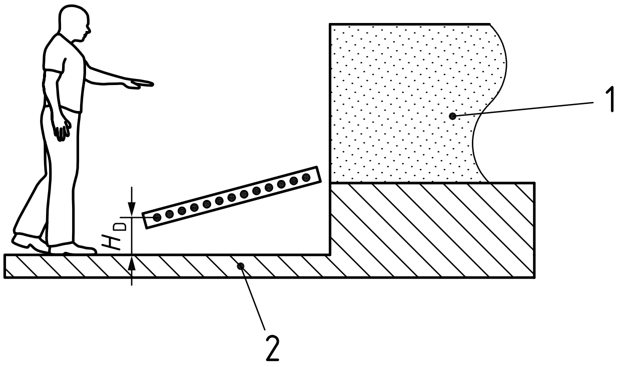


Key

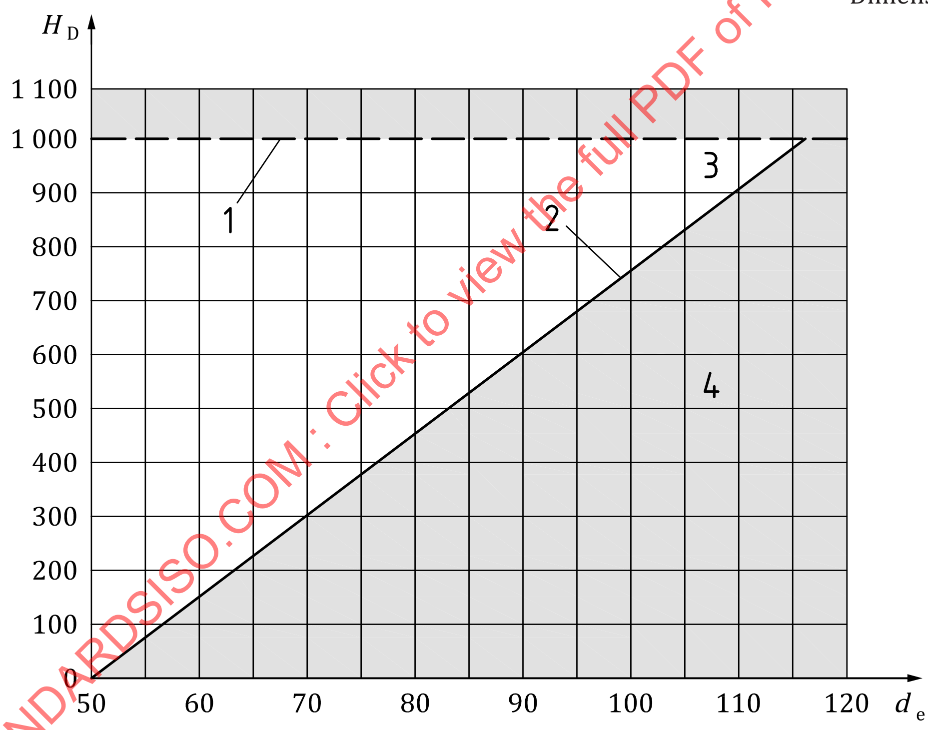
1 hazard zone

2 reference plane

H_D height of the horizontal detection zone from the reference plane

Figure 19 — Height of the detection zone (lowest beam)

Dimensions in millimetres



Key

1 maximum height

2 minimum height

3 permitted

4 not permitted

H_D height of the horizontal detection zone from the reference plane

d_e effective detection capability

Figure 20 — Allowable height of the horizontal detection zone from the reference plane H_D

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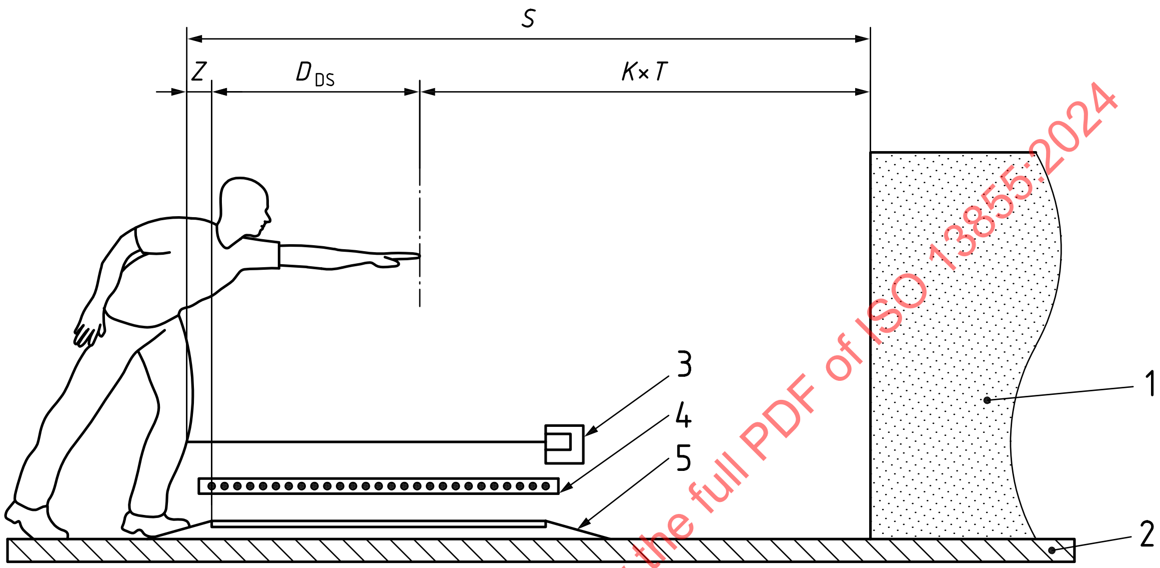
9.3 Separation distance of a detection zone for a parallel approach

When the direction of approach is considered parallel to the detection zone according to Clause 7, the separation distance S, in millimetres, from the edge of the detection zone furthest from the hazard zone shall be calculated using Formula (1) as given in 5.2, see Figure 21.

Using Formula (1) with an approach speed K = 1 600 mm/s and D_{DS} = 1 200 mm, the separation distance S becomes Formula (31):

$$S = (1\,600 \times T) + 1\,200 + Z \tag{31}$$



Key

1 hazard zone

2 reference plane

3 AOPDDR

4 AOPD

5 pressure-sensitive mat/floor

S separation distance

K approach speed

T overall system response time

D_{DS} reaching distance associated with a protective device

Z application-dependent supplemental distance factor according to 5.6

NOTE S and Z are shown only for the minimum distance applicable to the AOPDDR (laser scanner).

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Figure 21 — Separation distance for parallel approach

When determining an acceptable location of an SRMCD in accordance with 4.6, the 1 200 mm reaching distance applies.

9.4 Depth of a detection zone for a parallel approach

The minimum depth of the horizontal detection zone F_D shall hinder a person from stepping over the detection zone undetected. Where a stepping surface with a depth of greater than or equal to 70 mm exists beyond the detection zone, the minimum depth of the horizontal detection zone F_D shall be greater than or equal to 1 200 mm to prevent a person from stepping over and passing undetected [see Figure (22a)]. If additional measures (e.g. protective structures, physical obstructions or other fixed elements) are used to

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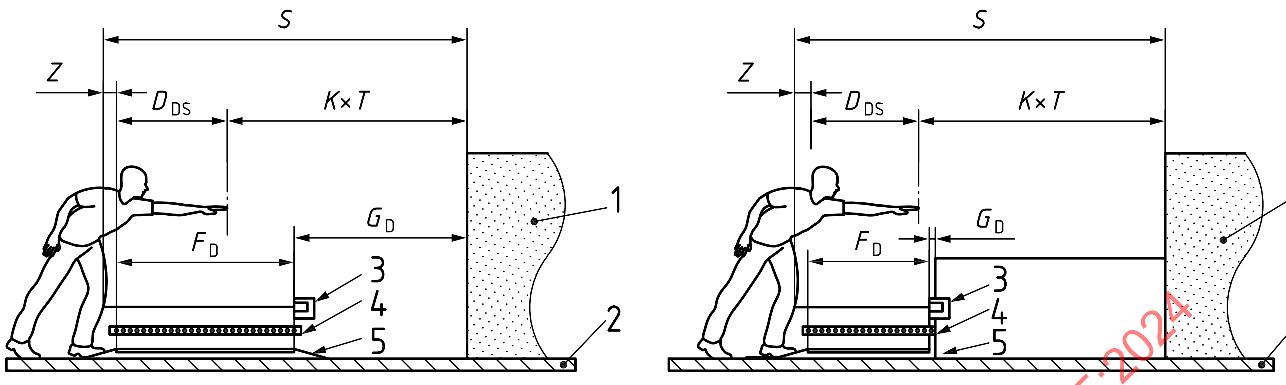
prevent this situation such that a person will be detected by the detection zone, the minimum depth of the horizontal detection zone F_D shall be greater than or equal to 900 mm (see Figure 22b).



$G_D \geq 70$ mm
$F_D \geq 1\,200$ mm

a) Person can step over the detection zone undetected

$G_D < 70$ mm
$F_D \geq 900$ mm

b) Person cannot step over the detection zone undetected (in this example *S* begins closer than F_D)

Key

1 hazard zone
2 reference plane
3 AOPDDR
4 AOPD
5 pressure-sensitive mat/ pressure-sensitive floor

G_D distance between detection zone and nearest obstruction
S separation distance
K approach speed
T overall system response time
Z application-dependent supplemental distance factor
D_{DS} reaching distance associated with a protective device
F_D depth of the horizontal detection zone

NOTE The minimum depth of a horizontal detection zone F_D in a parallel approach addresses a different distance than the reaching distance associated with a protective device D_{DS} = 1 200 mm according to 9.3.

Figure 22 — Minimum depth of detection zone

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10 Two-hand control devices

10.1 Two-hand control devices not preventing encroachment

The separation distance *S* from the nearest actuator to the hazard zone shall be calculated using Formula (32):

$$S = (K \times T) + D_{DS} \qquad (32)$$

where

K = 1 600 mm/s;

D_{DS} = 550 mm.

By replacing the approach speed *K* with 1 600 mm/s and the reaching distance associated with a protective device D_{DS} with 550 mm, Formula (32) becomes Formula (33):

$$S = (1\,600 \times T) + 550 \qquad (33)$$

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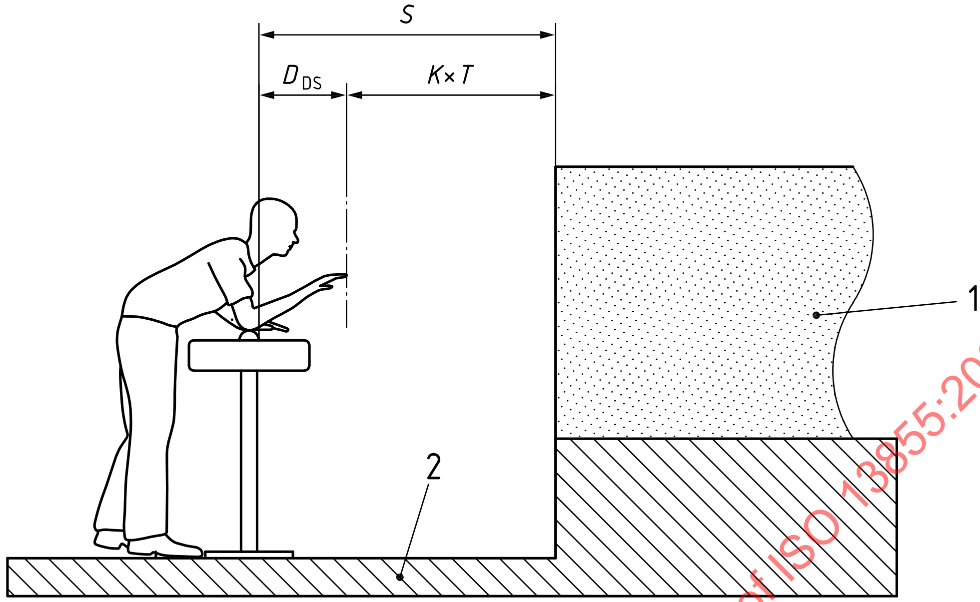
NOTE See also ISO 13851 for design criteria of two-hand control devices.

See Figure 23 and Annex G.



Key

1 hazard zone

2 reference plane

S separation distance

K approach speed

T overall system response time

D_{DS} reaching distance associated with a protective device

Figure 23 — Separation distance for two-hand control devices (no shroud)

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10.2 Two-hand control devices preventing encroachment

If the risk of encroachment of the hands or part of the hands towards the hazard zone is eliminated while the actuator is being operated, e.g. by adequate shrouding, actuator design or orientation of the workstation, then D_{DS} may be zero, with a minimum allowable separation distance of 100 mm.

NOTE ISO 13851 gives advice on shrouding to prevent defeating the intended operation of a two-hand control device. The measures described are not adequate in all applications to prevent encroachment of the hands or parts of the hands towards the hazard zone.

11 Single control devices

11.1 Hand-operated single control devices

The separation distance *S* from the actuator to the hazard zone shall be calculated according to Formula (32) as given in 10.1. See also Figure 24.

By replacing the approach speed *K* with 1 600 mm/s and the reaching distance associated with a protective device D_{DS} with 2 200 mm, Formula (32) becomes Formula (34):

$$S = (1\,600 \times T) + 2\,200 \quad (34)$$

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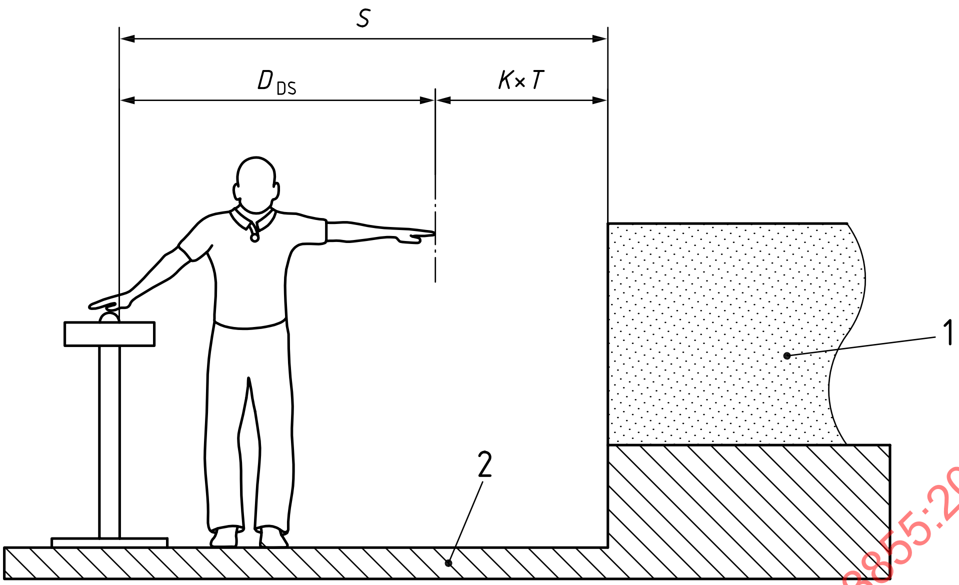

Key

1 hazard zone

2 reference plane

S separation distance

K approach speed

T overall system response time

D_{DS} reaching distance associated with a protective device

Figure 24 — Separation distance for hand-operated single control devices

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11.2 Foot-operated single control devices

The separation distance *S* from the actuator to the hazard zone shall be calculated according to Formula (32) as given in 10.1. See also Figure 25.

By replacing in Formula (32) the approach speed *K* with 1 600 mm/s and the reaching distance associated with a protective device D_{DS} with 2 500 mm, Formula (35) results:

$$S = (1\,600 \times T) + 2\,500 \quad (35)$$

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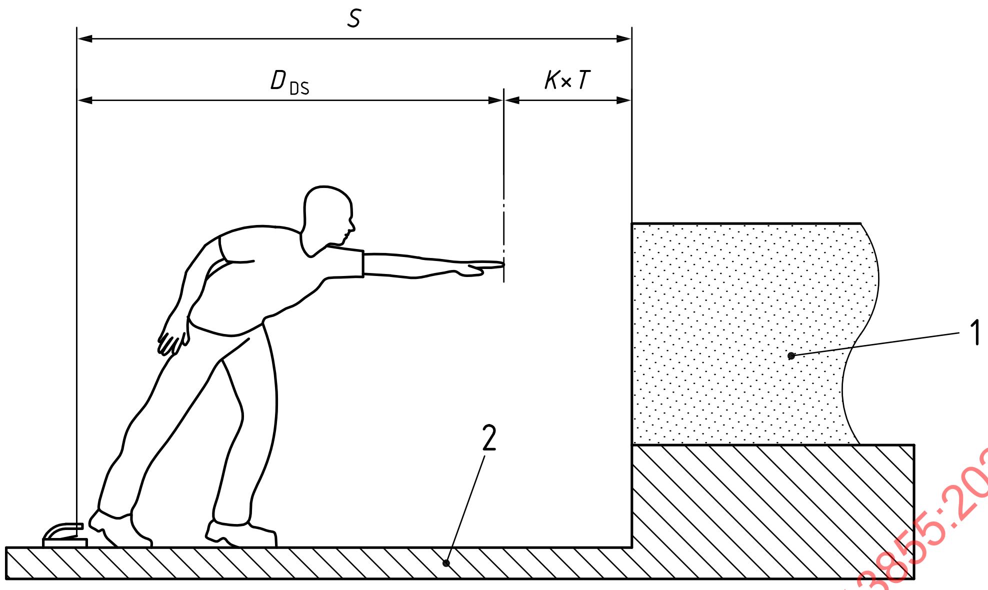

Key

1 hazard zone
2 reference plane
S separation distance
K approach speed
T overall system response time
D_{DS} reaching distance associated with a protective device

Figure 25 — Separation distance for foot-operated single control devices

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12 Interlocking guards

12.1 General

It can be possible to partially open an interlocking guard such that access is possible through the protective structure before actuation of the interlocking device initiates the safety function.

NOTE Examples include interlocking guards which open either linearly or angularly (see Figure 26), and the interlocking device actuator is

— securely fixed, and the degree of travel of the actuator prior to initiating a safety function is dependent upon

  — the design of the interlock device (e.g. distance of travel (hysteresis) as specified by the manufacturer), and

  — variable features (e.g. location of actuator, adjustable actuating angle);

— fixed by means of a flexible element (chain, cable) which increases the overall opening *e* prior to initiation of a safety function.

When determining an acceptable location of an SRMCD in accordance with 4.6, the guidance of this Clause is also applicable.

12.2 Interlocking devices without guard locking

12.2.1 General

In order to ensure that the hazard zone cannot be reached when opening an interlocking guard without guard locking before achieving the intended risk reduction, the separation distance *S* shall be determined.

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The separation distance from the nearest edge of the opening of the interlocking guard without guard locking to the hazard zone shall be calculated by using Formula (36).

$$S = (K \times T) + D_{GT} \tag{36}$$

where

K = 1 600 mm/s;

D_{GT} is the reaching distance through the protective structure taken from ISO 13857:2019 as described below.

By replacing the approach speed K with 1 600 mm/s, Formula (36) becomes Formula (37):

$$S = (1\,600 \times T) + D_{GT} \tag{37}$$

NOTE 1 Only an approach speed of 1 600 mm/s has been considered, since in such a case the approach movement does not result from an involuntary movement (reaction) of the person but from an intended access. It is assumed that a person accessing in such a way will also prevent a collision with parts of the guard or the machine and wait for an appropriate size of the opening before reaching in.

For interlocking guards, the resulting size and shape of the opening before activation of the interlocking device shall be considered when determining the reaching distance D_{GT} through the interlocking guard. See Figure 26.

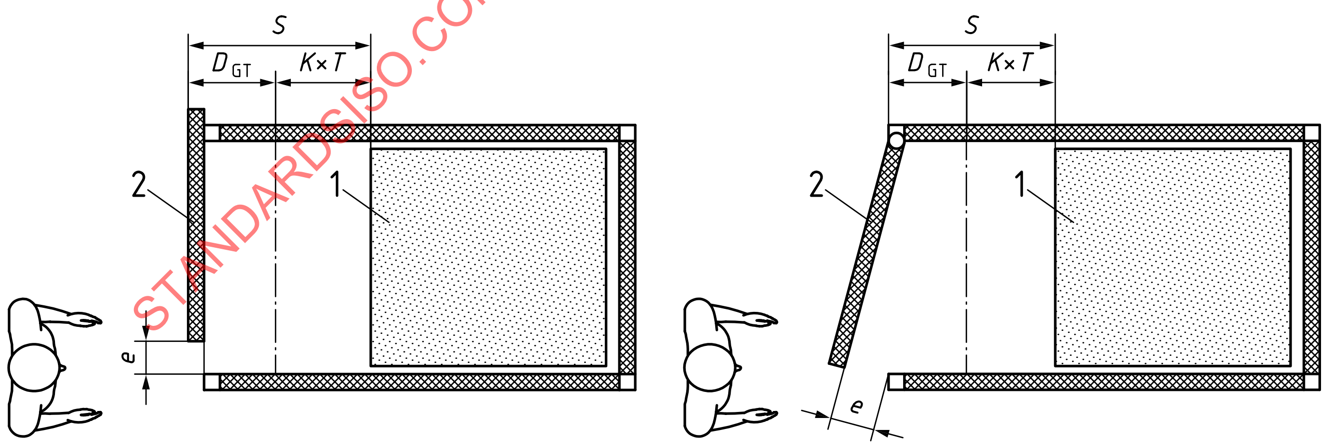
NOTE 2 Typically, the resulting opening is a slot created between the interlocking guard and associated frame, however other opening shapes can result (see Figure E.1).

ISO 13857:2019, Table 4 shall be applied to determine the reaching distance D_{GT} through the interlocking guard based on the opening e, unless a risk assessment and evaluation of the application justifies the use of other values.

NOTE 3 Examples include:

— proximity of person to the opening (e.g. person is forced to step back when opening the interlocking guard);

— angle of person approaching the opening.



a) Interlocking guard with linear motion **b) Interlocking guard with angular motion**

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Key

1 hazard zone

2 interlocking guard

S separation distance

K approach speed

T overall system response time

D_{GT} reaching distance through the protective structure

e dimension of the opening in the protective structure (slotted)

Figure 26 — Example of interlocking guards

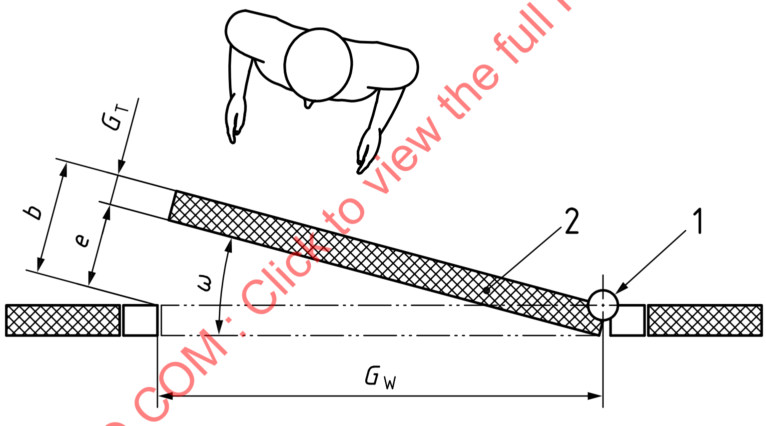
12.2.2 Calculation of the opening *e* for an interlocking guard with an interlocking device with rotary cam actuated position switch

When an interlocking device with rotary cam actuated position switch is used on an interlocking guard with angular motion, the opening *e* shall be calculated (see Figure 27). The opening *e* is dependent upon

— the actuating angle of the interlocking device with rotary cam actuated position switch *ω*,

— the width of the interlocking guard G_W, and

— the thickness of the interlocking guard G_T.



Key

1 interlocking device with rotary cam actuated position switch

2 interlocking guard

ω actuating angle of the interlocking device with rotary cam actuated position switch

b sum of opening size and thickness of interlocking guard

G_W width of the interlocking guard

G_T thickness of the interlocking guard

e dimension of the opening in the protective structure (slotted)

Figure 27 — Variables for determining opening (*e*) for an interlocking guard with an interlocking device with rotary cam actuated position switch

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The opening e between the machine frame and the interlocking guard with an interlocking device with rotary actuated position switch is calculated according to Formula (38):

$$e = b - G_T \quad (38)$$

where

$$b = G_W \times \sin(\omega) \quad (39)$$

By replacing b with $G_W \times \sin(\omega)$ Formula (38) becomes Formula (40):

$$e = (G_W \times \sin(\omega)) - G_T \quad (40)$$

Table 5 shows the values for b based upon typical actuating angles of interlocking devices with rotary cam actuated position switch ω and common widths of an interlocking guard G_W. The thickness of the interlocking guard G_T shall be accounted for in order to determine the opening e of the interlocking guard before actuation of the interlocking device with rotary cam actuated position switch.

Table 5 — Sample calculation of *b* for typical actuating angles of an interlocking device with rotary cam actuated position switch *ω*

Width of the interlocking guard G_W mm	Actuating angle of an interlocking device with rotary cam actuated position switch ω						
	3°	**4°**	**5°**	**6°**	**7°**	**8°**	**9°**
	Sum of opening size and thickness of interlocking guard $b = G_W \times \sin(\omega)$ mm						
100	5,2	7,0	8,7	10,5	12,2	13,9	15,6
200	10,5	14,0	17,4	20,9	24,4	27,8	31,3
300	15,7	20,9	26,1	31,4	36,6	41,8	46,9
400	20,9	27,9	34,9	41,8	48,7	55,7	62,6
500	26,2	34,9	43,6	52,3	60,9	69,6	78,2
600	31,4	41,9	52,3	62,7	73,1	83,5	93,9
700	36,6	48,8	61,0	73,2	85,3	97,4	109,5
800	41,9	55,8	69,7	83,6	97,5	111,3	125,1[a]
900	47,1	62,8	78,4	94,1	109,7	125,3[a]	140,8[a]
1 000	52,3	69,8	87,2	104,5	121,9[a]	139,2[a]	156,4[a]
1 100	57,6	76,7	95,9	115,0	134,1[a]	153,1[a]	172,1[a]
1 200	62,8	83,7	104,6	125,4[a]	146,2[a]	167,0[a]	187,7[b]
1 300	68,0	90,7	113,3	135,9[a]	158,4[a]	180,9[b]	203,4[b]
1 400	73,3	97,7	122,0[a]	146,3[a]	170,6[a]	194,8[b]	219,0[b]
1 500	78,5	104,6	130,7[a]	156,8[a]	182,8[b]	208,8[b]	234,7[b]

[a] If resulting opening $e > 120$ mm, access of other parts of the body is possible. See ISO 13857.

[b] If resulting opening $e > 180$ mm, whole body access is possible.

12.3 Interlocking devices with guard locking

Where the release time delay t_{DY} of the guard locking device is less than the overall response time T, the separation distance S shall ensure that persons cannot access the hazard zone before the intended risk reduction is achieved. The separation distance S shall be calculated according to Formula (41):

$$S = K \times (T - t_{DY}) + D_{GT} \quad (41)$$

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where

K is 1 600 mm/s;

T is the overall system response time;

t_{DY} is the release time delay of the guard locking device;

D_{GT} is the reaching distance through the protective structure taken from ISO 13857:2019, as described in 12.2.

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Annex A
(informative)

Achieving intended risk reduction

Application of a safeguard is one step in the overall process of risk reduction as addressed in ISO 12100. Each safeguard applied has one or more intended purposes to reduce risk.

NOTE 1 See ISO 12100:2010, 5.6.2 for further details regarding adequate risk reduction.

When calculating the separation distance *S* of a safeguard according to the provisions of this document, the time to achieve the intended risk reduction represents a decisive parameter. This time is when the hazardous machine function (usually a motion) is altered in such a way that the intended risk reduction is achieved. This concept has different names in industry and in standards, including:

— safe state;

— safe condition;

— termination of hazardous machine function;

— cessation of hazardous machine function.

This document presents information for the appropriate application of a safeguard based on the overall system response time *T*. The reliability of this decisive time parameter is necessary for proper application of safeguards according to this document. If the intended risk reduction is achieved before the machine has come to a complete stop, but it is not possible to determine when the moment occurs, it is necessary to consider the time at which the machine comes to a complete stop. There are many factors that can be applicable and only limited guidance is currently available. Some examples that can be considered are given in a) to f), but these references are not always directly relevant in a given application:

a) the force being applied to the human body;

b) the parts of the human body which can be affected;

c) the shape of the machine part (e.g. sharp edges, pointed parts);

d) the property of the material (e.g. soft rubber, deformable);

e) the speed of the movement;

f) the risk of crushing hazards.

NOTE 2 Some information about reduced energies (e.g. forces, speeds, kinetic) can be found in IRSST R-956[30].

NOTE 3 Minimum gaps to avoid crushing of parts of the human body can be found in ISO 13854.

If a separation distance is calculated according to the provisions of this document, the relationship between the overall system response time *T* and the moment when the intended risk reduction is achieved before the machine comes to a complete stop should be made explicit. Such a relationship can, for example, be defined as follows:

— With crushing hazards the intended risk reduction can be achieved 2 mm prior to the position where the machine comes to a complete stop, unless there is a risk of crushing of the head.

This means that the time represented by these 2 mm may be used to reduce the overall system response time *T*.

NOTE 4 A compression of 2 mm can be regarded as harmless to the parts of the human body other than the head.

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Annex B
(informative)

Measurement and calculation of system performance to achieve the intended risk reduction

B.1 General

Instructions or guidance on specific procedures applicable to measurement and calculation of time or distance to achieve the intended risk reduction should be provided.

B.2 Machine test conditions

The signal to simulate the activation of the protective device (i.e. initiate the safety function) should be given to the machine at the moment/position/phase of motion which gives the longest system response time or distance. For some risk reduction measures it is necessary to determine the total distance of travel after the safety function has been initiated. See 5.4 and Annex A for additional information regarding time to achieve the intended risk reduction.

The time or distance to achieve the intended risk reduction should be measured for the worst credible (longest) time or distance of a machine under maximum capability during normal operating conditions. Various factors specific to an application can impact the worst credible situation such as, but not limited to:

— tool weight;

— temperature;

— switching times of valves;

— ageing of components;

— operating speed.

Among conditions to consider as the worst credible scenario include, but are not limited to, when:

— the machine is at maximum capable speed;

— the machine is at maximum extension (extending the moment arm);

— the machine is at 90° on a sinusoidal crank.

The machine should be tested under conditions which most realistically replicate the normal operating conditions. To achieve the intended risk reduction during all machine cycles, it can be necessary to test the machine in conditions which replicate machine performance at both initial start-up and after multiple cycles.

To test machine performance under initial start-up conditions, the test should be performed with the machine at normal operating conditions. To replicate performance at normalized internal conditions, multiple cycles of the machine can be required. The test results can be affected by temperature of wear surfaces, lubricants, hydraulic fluid and brake/clutch wear pads. Both sets of data should be evaluated according to B.3. The largest resulting value should be used for final calculation of the separation distance *S*.

B.3 Test interval and measurement procedure

The interval between tests should follow the typical production cycle interval unless it can be shown that shorter intervals will not adversely affect the performance measurements.

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Measurements should be taken using a stopping performance device which has been calibrated according to the manufacturer's instructions when applicable. One measurement is not sufficient. At least ten measurements are required under each test condition. In addition to stating the calculated separation distance *S* and identifying the machine on which the measurements were made, the measurement procedure should also contain a list of assumptions that were made about how the worst-case scenario was determined and how the intended risk reduction was defined. An adequately formulated measurement report should contain the following information:

a) identification of the machine;

b) safeguard(s) and interface(s) used;

c) measuring equipment used;

d) verification (including calibration, when applicable) of measuring equipment;

e) identification of the person/company that performed the measurements;

f) date of measurements;

g) measuring method used;

h) assumptions made for the measurements and calculations;

i) additional information about the machine or measuring scenario;

j) calculated overall system response time *T*;

k) calculated separation distance *S*, showing values used in formulae.

The information listed above should be included with the documentation of the calculated separation distance *S*.

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B.4 Fault conditions

For the calculation of the separation distance *S* in accordance with this document, maximum capability during normal operating conditions of moving equipment in the hazard zone may be taken. It is possible that it will not be necessary to consider the speed of moving equipment under fault conditions as determined by the risk assessment.

Where a person approaches a hazardous situation, two independent events need to occur at the same time: the person stretches an arm out towards the hazard zone and the moving equipment fails in speed or extension at the same time, which is unlikely.

The calculation of speed, even under fault condition, can be needed, e.g. when designing restricted travel or motion of machine axis and persons can be hit in case of fault. Under such circumstances, a person is present but not approaching and a single fault can lead to a hazardous situation. Such considerations are not dealt with in this document, but can be the subject of type-C standards.

B.5 Calculation of the overall system response time *T* to achieve the intended risk reduction

A statistical method to estimate 99,7 % of all values in a normally distributed population is to calculate the mean value ±3 sample standard deviations. The highest measured value or the mean plus three sample standard deviations, whichever is greater, should be used. See B.6 for an example. The mean value alone should not be used, since the machine in 50 % of the cases would have a longer overall system response time.

The practice of removing outliers in the measurements is not recommended unless it can be safe to assume that the outlier is due to an error in the measurement.

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B.6 Example measurement analysis — Calculation of the sample standard deviation

System response time measurements were performed for a machine at both cold start-up and again after the machine had warmed up (see Table B.1). For each condition, 10 system response time measurements were taken. The following steps show how to calculate system response time.

Table B.1 — Measured system response times

Measurement	System response time s Cold machine start-up	Hot machine
1	0,561	0,663
2	0,553	0,654
3	0,612	0,655
4	0,544	0,651
5	0,553	0,727
6	0,571	0,656
7	0,567	0,678
8	0,583	0,665
9	0,656	0,683
10	0,554	0,714

Step 1: Calculate the system response time under cold start-up conditions

The mean plus three sample standard deviations, 0,679 s, is greater than the highest measured time, 0,656 s, therefore the calculated system response time for cold start-up is 0,679 s.

Step 2: Calculate the system response time for machine running at normal conditions

The mean plus three sample standard deviations, 0,754 s, is greater than the highest measured time, 0,727 s, therefore the calculated system response time at normal operating conditions is 0,754 s.

Step 3: Compare measured system response times

The highest encountered system response time at normal operating conditions, 0,754 s, is greater than the highest encountered system response time for cold start-up, 0,679 s, therefore 0,754 s should be used in the calculation of the separation distance. See Table B.2.

Table B.2 — Comparison of system response time values

Variable	Calculation results s Cold machine start-up	Hot machine
Mean ($\bar{x}$)	0,575	0,675
Sample standard deviation (s_x)	0,034 4	0,026 5
$\bar{x} + 3 s_x$	0,679	0,754
Highest measured value	0,656	0,727
Highest encountered value	0,679	0,754
Value used for calculation of the separation distance	0,754	

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Annex C
(normative)

Devices with multiple beams or arrangements of single beams with effective detection capability d_e > 120 mm or undefined — Number of beams and their height above the reference plane without change in elevation

For devices with multiple beams or arrangements of single beams with effective detection capability d_e greater than 120 mm or undefined intended to detect whole body access without change in elevation (see 4.3), the heights given in Table C.1 or Table C.2 shall be applied. Table C.2 shall only be applied in industrial environments and where allowed by the risk assessment.

NOTE These heights have been found to be the best compromise between an adequate risk reduction and the most practical in application. Not all applications allow the use of devices with multiple beams or arrangements of single beams with effective detection capability d_e > 120 mm or undefined. Further protective measures to prevent access to the hazard zone or SRMCD can be required.

Table C.1 — Heights above and parallel to the reference plane

Number of beams	Heights above and parallel to the reference plane, unless otherwise noted mm				Applicable only for openings with dimensions mm	
	Beam 1	**Beam 2**	**Beam 3**	**Beam 4**	**Height *h***	**Width *w***
4	200	500	800	1 100	unrestricted	unrestricted
3	200	600	1 000		unrestricted	unrestricted
2	200	400			≤ 600	unrestricted
1	200				≤ 500	> 300
	vertical beam, w/2				> 500	≤ 300
	⌀/2				240 ≤ ⌀ ≤ 500 for round openings	

Table C.2 — Alternative heights above reference plane for industrial applications where allowed by a risk assessment

Number of beams	Heights above and parallel to the reference plane mm				Applicable only for openings with dimensions: mm	
	Beam 1	**Beam 2**	**Beam 3**	**Beam 4**	**Height *h***	**Width *w***
4	300	600	900	1 200	unrestricted	unrestricted
3	300	700	1 100		unrestricted	unrestricted
2	200	400			≤ 600	unrestricted
1	200				≤ 500	> 300
	vertical beam, *w*/2				> 500	≤ 300
	⌀/2				240 ≤ ⌀ ≤ 500 for round openings	

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The heights for 2, 3 and 4 beams given in Table C.1 and Table C.2 apply to beams

— positioned parallel to the reference plane;
— where the beams are in the same plane; and
— where the approach to the resulting plane is orthogonal according to Clause 7.

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Annex D
(normative)

Supplier information for time and distance to achieve the intended risk reduction

When a machine has a stopping time or stopping distance limiting safety function that causes a stop before exceeding the set limit, the data according to this Annex are not required.

NOTE 1 For parameterization of limits, see ISO 13849-1:2023, 5.2.2.7 and 6.3.

When information is provided regarding time and distance to achieve the intended risk reduction, the following metric shall be used to present standardized data. This information is needed to calculate the separation distance when applying safeguards according to this document. To make this information useful and practical, values need to be provided for varying steps up to maximum conditions to predict actual running conditions.

Testing shall conform with documented overall system response time testing conditions (see Annex B), and include the following:

a) the machine shall be warmed up prior to testing;

b) the machine shall be installed per supplier's requirements;

c) environmental requirements (e.g. power, temperature) shall be met;

d) a proper test procedure shall be established;

e) the method of measurement shall be described.

The supplier shall forecast the degradation of machine performance to achieve the intended risk reduction due to normal use and recommend when the machine should be refurbished.

The data recommended is as follows:

— the time to achieve the intended risk reduction shall be determined from the initiation of the safety function to when all hazardous conditions have achieved acceptable risk;

— if validated simulation values are available, then these values may be obtained using simulation.

NOTE 2 This data varies depending on additive delays due to control system feature and configuration (e.g. cableless pendants).

The stopping distance shall be determined as the total distance travelled after the initiation of a protective stop. Distance shall be provided in linear or angular units as appropriate.

For stop Category 0 in accordance with IEC 60204-1, the measurement procedures under maximum conditions (e.g. maximum speed, maximum load and maximum displacement, when applicable) are sufficient. If the machine has a stop Category 1 in accordance with IEC 60204-1, additional data or correction factors shall be provided. For stop Category 1, the stopping time and distance values shall be stated for 100 % of maximum depending on application specific factors (e.g. speed, payload, extension).

A description of how to perform the measurement of time or distance to achieve the intended risk reduction for a particular application, machine, and or tool and loads shall be provided by the supplier.

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Annex E
(informative)

Variable key for determining separation distance for safeguards

E.1 Variables introduced in Clause 4

Table E.1 — Variables introduced in Clause 4

Used in this document						Other references				
Variable	**Parameter**	**Units**	**Reference formula(e)**	**Reference figure(s)**	**Reference table(s)**	ISO 13855:2010[a]	ISO 13857:2019	IEC 62046:2018	IEC 61496-2:2020	IEC 61496-3:2018
H_S	height of step	mm	–	2	1	–	–	–	–	–
W_S	width of step from edge to detection zone	mm	–	2	1	–	–	–	–	–
D_{DS}	reaching distance associated with a protective device	mm	1, 6, 8, 13, 32	2, 21, 22, 23, 24, 25	–	*C*	–	*C*	–	–
e	opening in protective structure	mm	38, F.2	26, 27	–	–	*e*	–	–	–
G_D	distance between detection zone and nearest obstruction	mm	–	22	–	*X*	–	*E*	–	–
d_e	effective detection capability	mm	18, 19, 20, 21, 22, 23, 27, 28, 30	14, 20, G.2, G.3	3	*d*	–	*d*	*d*	*d*
[a] Will be withdrawn once this edition is published.										

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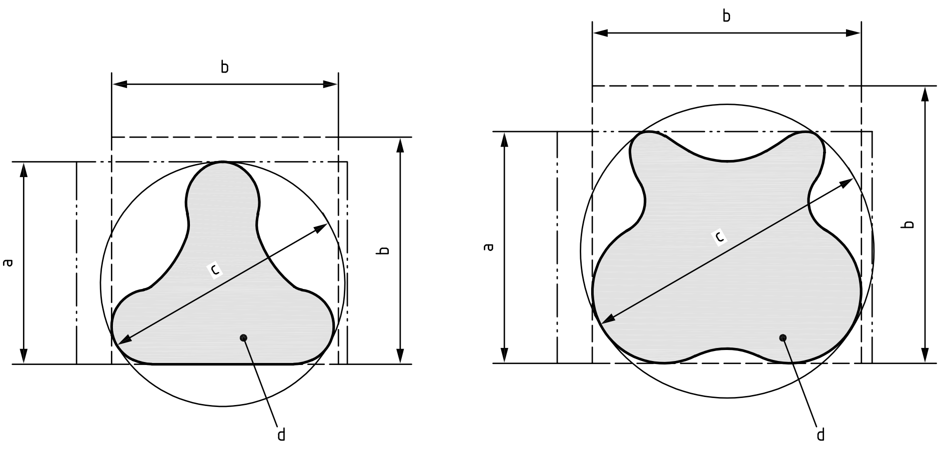

a Slotted opening.

b Square opening.

c Round opening.

d Irregular opening.

Figure E.1 — Openings of irregular shape

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E.2 Variables introduced in Clause 5

Table E.2 — Variables introduced in Clause 5

Used in this document						Other references				
Variable	**Parameter**	**Units**	**Reference formula(e)**	**Reference figure(s)**	**Reference table(s)**	ISO 13855:2010[a]	ISO 13857:2019	IEC 62046:2018	IEC 61496-2:2020	IEC 61496-3:2018
S	separation distance	mm	1, 6, 8, 12, 14, 15, 16, 17, 19, 20, 22, 23, 24, 26, 28, 29, 31, 32, 33, 34, 35, 36, 37	5, 11, 13, 14, 16, 17, 21, 22, 23, 24, 25, 26	2	S	–	S	–	S
K	approach speed	mm/s	1, 6, 8, 14, 17, 25, 26, 32, 36	2, 11, 13, 14, 17, 21, 22, 23, 24, 25, 26	–	K	–	–	K	K
T	overall system response time	s	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 14, 15, 16, 17, 19, 20, 22, 23, 24, 25, 26, 28, 29, 31, 32, 33, 34, 35, 36, 37	2, 4, 11, 13, 14, 17, 21, 22, 23, 24, 25, 26	–	T	–	T	–	T
$t_{SRP/CS}$	response time of the SRP/CS or SCS	s	2, 4, 9, 10	4	–	–	–	–	–	–
t_I	response time of the input	s	3, 7, F.1	4	–	t_1	–	–	–	–
t_L	response time of the SRP/CS or SCS logic	s	3, 7, F.3	4	–	t_2	–	–	–	–
t_O	response time of the SRP/CS or SCS output	s	3, 7	4	–	t_2	–	–	–	–
t_{ME}	response time of the machinery	s	2	4	–	t_2	–	–	–	–
t_D	response time related to dissipation of source energy	s	3, 7	4	–	–	–	–	–	–
t_R	response time related to mechanical response	s	3, 7	4	–	–	–	–	–	–
t_M	response time related to mechanical inertia	s	3, 7, 9	4	–	t_2	–	–	–	–
t_F	time related to a tolerance factor for the machinery	s	2, 3, 5, 7	4	–	–	–	–	–	–
T_m	overall system response time determined by measurement	s	5	4	–	–	–	–	–	–
t_{SF}	time delay from the initiation of a safety function	s	4	–	–	–	–	–	–	–

[a] Will be withdrawn once this edition is published.

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