INTERNATIONAL STANDARD

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

Sécurité des machines — Positionnement des moyens de protection par rapport à la vitesse d'approche des parties du corps

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13855 was prepared by Technical Committee ISO/TC 199, *Safety of machinery*.

This second edition cancels and replaces the first edition (ISO 13855:2002), which has been technically revised.

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 or more type(s) 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 controls, 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-B standard as stated in ISO 12100-1.

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.

The effectiveness of certain types of safeguard described in this International Standard to minimize risk relies, in part, on the relevant parts of that equipment being correctly positioned in relation to the hazard zone. In deciding on these positions, a number of aspects are taken into account, such as:

— the necessity of a risk assessment according to ISO 14121-1;

— the practical experience in the use of the machine;

— the overall system stopping performance;

— the time taken to ensure the safe condition of the machine 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;

— 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.

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

1 Scope

This International Standard establishes the positioning of safeguards with respect to the approach speeds of parts of the human body.

It specifies parameters based on values for approach speeds of parts of the human body and provides a methodology to determine the minimum distances to a hazard zone from the detection zone or from actuating devices of safeguards.

The values for approach speeds (walking speed and upper limb movement) in this International Standard are time tested and proven in practical experience. This International Standard gives guidance for typical approaches. Other types of approach, for example running, jumping or falling, are not considered in this International Standard.

NOTE 1 Other types of approach can result in approach speeds that are higher or lower than those defined in this International Standard.

Safeguards considered in this International Standard include:

a) electro-sensitive protective equipment [see IEC 61496 (all parts)], including:

— light curtains and light grids (AOPDs);

— laser scanners (AOPDDRs) and two-dimensional vision systems;

b) pressure-sensitive protective equipment (see ISO 13856-1, ISO 13856-2 and ISO 13856-3), especially pressure-sensitive mats;

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

d) interlocking guards without guard locking (see ISO 14119).

This International Standard specifies minimum distances from the detection zone, plane, line, point or interlocking guard access point to the hazard zone for hazards caused by the machine (e.g. crushing, shearing, drawing-in).

Protection against the risks from hazards arising from the ejection of solid or fluid materials, emissions, radiation and electricity are not covered by this International Standard.

NOTE 2 Anthropometric data from the 5th to the 95th percentile of persons of 14 years and older were used in the determination of the intrusion distance value "C" in the equations.

NOTE 3 The data in this International Standard are based on experience of industrial application; it is the responsibility of the designer to take this into account when using this International Standard for non-industrial applications.

NOTE 4 Data specifically for children have not been used in this International Standard. Until specific data are available for approach speeds for children, it is the responsibility of the designer to calculate the distances taking into account that children might be quicker and that a child might be detected later.

The International Standard is not applicable to safeguards (e.g. pendant two-hand control devices) that can be moved, without using tools, nearer to the hazard zone than the calculated minimum distance.

The minimum distances derived from this International Standard are not applicable to safeguards used to detect the presence of persons within an area already protected by a guard or electro-sensitive protective equipment.

2 Normative references

The following referenced documents are indispensable for the application 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 12100-1, *Safety of machinery — Basic concepts, general principles for design — Part 1: Basic terminology, methodology*

ISO 13857:2008, *Safety of machinery — Safety distances to prevent hazard zones being reached by the upper and lower limbs*

ISO 14121-1:2007, *Safety of machinery — Risk assessment — Part 1: Principles*

IEC 61496-1:2004, *Safety of machinery — Electro-sensitive protective equipment — Part 1: General requirements and tests*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12100-1 and the following apply.

3.1.1
actuation
⟨safeguards⟩ physical initiation of the safeguard when it detects a body or parts of a body

3.1.2
overall system stopping performance
T
time interval between the actuation of the sensing function and the termination of the hazardous machine function

NOTE Adapted from IEC 61496-1:2004.

3.1.3
detection capability
d
sensing function parameter limit specified by the supplier that will cause actuation of the protective equipment

[IEC/TS 62046:2008, 3.1.4]

3.1.4
electro-sensitive protective equipment
ESPE
assembly of devices and/or components working together for protective tripping or presence-sensing purposes and comprising at a minimum:

— a sensing device,

- controlling/monitoring devices,
- output signal switching devices

[IEC 61496-1:2004, definition 3.5]

NOTE ESPEs refer only to non-contact sensing devices.

3.1.5
indirect approach
approach where the shortest path to the hazard zone is obstructed by a mechanical obstacle

NOTE The hazard zone can only be approached by going around the obstacle.

3.1.6
circumventing the detection zone
reaching the hazard zone without actuation of the protective device by passing over, under or to the side of the detection zone

3.1.7
termination of the hazardous machine function
condition achieved when the hazard parameters are reduced to a level which cannot cause physical injury or damage to health

NOTE See examples in Annex B.

3.1.8
detection zone
zone within which a specified test piece is detected by the protective equipment

NOTE 1 The detection zone may also be a point, line or plane.

NOTE 2 Adapted from IEC 61496-1:2004, definition 3.4.

3.1.9
minimum distance
S
calculated distance between the safeguard and the hazard zone necessary to prevent a person or part of a person reaching the hazard zone before the termination of the hazardous machine function

NOTE Different minimum distances may be calculated for different conditions or approaches, but the greatest of these minimum distances is used for selecting the position of the safeguard.

3.1.10
intrusion distance
C
distance that a part of the body (usually a hand) can move past the safeguard towards the hazard zone prior to actuation of the safeguard

3.2 Symbols and abbreviated terms

3.2.1 Symbols

Symbol	Term	Unit
T	overall system stopping performance	s
S	minimum distance	mm
C	intrusion distance	mm
t_1	reaction time of the protective device	s
t_2	stopping time of the machine	s
t_3	opening time to open the guard	s
K	approach speed parameter	mm/s
d	sensor detection capability	mm
H	height of detection zone above reference plane	mm
h	height of the step	mm
X	distance between the end of the detection zone and the hazard zone	mm
S_{RO}	minimum distance when reaching over	mm
S_{RT}	minimum distance when reaching through	mm
C_{RO}	intrusion distance to the hazard zone when reaching over	mm
C_{RT}	intrusion distance to the hazard zone when reaching through	mm
a	height of the hazard zone	mm
b	height of the safeguard (e.g. ESPE, protective structure)	mm
S^*	distance actually covered	mm
l_1; l_2; l_3	shortest distance around obstacles	mm
S_1; S_2; S_3	distance of l_1, projected on a horizontal plane distance of l_2, projected on a horizontal plane distance of l_3, projected on a horizontal plane	mm
e	opening size	mm
v	speed of the opening motion of the power-operated interlocking guard	mm/s

3.2.2 Abbreviated terms

AOPD Active opto-electronic protective device

AOPDDR Active opto-electronic protective device responsive to diffuse reflection (e.g. laser scanners)

VBPD Vision-based protective device

ESPE Electro-sensitive protective equipment

4 Methodology

Figure 1 provides a schematic representation of the methodology for determining the correct positioning of sensing or actuating devices of safeguards in accordance with this International Standard, which is as follows.

a) Identify the hazards and assess the risks (as specified in ISO 12100-1 and ISO 14121-1);

b) If a type-C standard exists for the machine, select one of the specified types of safeguard from that machine-specific standard, and then use the distance specified by that standard;

NOTE 1 Type-C standards specify minimum distances directly or by reference to this International Standard.

c) If there is no type-C standard, use the equations in this International Standard to calculate the minimum distance for the safeguard selected;

NOTE 2 For selection of the appropriate type of safeguard, see ISO 12100-2:2003, Clause 5, and IEC/TS 62046.

d) If it is possible to circumvent (go around) the detection zone, an additional calculation using the equations in 6.5 shall be made;

e) Where combinations of safeguards are used, a calculation of the minimum distance shall be made, taking into account each safeguard and possible circumventing;

f) Calculate the minimum distances for each possibility of reaching the hazard zone. Then select the most protective (greatest) of the minimum distances;

g) If possible, incorporate the distance(s) in the machine design, otherwise see step i);

h) Check that the installation of the safeguard does not allow access without detection. If undetected access is possible, redesign [step i)], otherwise go to step j);

i) Can parameters be modified or alternative safeguards be used? If neither is possible, additional safeguards shall be used;

j) Check whether the determined position allows persons to remain between the safeguard and the hazard zone without being detected. In this case, supplementary measures will be required depending on an additional risk assessment.

NOTE 3 An example of a supplementary measure is a manual reset switch positioned outside the hazard zone and the space between the safeguard and the hazard zone. Its position is selected to allow someone operating it to readily check that no one is within the hazard zone or in the space between the safeguard and the hazard zone. For the requirements of a manual reset function, see ISO 13849-1:2006, 5.2.2.

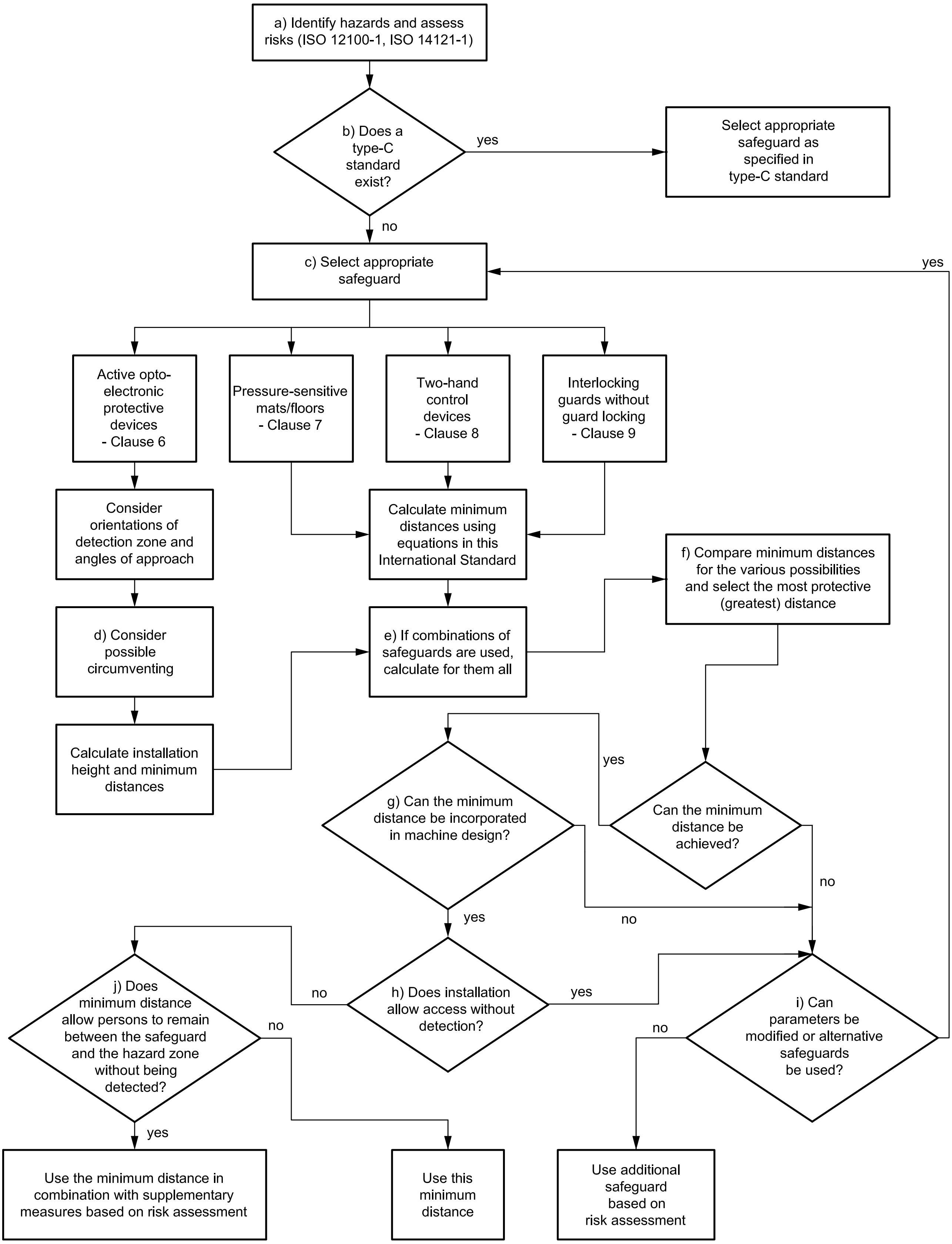


Figure 1 — Methodology

5 General equation for the calculation of the overall system stopping performance and minimum distances

5.1 Overall system stopping performance

The overall system stopping performance comprises at least two phases. The two phases are linked by Equation (1):

$$T = t_1 + t_2 \tag{1}$$

where

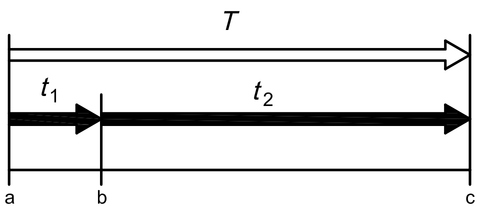
T is the overall system stopping performance;

t_1 is the maximum time between the occurrence of the actuation of the safeguard and the output signal achieving the OFF-state;

t_2 is the stopping time, which is the maximum time required to terminate the hazardous machine function after the output signal from the safeguard achieves the OFF-state. The response time of the control system of the machine shall be included in t_2.

t_1 and t_2 are influenced by various factors, e.g. temperature, switching time of valves, ageing of components.

t_1 and t_2 are illustrated in Figure 2. t_1 and t_2 are functions of the safeguard and the machine, respectively, and are determined by design and evaluated by measurement. The evaluation of these two values shall include the uncertainties resulting from the measurements, calculations and/or construction.



[a] Actuation of safeguard.

[b] Operation of safeguard (OFF signal generated).

[c] Termination of hazardous machine function (safe condition).

Figure 2 — Relationship between t_1 and t_2

The overall system stopping performance, T, is an essential characteristic for the location of the protective device. Any deviation of the stopping time of the machine, t_2, shall be taken into account during the estimation of T (see Annex D). Where the stopping time can deteriorate during the lifetime of the machine, technical or organizational measures should be taken to ensure the correct overall system stopping performance. These measures can be, for example:

— braking performance control devices;

— checks, the nature and the frequency of which should be defined in the user's manual.

NOTE There can be additional aspects to take into account, e.g.:

a) integrity of the protective function (safety in case of faults) (see ISO 13849-1, ISO 13849-2 and IEC 62061);

b) stopping performance monitoring (see, e.g. IEC/TS 62046);

c) cases where inadequate stopping performance prevents the application of this International Standard, e.g.

   1) it is not possible to stop the machine during a cycle, or

   2) the stopping performance cannot be predicted.

Measurements of stopping performance of a system require careful consideration in order to obtain accurate and relevant values. Annex D gives guidance on the steps to take to ensure appropriate results.

5.2 Minimum distance

The minimum distance to the hazard zone shall be calculated by using the general Equation (2).

$$S = (K \times T) + C \tag{2}$$

where

S is the minimum 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;

T is the overall system stopping performance, in seconds (s), (see 3.1.2 and 5.1);

C is the intrusion distance, in millimetres (mm).

Clauses 6 to 9 show how this equation is used with particular types and arrangements of protective devices. For worked examples, see Annex A.

6 Calculation of minimum distances for electro-sensitive protective equipment employing active opto-electronic protective systems

6.1 General

6.1.1 This clause specifies requirements for two main situations based on the direction of approach of the person or part of the person's body being:

a) orthogonal (at right angles or normal) to the detection zone (see 6.2), or

b) parallel to the detection zone (see 6.3).

Requirements are also provided for arrangements where:

— an angled approach (between orthogonal and parallel) needs to be considered (see 6.4);

— it is necessary to address possible circumventing of the electro-sensitive protective equipment (see 6.5);

— the path from the detection zone to the hazard zone is restricted by obstacles (indirect approach) (see 6.6).

NOTE 1 These situations also appear in combination.

Where the minimum distance is such that it would allow a person to remain undetected between the detection zone and the hazard zone, additional presence-sensing equipment or other solutions should be provided to prevent this.

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

6.1.2 Safeguards shall be configured and positioned such that undetected access to the hazard zone is not possible.

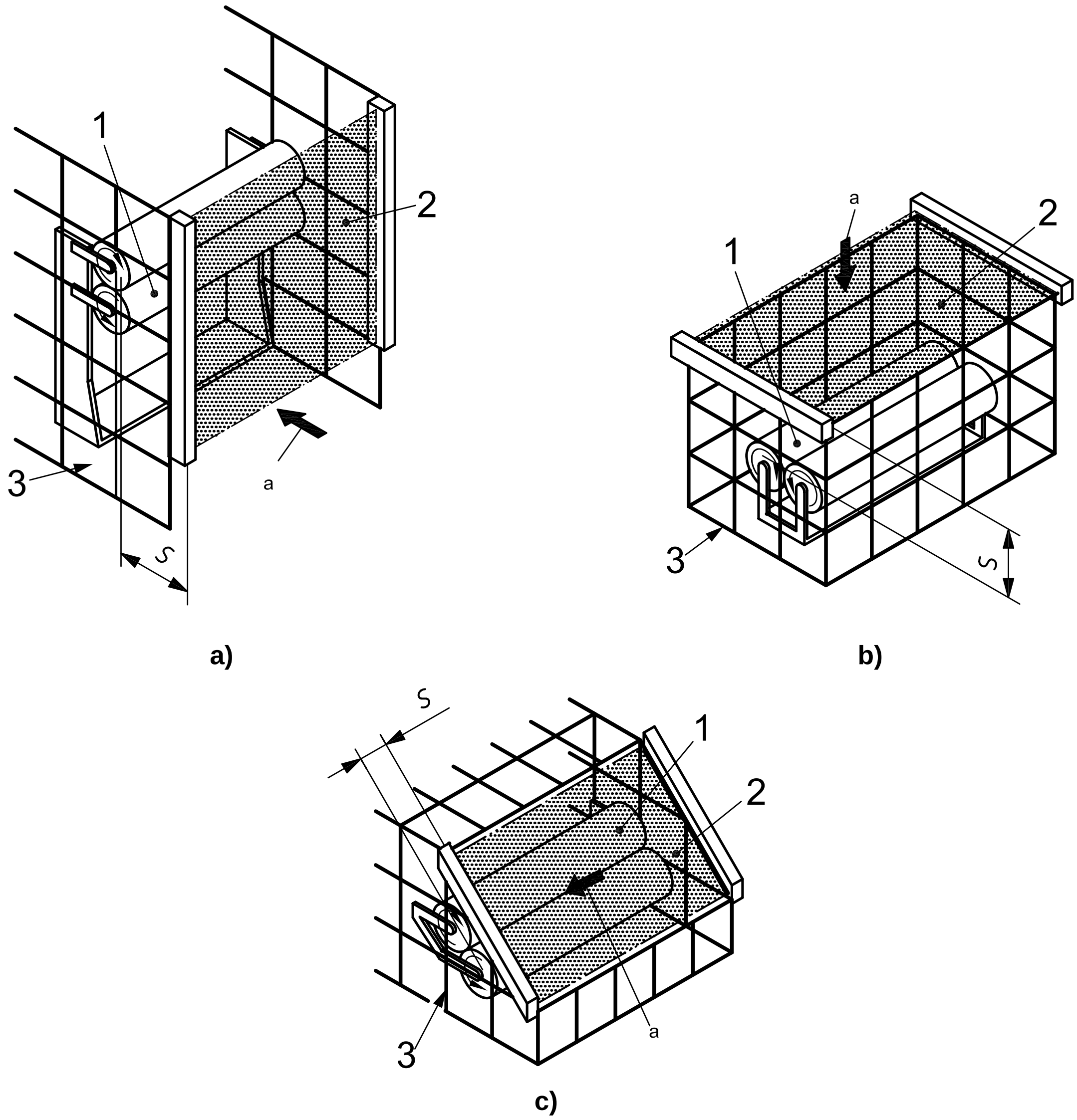
6.1.3 Where necessary, additional safeguards shall be provided to prevent circumventing the detection zone of the safeguard (see Figure 9).

6.1.4 For the use of laser scanners (AOPDDR) or vision-based protective devices (VBPD) with a two-dimensional protection zone, the calculation of the minimum distance shall be in line with 6.2, 6.3 or 6.4, depending on the approach direction.

6.2 Detection zone orthogonal to the direction of approach

6.2.1 General

Figure 3 gives three examples where the detection zone is orthogonal to the direction of approach.



Key

1 hazard zone

2 detection zone

3 fixed guard

S minimum distance

[a] Direction of approach.

Figure 3 — Three examples where the detection zone is orthogonal to the direction of approach

6.2.2 Vertical detection zones detecting whole body access

When the safeguard is used only for the detection of whole body access:

a) the height of the lowest beam shall be $\leqslant$ 300 mm to prevent access under the detection zone. Where it is foreseeable that electro-sensitive protective equipment will be used in non-industrial applications, for example in the presence of children, the height of the lowest beam shall be < 200 mm;

b) the height of the uppermost beam shall be $\geqslant$ 900 mm to prevent stepping over the detection zone. This is not applicable for single beams or for detection zones parallel to the direction of approach (see 6.3).

6.2.3 Electro-sensitive protective equipment employing active opto-electronic protective devices with a sensor detection capability of $\leqslant$ 40 mm in diameter

6.2.3.1 Calculation

The minimum distance, S, in millimetres, from the detection zone to the hazard zone shall not be less than that calculated using Equation (2):

$$S = (K \times T) + C \tag{2}$$

where

K = 2 000 mm/s;

C = 8 (d – 14), but not less than 0;

d is the sensor detection capability of the device, in millimetres (mm).

Then

$$S = (2\,000 \times T) + 8(d - 14) \tag{3}$$

Equation (3) applies to all minimum distances of S up to and including 500 mm. The minimum value of S shall be 100 mm.

Where the values for S, calculated using Equation (3), exceed 500 mm, Equation (4) can be used. In this case, the minimum value of S shall be 500 mm.

$$S = (K \times T) + C \tag{2}$$

where

K = 1 600 mm/s;

C = 8 (d – 14), but not less than 0;

d is the sensor detection capability of the device, in millimetres (mm).

Then

$$S = (1\,600 \times T) + 8(d - 14) \tag{4}$$

Where it is foreseeable that electro-sensitive protective equipment employing active opto-electronic protective devices will be used in non-industrial applications, for example in the presence of children, the minimum distance, S, shall be calculated with Equation (3) and be increased by at least 75 mm. In such cases, Equation (4) is not applicable.

6.2.3.2 Cycle re-initiation of machine operation employing active opto-electronic protective devices with control function

Where active opto-electronic protective devices are used for cycle re-initiation of a machine

— their sensor detection capability shall be $\leqslant$ 30 mm,

— Equation (3) (see 6.2.3.1) shall apply, and

— the minimum distance, S, shall be $>$ 150 mm.

If the sensor detection capability is $\leqslant$ 14 mm,

— Equation (3) shall apply, and

— the minimum distance, S, shall be $>$ 100 mm.

NOTE 1 Conditions for using electro-sensitive protective equipment in cycle initiation of machine operation are given in ISO 12100-2:2003, 5.2.5.3, and IEC/TS 62046:2008, 5.6.

NOTE 2 Additional requirements for electro-sensitive protective equipment are given in IEC 61496-1.

NOTE 3 It is possible for electro-sensitive protective equipment with a sensor detection capability $>$ 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.

6.2.4 Electro-sensitive protective equipment with a sensor detection capability of $>$ 40 mm and $\leqslant$ 70 mm diameter

Electro-sensitive protective equipment with a sensor detection capability of $>$ 40 mm and $\leqslant$ 70 mm diameter do not 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.

This equipment shall be installed in accordance with the following parameters.

The minimum distance from the detection zone to the hazard zone shall be calculated using Equation (5).

$$S = (K \times T) + C \qquad (2)$$

where

K = 1 600 mm/s;

C = 850 mm.

Then

$$S = (1\,600 \times T) + 850 \qquad (5)$$

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

6.2.5 Multiple separate beams

Arrangements of 2, 3 or 4 separate beams can be used to detect intrusion of the whole body into the hazard zone but are not suitable for detecting parts of the body (e.g. hand or fingers).

If the risk assessment indicates that multiple separate beams are appropriate, they shall be positioned at a minimum distance from the hazard zone in accordance with Equation (5) (see 6.2.3).

During risk assessment, methods which can possibly be used to bypass such equipment shall be taken into account. The risk assessment shall consider methods by which beam arrangements can be circumvented. For example:

- crawling below the lowest beam;
- reaching over the top beam;
- reaching through between two of the beams;
- bodily access by passing between two beams.

For additional information, see Annex E.

6.2.6 Single beams

These beams have only been considered when they are used parallel to the ground and the beam is broken by a person's body in the upright position. A single beam as the only means of protection is not suitable for preventing whole body access.

NOTE A single beam device is normally used in combination with other safeguards or other structures, which restrict the opening(s) such that it is not possible to pass the protective device without being detected.

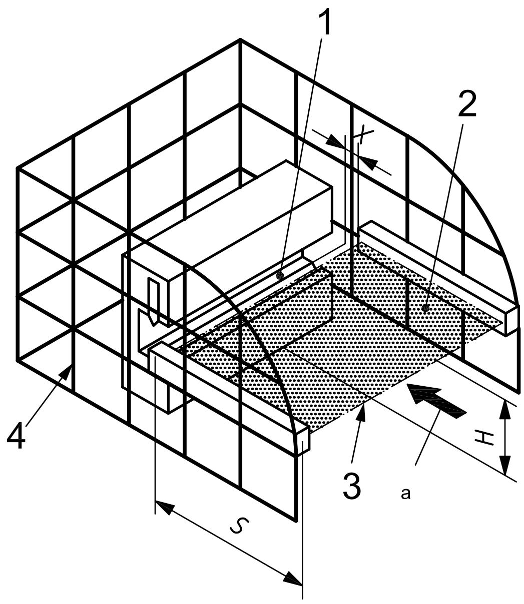
The minimum distance, S, shall be calculated according to Equation (6)

$$S = (1\,600 \times T) + 1\,200 \qquad (6)$$

A height of 750 mm from the ground or reference plane (see ISO 13857) has been found in industry to be a practical solution to the problems of inadvertent access from stepping over or bending under the beam.

6.3 Detection zone parallel to the direction of approach

See Figure 4.



Key

1 hazard zone

2 detection zone

3 edge of the detection zone

4 fixed guard

H height of detection zone above reference plane

S minimum distance

X distance between the end of the detection zone and the hazard zone

[a] Direction of approach.

Figure 4 — Detection zone parallel to direction of approach

When the direction of approach is parallel to the detection zone, the minimum distance, S, shall be calculated using Equation (7).

$$S = (K \times T) + C \quad (2)$$

where

K = 1 600 mm/s;

C = 1 200 mm – 0,4 H, but not less than 850 mm, where H is the height of the detection zone above the reference plane, for example the floor, in millimetres (mm).

Then

$$S = (1\,600 \times T) + (1\,200 - 0{,}4\,H) \quad (7)$$

For a safeguard where the direction of approach is parallel to the detection zone, the height, H, of the detection zone shall not be greater than 1 000 mm. However, if H is greater than 300 mm (200 mm for non-industrial applications, for example in the presence of children) there is a risk 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 lowest allowable height of the detection zone shall be calculated using Equation (8).

$$H = 15\,(d - 50) \quad (8)$$

If d is less than 50 mm, H shall never be less than 0.

Thus, for a given height of the detection zone, the corresponding sensor detection capability, d, shall be calculated using Equation (9).

$$d = \left(\frac{H}{15}\right) + 50 \qquad (9)$$

That means, where the height of the detection zone is known or fixed, a maximum sensor detection capability can be calculated.

For example, when calculating the horizontal section of L-shaped electro-sensitive protective equipment or if a sensor detection capability is known or fixed, a minimum height can be calculated, up to the allowable maximum of 1 000 mm.

When using the device as both a trip and presence-sensing device, the distance X (see Figure 4) shall not be less than the detection capability, d.

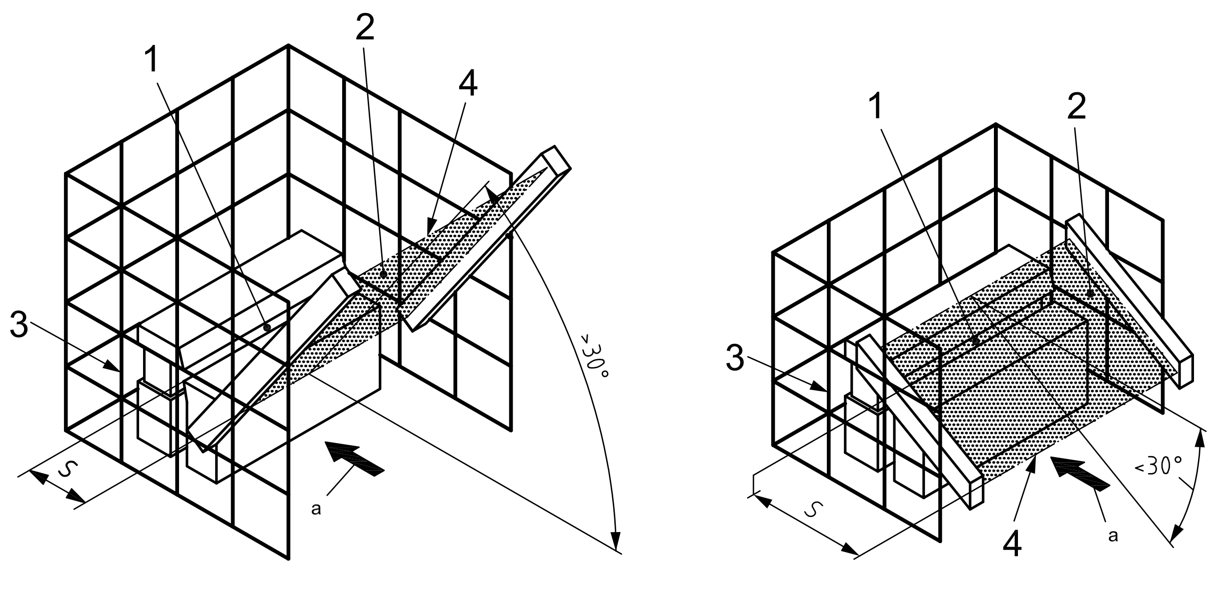
Measures shall be applied so that the protective devices cannot be used to gain access to the hazard zone (e.g. by stepping or climbing on the housing).

6.4 Detection zone angled to the direction of approach

If the detection zone has been installed such that it is angled greater than ± 30° of the direction of approach, it shall be treated as an orthogonal approach [see 6.2 and Figures 5 a) and 6].

If the detection zone has been installed such that it is angled less than ± 30° of the direction of approach, it shall be treated as a parallel approach [see 6.3 and Figures 5 b) and 6].

A tolerance of ± 5° should be used for these angles.

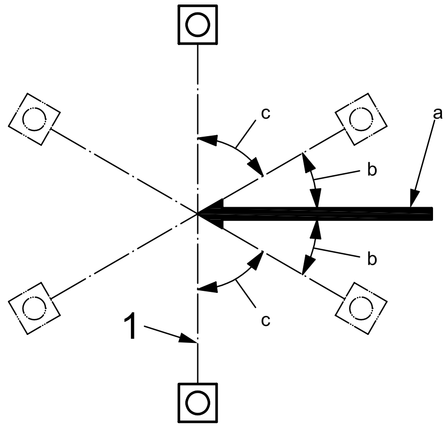


a) Orthogonal approach **b) Parallel approach**

Key

1 hazard zone
2 detection zone
3 fixed guard
4 edge of detection zone
S minimum distance
a Direction of approach.

Figure 5 — Detection zone angled to the direction of approach



Key

1 locations of ESPE at different angles to the direction of approach

a Direction of approach.

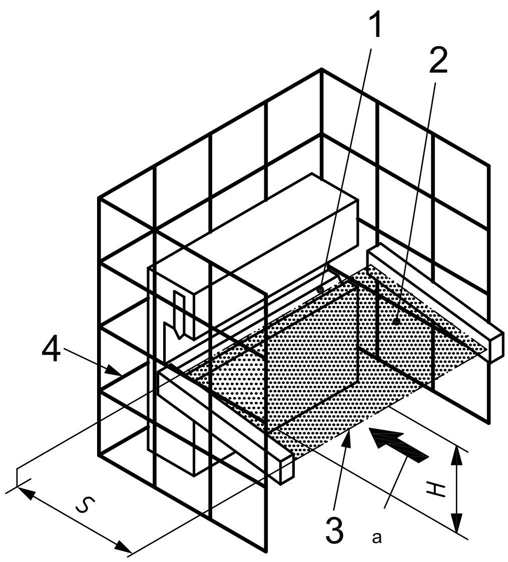
b Angles of parallel approach; less than ± 30°.

c Angles of orthogonal approach.

Figure 6 — Different angles to the direction of approach

When an angled approach is considered as parallel approach (see Figure 6), then Equation (8) linking H and d (see 6.3) shall apply to the edge of the detection zone furthest from the hazard zone (see Figure 7).

NOTE In some applications the detection zone could extend more than 1 000 mm above the reference plane. For calculations using Equation (7), parts of the detection zone greater than 1 000 mm above the reference plane are not considered.



Key

1 hazard zone

2 detection zone

3 edge of detection zone

4 fixed guard

H height of the detection zone (lowest beam)

S minimum distance

a Direction of approach.

Figure 7 — Height of the detection zone (lowest beam)

6.5 Addressing possible circumventing of electro-sensitive protective equipment by reaching over the detection zone

6.5.1 General

Access to the hazard zone by circumventing of the electro-sensitive protective equipment shall be avoided.

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

If access to the hazard zone by reaching over the detection zone of vertically mounted electro-sensitive protective equipment cannot be excluded, the height and the minimum distance, S, of the safeguard shall be determined. S shall be determined by comparison of the calculated values in 6.2 and 6.3 based on the approach of limbs or parts of the body and the values for reaching over determined in 6.5.2, 6.5.3 and 6.5.4. The greater value resulting from this comparison shall be applied.

6.5.2 Prevention of reaching over a vertical detection zone of electro-sensitive protective equipment without an additional protective structure

The minimum distance, S, in millimetres from the detection zone to the hazard zone for prevention of circumventing by reaching over the ESPE shall not be less than that calculated using Equation (10).

For C_{RO}, the values in Table 1 shall apply. C_{RO} is given in this table as the additional distance in millimetres, based on the distance which a part of the body (usually a hand) can move towards the hazard zone prior to the actuation of the electro-sensitive protective equipment. Table 1 only deals with reaching over the detection zone of the ESPE.

Figure 8 illustrates reaching over a vertical detection zone without an additional protective structure.

Where the height of an ESPE is already fixed, Table 1 can be used to derive the minimum distance, S. Where the minimum distance is already fixed, Table 1 can also be used to derive the required height of the ESPE.

$$S = (K \times T) + C_{RO} \tag{10}$$

where

K = 2 000 mm/s

Then

$$S = (2\,000 \times T) + C_{RO} \tag{11}$$

This equation applies to all minimum distances of S up to and including 500 mm. The minimum value of S shall not be less than 100 mm. First calculate S using Equation (11). Where values of S exceed 500 mm then Equation (12) can be applied. The value of S shall not be less than 500 mm.

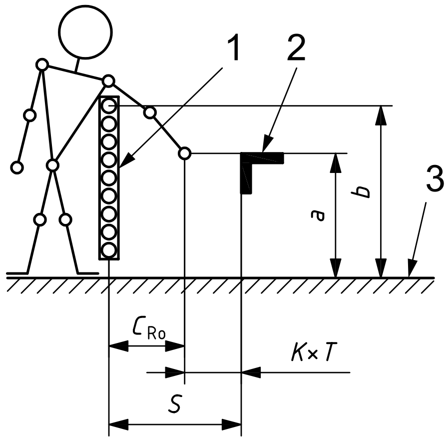
$$S = (K \times T) + C_{RO} \tag{10}$$

where

K = 1 600 mm/s;

Then

$$S = (1\,600 \times T) + C_{RO} \tag{12}$$



Key

1 electro-sensitive protective equipment

2 hazard zone

3 reference plane

a height of the hazard zone

b height of the upper edge of the detection zone of electro-sensitive protective equipment

C_{RO} additional distance which a part of the body can be moving towards the hazard zone prior to the actuation of the safeguard (see values in Table 1)

S minimum distance for reaching over

Figure 8 — Reaching over the vertical detection zone of electro-sensitive protective equipment

Table 1 — Reaching over the vertical detection zone of electro-sensitive protective equipment

Dimensions in millimetres

Height of hazard zone *a*	**Height of upper edge of the detection zone of the electro-sensitive protective equipment** *b*											
	900	**1 000**	**1 100**	**1 200**	**1 300**	**1 400**	**1 600**	**1 800**	**2 000**	**2 200**	**2 400**	**2 600**
	Additional distance to hazard zone C_{RO}											
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

When a value of zero is given, the calculation of the minimum distance, *S*, should be made in accordance with 6.2 to 6.4.

NOTE 1 Electro-sensitive protective equipment with a height of the

— upper edge of the detection zone below 900 mm is not included since they do not offer sufficient protection against circumventing or stepping over

— lower edge of the detection zone above 300 mm in relation to the reference plane does not offer sufficient protection against crawling below.

NOTE 2 The data for this table were researched at a study of the German BG, see [22].

NOTE 3 Most values given in Table 1 are lower in relation to the values of ISO 13857:2008, Tables 1 and 2, since parts of the body cannot support themselves on safeguards in case of reaching over.

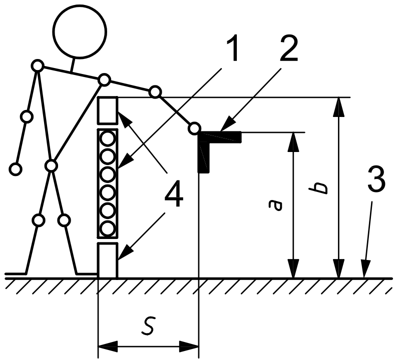
[a] Approach to the hazard zone by reaching over is impossible.

When determining the values of Table 1 it shall not be interpolated. If the known values *a*, *b* or C_{RO} are between two values of Table 1, the greater minimum distance shall be used.

For examples, see Annex A.

6.5.3 Prevention of reaching over a vertical detection zone of electro-sensitive protective equipment combined with a protective structure, such as a fixed guard

If the hazard zone can be approached by reaching over the protective structure (see Figure 9), the minimum distance, *S*, shall not be less than the horizontal safety distance to hazard zone, *c*, determined from ISO 13857:2008, 4.2.2, Table 1 (low risk) or Table 2 (high risk).



Key

1 electro-sensitive protective equipment
2 hazard zone
3 reference plane
4 protective structure (e.g. fixed guard)
a height of the hazard zone
b height of the upper edge of the protective structure
S minimum distance for reaching over [*S* is equal to value *c* from ISO 13857:2008, 4.2.2, Table 1 (low risk) or Table 2 (high risk)]

Figure 9 — Example of reaching over the vertical detection zone of electro-sensitive protective equipment combined with protective structure

6.5.4 Reaching over an angled detection zone

When an approach is considered as orthogonal [see Figures 5 a) and 6], and the hazard zone can be approached by reaching over the electro-sensitive protective equipment, the minimum distance, *S*, shall be the greater of:

a) the distance calculated using the appropriate equation from 6.2.3.1 or 6.2.4; or

b) the distance calculated using the appropriate equation from 6.2.3.1 or 6.2.4, substituting *C* with the additional distance for reaching over, C_{RO}, given in Table 1.

The minimum distance shall apply from the beam nearest to the hazard.

6.6 Indirect approach — Path from detection zone to hazard zone restricted by obstacles

6.6.1 General

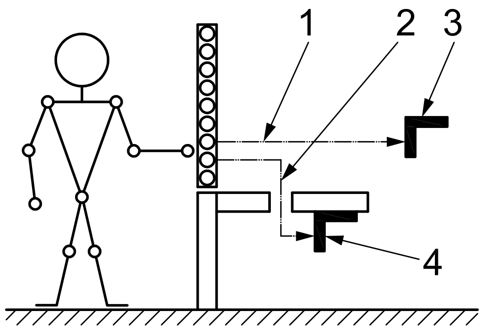
In an application using an ESPE where two or more hazard zones are present, the minimum distance for each hazard zone shall be calculated.

When the access to a hazard zone by the upper limbs is hindered by obstacles that are permanently fixed, the minimum distance can be the shortest path around these obstacles (see Figure 10 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 minimum 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 Obstacles are parts of the machine, such as housings, covers, impeding device, ancillary equipment that prevent direct passage to the hazard.



Key

1 direct approach

2 indirect approach

3 hazard zone 1

4 hazard zone 2

Figure 10 — Example of indirect approach

6.6.2 Calculation of minimum distances for indirect approaches

For the indirect approach, the distance actually covered from the electro-sensitive protective equipment to the hazard zone is calculated using Equation (13).

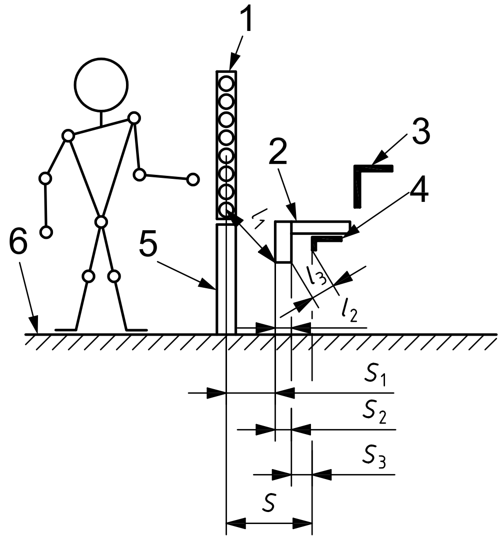
$$S^{*} = (K \times T) + C = l_1 + l_2 + l_3 \qquad (13)$$

where

S^{*} is the distance actually covered.

In this calculation, the parameter for the approach speed, K, with the value 1 600 mm/s shall be applied. l_1, l_2 and l_3 shall be measured along the shortest path around, under or over the obstacle(s) from any point of the detection zone (see 6.2 to 6.5). For the indirect approach, the minimum distance, S, is regarded as the horizontally projected distance of the distance actually covered, S^{*} (See Figure 11).

An example for the calculation of the minimum distance, S, is shown in C.1.



Key

1	electro-sensitive protective equipment	S	minimum distance, in a horizontal plane, from the hazard zone to the outermost edge of the detection zone
2	obstacle		
3	hazard zone 2	S	$= S_1 + S_2 + S_3$
4	hazard zone 1	S_1	distance of l_1, projected on a horizontal plane
5	protective structure	S_2	distance of l_2, projected on a horizontal plane
6	reference plane	S_3	distance of l_3, projected on a horizontal plane
l_1; l_2; l_3	shortest distance around obstacles in direction to the hazard zone	S^*	$= l_1 + l_2 + l_3$

Figure 11 — Illustration of calculating of the distance actually covered

The minimum distance for locating the detection zone when an indirect approach is possible can be calculated by the method described above.

NOTE It can be acceptable to use a lower approach speed for certain infrequent operations where only indirect access 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 [22]).

7 Method of calculating the positioning of pressure-sensitive mats or floors

7.1 General

The selection and use of pressure-sensitive mats/floors is dependent on the appropriate type-C standard or a risk assessment in accordance with ISO 14121-1, if no type-C standard exists.

The minimum width of pressure-sensitive mats/floors shall be at least 750 mm to prevent the possibility of easy stepping over without actuation of the device.

NOTE It has been shown that the 95th percentile of two steps (i.e. starting and finishing with the same foot) measured from heel contact at walking speed is approximately 1 900 mm. By dividing by two and subtracting the 5th percentile shoe length, a stride length of 700 mm is obtained. If it is assumed that an allowance has to be made, for example, between the detection zone and the stride length of for example 50 mm, this gives a minimum width of 750 mm for the detection zone.

The minimum distances derived in this clause for pressure-sensitive mats/floors assume the approach speed to the hazard zone will be at walking speed (1 600 mm/s).

The minimum distance, S, in millimetres, from the hazard zone to the outermost edge of the detection zone of the protective device, shall be calculated using Equation (14):

$$S = (1\,600 \times T) + 1\,200 \qquad (14)$$

7.2 Step mounting

If the protective device is mounted on a step or raised platform, then the minimum distance may be reduced by 0,4 h, where h is the height of the step in millimetres (mm). The minimum distance, S, from the detection zone to the hazard zone may be calculated using Equation (15):

$$S = (1\,600 \times T) + (1\,200 - 0{,}4\,h) \qquad (15)$$

8 Two-hand control devices

The minimum distance, S, from the nearest actuator to the hazard zone shall be calculated using Equation (16).

$$S = (K \times T) + C \qquad (2)$$

where

K = 1 600 mm/s;

C = 250 mm.

Then

$$S = (1\,600 \times T) + 250 \qquad (16)$$

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, for example by adequate shrouding, then C may be zero, with a minimum allowable distance for S of 100 mm.

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

9 Interlocking guards without guard locking

In order to ensure that the hazard zone cannot be reached when opening an interlocking guard without guard locking before the hazardous machine motion has stopped, the minimum distance, S, shall be determined.

The minimum distance from the nearest edge of the opening of the interlocking guard without guard locking to the hazard zone shall be calculated by using Equation (2).

$$S = (K \times T) + C \qquad (2)$$

where

K = 1 600 mm/s;

C is a safety distance taken from Table 4 or Table 5 of ISO 13857:2008, if it is possible to push fingers or a hand through the opening towards the hazard before a stop signal is generated.

In some cases, T may be reduced by the opening time, t_3, which is required to open the guard to the extent that the opening size permits access of the relevant parts of the body. The opening sizes, e, given in Tables 4 and 5 of ISO 13857:2008 shall be considered. The calculation shall start with the smallest part of the body by which the hazard zone can be reached.

If the opening time, t_3, depends on the interlocking guard, it shall be used and it shall be determined by calculation or test.

For power-operated interlocking guards including interlocking roller doors, t_3 can be calculated according to Equation (17):

$$t_3 = \frac{e}{v} \tag{17}$$

where

- e is the opening size, in millimetres (mm);
- v is the speed of the opening motion of the power-operated interlocking guard, in millimetres per second (mm/s).

NOTE A minimum distance which is too large can be reduced by applying an interlocking guard with guard locking (see ISO 14119).

Annex A
(informative)

Worked examples

A.1 General

This annex gives examples to show how this International Standard can be used.

It is assumed in these examples that either the appropriate type-C standard or the risk assessment for the relevant machine allows the use of the safeguard chosen for these examples.

The calculation of the minimum distance, S, consists of three steps.

a) First step: minimum distance for reaching through the detection zone, S_{RT};

b) Second step: minimum distance for reaching over the detection zone, S_{RO};

c) Third step: comparison of S_{RT} and S_{RO} to determine S.

NOTE In certain applications, it could be necessary to address other possible circumventing than reaching over the safeguard.

A.2 Example 1

A machine has a stopping time of 60 ms (t_2). It is fitted with electro-sensitive protective equipment employing a vertical active opto-electronic protective device, having a sensor detection capability of 14 mm and a response time of 30 ms (t_1). In this example, it is assumed that it is not possible to reach over the ESPE. Therefore, the second and third steps are not necessary.

Using Equation (3):

$$S = (2\,000 \times T) + 8(d - 14)$$

where

S is the minimum distance from the hazard zone to the detection zone, in millimetres (mm);

T is the overall system stopping performance of (60 + 30) ms = 90 ms = 0,09 s;

d = 14 mm.

Then

$$S = (2\,000 \times 0{,}09) + 8(14 - 14)$$
$$S = 180 \text{ mm}$$

A.3 Example 2

The same machine as in Example 1 is used, but with a sensor detection capability of 30 mm.

Using Equation (3):

$$S = (2\,000 \times T) + 8(d - 14)$$

where

T is the overall system stopping performance of (60 + 30) ms = 90 ms = 0,09 s;

d = 30 mm.

Then

$$S = (2\,000 \times 0{,}09) + 8(30 - 14)$$
$$S = 180 + 128$$
$$S = 308 \text{ mm}$$

A.4 Example 3

Calculate the minimum distance, S, for the detection zone of vertically mounted electro-sensitive protective equipment and determine the height, b, of the upper edge of the detection zone.

A machine has a stopping time of 250 ms (t_2), including the control system response time. It is fitted with electro-sensitive protective equipment employing a vertical active opto-electronic protective device (AOPD), having a sensor detection capability of 30 mm (d) and a response time of 30 ms (t_1). The height of the hazard zone above the reference plane is 800 mm (a). The active opto-electronic protective equipment is active from the height of 200 mm.

a) First step:

Calculate the minimum distance for reaching through the electro-sensitive protective equipment, S_{RT}.

Using Equation (3):

$$S_{RT} = (K \times T) + C_{RT} = (2\,000 \times T) + 8(d - 14)$$

where

S_{RT} is the minimum distance from the hazard zone to the detection zone, in millimetres (mm), according to 6.2.3.1;

T is the overall system stopping performance of (250 + 30) ms = 280 ms = 0,28 s;

d = 30 mm.

Then

$$S_{RT} = (2\,000 \times 0{,}28) + 8\,(30 - 14)$$
$$S_{RT} = 688 \text{ mm}$$

since $S_{RT} > 500$ mm, Equation (4) can be applied:

$$S_{RT} = (1\,600 \times T) + 8(d - 14)$$

Then

$$S_{RT} = (1\,600 \times 0{,}28) + 8(30 - 14)$$
$$S_{RT} = 576 \text{ mm}$$

b) Second step:

1) Determination of:

— the additional distance to hazard zone, C_{RO};

— the minimum height of the electro-sensitive protective equipment for detection of reaching over b.

Using Equation (2):

$$S = (K \times T) + C$$

set $S_{RO} = S_{RT}$, which implies

$C_{RO} = C_{RT} = 128$ mm

In Table A.1, row "a = 800 mm" (see ①), the next smaller (safer) value of C_{RO} = 0 mm (see ②).

2) Determine the height of the upper edge of the detection zone of the electro-sensitive protective equipment, b, by using Table A.1.

The corresponding value is b = 1 600 mm (see ③).

Table A.1 — Reaching over the vertical detection zone of electro-sensitive protective equipment

Dimensions in millimetres

Height of hazard zone a	Height of upper edge of the detection zone of the electro-sensitive protective equipment b											
	900	**1 000**	**1 100**	**1 200**	**1 300**	**1 400**	**1 600③**	**1 800**	**2 000**	**2 200**	**2 400**	**2 600**
	Additional distance to hazard zone C_{RO}											
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
800①	1 150	1 050	950	800	500	450	0②	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 For additional information, see notes of Table 1.

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

c) Third step:

Since C_{RO} = 0, therefore S_{RO} is smaller than S_{RT}, use S_{RT}

$$S = S_{RT} = 576 \text{ mm}$$

A.5 Example 4

Calculate the minimum distance, S, for the detection zone of vertically mounted electro-sensitive protective equipment with a height, b, of the upper edge of the detection zone of 1 300 mm.

A machine has a stopping time of 250 ms (t_2), including the control system response time. It is fitted with electro-sensitive protective equipment employing a vertical active opto-electronic protective device (AOPD), having a sensor detection capability of 30 mm (d) and a response time of 30 ms (t_1). The height of the hazard zone above the reference plane is 650 mm (a); The active opto-electronic protective equipment is active from a height of 200 mm and the height of the upper edge of its detection zone (b) is 1 340 mm.

a) First step:

Determination of the minimum distance, S_{RT}, of the electro-sensitive protective equipment for reaching through:

Using Equation (3):

$$S_{RT} = (K \times T) + C_{RT} = (2\,000 \times T) + 8(d - 14)$$

where

S_{RT} is the minimum distance from the hazard zone to the detection zone, in millimetres (mm), according to 6.2.3.1;

T is the overall system stopping performance of (250 + 30) ms = 280 ms = 0,28 s;

d = 30 mm.

Then

$$S_{RT} = (2\,000 \times 0{,}28) + 8(30 - 14)$$
$$S_{RT} = 688 \text{ mm}$$

$S_{RT} > 500$ mm, therefore using Equation (4):

$$S = (1\,600 \times T) + 8(d - 14)$$

Then

$$S_{RT} = (1\,600 \times 0{,}28) + 8(30 - 14)$$
$$S_{RT} = 576 \text{ mm}$$

b) Second step:

When determining the values of Table A.2, it shall not be interpolated. If a = 650 mm, the nearest (safer) value in Table A.2 is a = 800 mm. If b = 1 340 mm, then the nearest (safer) value in Table A.2 is b = 1 300 mm.

Determine the minimum distance for reaching over the electro-sensitive protective equipment, S_{RO}.

1) Using Table A.2, with a = 800 mm (see ①) and b = 1 300 mm (see ②):

Find C_{RO} = 500 mm (see ③) as the minimum additional distance for reaching over.

Table A.2 — Reaching over the vertical detection zone of electro-sensitive protective equipment

Dimensions in millimetres

Height of hazard zone *a*	Height of upper edge of the detection zone of the electro-sensitive protective equipment *b*											
	900	**1 000**	**1 100**	**1 200**	**1 300②**	**1 400**	**1 600**	**1 800**	**2 000**	**2 200**	**2 400**	**2 600**
	Additional distance to hazard zone C_{RO}											
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
800①	1 150	1 050	950	800	500③	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 For additional information, see notes of Table 1.

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

2) Using Equation (10):

$$S = S_{RO} = (K \times T) + C_{RO}$$

where

$$S_{RO} = (2\,000 \times 0{,}28) + 500$$

$S_{RO} > 500$ mm, therefore using Equation (12):

$$S = (1\,600 \times T) + C_{RO}$$

Then

$$S_{RO} = (1\,600 \times 0{,}28) + 500$$

$$S_{RO} = 448 + 500 = 948 \text{ mm}$$

c) Third step:

Determination of the minimum distance, S, by comparing S_{RT} and S_{RO}:

$$S_{RT} < S_{RO}$$

Consequently, the minimum distance to the hazard zone is $S = S_{RO}$ = 948 mm.

A.6 Example 5

Calculate the minimum distance, S, for the detection zone of vertically mounted electro-sensitive protective equipment, which is combined with a fixed guard.

A machine has a stopping time of 250 ms (t_2), including the control system response time. It is fitted with electro-sensitive protective equipment employing a vertical active opto-electronic protective device (AOPD), having a sensor detection capability of 30 mm (d) and a response time of 30 ms (t_1). The height of the hazard zone above the reference plane is 800 mm (a); The active opto-electronic protective equipment is active from the height of 200 mm and its height of the upper edge of the guard is 1 600 mm (b).

a) First step:

Determination of the minimum distance, S_{RT}, of the electro-sensitive protective equipment for reaching through:

Using Equation (3):

$$S = (2\,000 \times T) + 8(d - 14)$$

where

S = S_{RT} is the minimum distance from the hazard zone to the detection zone, in millimetres (mm), according to 6.2.3.1 (reaching through);

T is the overall system stopping performance of (250 + 30) ms = 280 ms = 0,28 s;

d = 30 mm.

Then

$$S_{RT} = (2\,000 \times 0{,}28) + 8(30 - 14)$$
$$S_{RT} = 688 \text{ mm}$$

$S_{RT} > 500$ mm, therefore using Equation (4):

$$S = (1\,600 \times T) + 8(d - 14)$$

Then

$$S_{RT} = (1\,600 \times 0{,}28) + 8(30 - 14)$$
$$S_{RT} = 576 \text{ mm}$$

b) Second step:

Determine the minimum distance for reaching over the electro-sensitive protective equipment, S_{RO}.

Using ISO 13857:2008, Table 2, with a = 800 mm and b = 1 600 mm.

Find:

S_{RO} = c = 600 mm as the minimum distance to the hazard zone for reaching over.

c) Third step:

Determination of the minimum distance, S, by comparing S_{RT} and S_{RO}:

$$S_{RO} > S_{RT}$$

consequently, the minimum distance to the hazard zone is $S = S_{RO}$ = 600 mm.

A.7 Examples comparing different protective devices

A.7.1 Example 6

Inadvertent access to the hazard zone of a machine is detected by an opto-electronic protective device. A hazard zone height of 600 mm is assumed.

The risk assessment indicates that multiple separate beams would be appropriate and, therefore, a three-beam ESPE according to Annex E is selected.

The stopping time of the machine system is 300 ms (t_2) and the response time of the safeguard is 35 ms (t_1).

From Table E.1, the beams should be set at 300 mm, 700 mm and 1 100 mm from the floor.

a) First step:

The minimum distance is given by Equation (5):

$$S_{RT} = (1\,600 \times T) + 850$$

where

T = 335 ms = 0,335 s.

Then

$$S_{RT} = (1\,600 \times 0{,}335) + 850$$
$$S_{RT} = 536 + 850$$
$$S_{RT} = 1\,386 \text{ mm}$$

b) Second step:

Since the height of the uppermost beam is 1 100 mm, reaching over is considered.

From Table A.1, it is seen that 750 mm is used as the value of C_{RO} in the equation.

Then

$$S_{RO} = (1\,600 \times 0{,}335) + 750$$
$$S_{RO} = 536 + 750$$
$$S_{RO} = 1\,286 \text{ mm}$$

c) Third step:

$$S_{RO} < S_{RT}$$

Therefore

$S = S_{RT}$ = 1 386 mm is selected as the minimum distance.

A.7.2 Example 7

The same machine as in Example 6 is used, but using a floor-mounted pressure-sensitive mat or a floor-mounted opto-electronic protective device instead of a three-beam device.

a) First step:

The minimum distance is given by Equation (14):

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

Then

$$S = (1\ 600 \times 0{,}335) + 1\,200$$
$$S = 536 + 1\,200$$
$$S = 1\,736 \text{ mm}$$

b) Second and third steps:

Compared with the value for overreaching from Table A.1, as determined in Example 6, 1 736 mm is selected as the minimum distance.

A.7.3 Example 8

The same machine is used as in Example 6, but fitted with a two-hand control device.

Using Equation (15):

$$S = (1\,600 \times T) + 250$$

Then

$$S = (1\,600 \times 0{,}335) + 250$$
$$S = 536 + 250$$
$$S = 786 \text{ mm}$$

If adequate shrouding is used, S can be reduced to 536 mm (see Clause 8).

Annex B
(informative)

Termination of hazardous machine functions

When calculating the minimum distance, S, of a safeguard according to the provisions of this International Standard, the system stopping performance represents a decisive parameter. This time is influenced by the moment when the hazardous machine function (usually a motion) is altered in such a way that it is harmless for the human body. This moment is achieved if a physical injury or damage to health can be excluded.

If this moment occurs before the machine has come to a complete halt, 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 halt.

There are many factors that can be applicable and there is only limited guidance available. Some examples that can be considered are given below, but the International Standards referenced might not be 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.

There are no type-B standards available for evaluating the effects of forces on the human body.

NOTE 1 Some information about forces and kinetic energies can be found in ISO 14120:2002, 5.2.5.2.

NOTE 2 Minimum gaps to avoid crushing of parts of the human body can be found in ISO 13854.

NOTE 3 See also the list of examples of hazardous situations in ISO 14121-1:2007, Annex A.

If the minimum distances are calculated according to the provisions of this International Standard, the relationship between the termination of hazardous machine function and the moment when the machine comes to a complete halt should be made explicit. Such a relationship can, for example, be defined as follows.

— With crushing hazard the termination of hazardous machine functions can be defined as 2 mm prior to the position where the machine comes to a complete halt, unless there is a risk of crushing of the head. This means that the time represented by these 2 mm can be used to reduce the overall system stopping performance.

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

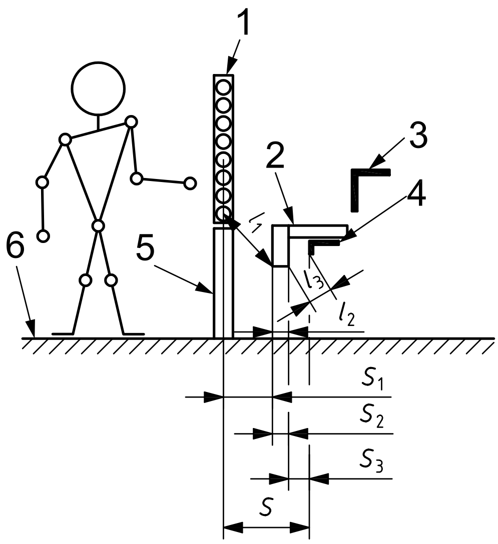
Annex C
(informative)

Example for considering indirect approaches

This annex gives an example of the calculation of the way around obstacles.

A machine has a stopping time of 250 ms (t_2). It is fitted with electro-sensitive protective equipment employing a vertical active opto-electronic protective device, having a sensor detection capability of 30 mm (d) and a response time of 30 ms (t_1).

Reaching the hazard zone requires reaching around an obstacle (see Figure C.1).



Key

1	electro-sensitive protective equipment	S	minimum distance, in a horizontal plane, from the hazard zone to the outermost edge of the detection zone
2	obstacle	S	$= S_1 + S_2 + S_3$
3	hazard zone 2	S_1	distance of l_1, projected on a horizontal plane
4	hazard zone 1	S_2	distance of l_2, projected on a horizontal plane
5	protective structure	S_3	distance of l_3, projected on a horizontal plane
6	reference plane	S^*	$= l_1 + l_2 + l_3$
l_1; l_2; l_3	shortest distance around obstacles in direction to the hazard zone		

Figure C.1 — Dependence of horizontal distance to the minimum distance due to indirect approach

The example uses the following design data:

$l_1 = 100$ mm

$l_3 = 200$ mm

Using Equation (4) and 6.2.3.1:

$$S^* = (1\,600 \times T) + 8(d - 14)$$

where

S^* = $(K \times T) + C = l_1 + l_2 + l_3$ [using Equation (13)], is the distance actually covered from the hazard zone to the detection zone, in millimetres (mm);

T is the overall system stopping performance of (250 + 30) ms = 280 ms = 0,28 s;

d = 30 mm.

Then

$$S^* = (1\,600 \times 0{,}28) + 8\,(30 - 14)$$
$$S^* = 576 \text{ mm}$$

The horizontal distance assumed in this example, which has been determined by design and which results from l_1 and l_3, amounts to:

$$S_1 = 60 \text{ mm};$$
$$S_3 = 75 \text{ mm}$$

By equating the horizontal component of the access distance l_2 with S_2, the result is:

$$S_2 = l_2 = S^* - (l_1 + l_3) = 576 \text{ mm} - 300 \text{ mm} = 276 \text{ mm}$$

The horizontal distance of the electro-sensitive protective equipment to the hazard zone is therefore:

$$S = S_1 + S_2 + S_3 = 60 \text{ mm} + 276 \text{ mm} + 75 \text{ mm}$$

$$S = 441 \text{ mm}$$

Annex D
(informative)

Measurement and calculation of overall system stopping performance

D.1 When to give a stop signal

The signal to simulate the activation of the protective device (i.e. the stop signal) should be given to the machine at the moment/position/phase of motion which gives the longest stopping time. The worst-case scenario for the stopping time of the machine should be used (to the extent it is realistic). When determining this scenario, factors such as tool weight, temperature, switching times of valves and ageing of components should be considered. In most cases, the worst-case scenario is when the maximum speed of the machine occurs.

For the calculation of minimum distances in accordance with this International Standard, the designed (e.g. programmed) speed of moving equipment in the hazardous area can be taken. The speed of moving equipment need not be considered under fault conditions.

NOTE 1 Where a person approaches a dangerous situation, two independent faults (events) need to happen at the same time: the person stretches an arm out towards the hazardous point and the moving equipment fails in speed or extension at the same time, which is unlikely.

NOTE 2 The calculation of speed, even under fault condition, is necessary, 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 dangerous situation. Such considerations are not dealt with in this International Standard, but is the subject of type-C standards.

D.2 How to calculate the overall system stopping performance

One measurement is not sufficient for calculating the minimum distance. At least 10 measurements are required.

A statistical way of covering 99,7 % of all individuals in a normally distributed population is to calculate the mean value ± 3 standard deviations.

The highest measured value or the mean plus three standard deviations, whichever is the greater, should be used in the calculation of the minimum distance.

D.3 Practices to be avoided

The mean value alone should not be used for the calculation of the minimum distance, since the machine in 50 % of the cases would have a longer overall system stopping performance. Only in applications in which the stopping time is monitored may the mean value alone be used.

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.

D.4 Good practice for making a protocol

Except for stating the calculated minimum distance and identifying the machine on which the measurements were made, the protocol should also contain a list of assumptions that were made about how the worst-case scenario was determined and how the safe condition was defined.

An adequately formulated protocol should contain the following information:

a) identification of the machine;

b) safeguard used;

c) measuring equipment used;

d) verification (including calibration) 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 stopping performance;

k) calculated minimum distance, showing values used in equations.

Annex E
(informative)

Number of beams and their height above the reference plane

The heights for 2, 3 and 4 beams given in Table E.1 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 multiple separate beams. Further protective measures to prevent access to the hazard zone can be required. For the lowest beam [see 6.2.2 a)] 400 mm can only be used when the risk assessment allows it.

Table E.1 — Number of beams and their height above the reference plane

Number of beams	**Heights above the reference plane, for example the floor** mm
4	300, 600, 900, 1 200
3	300, 700, 1 100
2	400[a], 900

[a] For the lowest beam [see 6.2.2 a)] 400 mm can only be used when the risk assessment allows it.

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