
**Safety of machinery — Positioning of
protective equipment with respect to the
approach speeds of parts of the human
body**

*Sécurité des machines — Positionnement des dispositifs 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 3.

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 International Standard 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*.

Annexes A, B and C of this International Standard are for information only.

Introduction

The effectiveness of certain types of protective equipment 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 danger zone. In deciding on these positions, a number of aspects are to be taken into account, such as:

- the need to identify hazards and to assess risks;
- the practical experiences of users, including accident statistics and existing national standards;
- the state of the art and possible future technical developments;
- the type of equipment to be used;
- the response times of protective equipment used;
- the time taken to ensure the safe condition of the machine following operation of the protective equipment, for example to stop the machine;
- the bio-mechanical and anthropometric data of body parts;
- the path taken by the body part when moving from the sensing or actuating means towards the danger zone;
- the possible presence of a person between the device and the danger zone;
- the possibility of undetected access to the danger zone.

If these aspects are further developed, the current state of the art, reflected in this International Standard, will be updated.

This International Standard gives guidance based on the assumption that the correct device has been chosen either by reference to the appropriate Type-C standard or by carrying out a risk assessment.

The calculated distances, when implemented, will provide sufficient protection for persons against the risks caused by approaching a danger zone which generate any of the following mechanical hazards, such as: crushing, shearing, cutting or severing, entanglement, drawing-in or trapping, friction or abrasion, stabbing or puncture and impact.

Protection against the risks from mechanical hazards arising from the ejection of solid or fluid materials and non-mechanical hazards such as toxic emissions, electricity, radiation etc. are not covered by this International Standard.

The distances are derived from data that take into account population groups likely to be found in European countries and are consequently applicable to those groups.

NOTE 1 If this International Standard is to be used for non-industrial purposes, then the designer should take into account that this data is based on industrial experience.

NOTE 2 Until specific data is available for approach speeds for children, this International Standard uses adult speeds and lower detection factors, where relevant, to calculate the distances that could be within the reach of children.

This International Standard has been prepared to be a harmonized standard in the sense of the Machinery Directive of the European Union and associated regulations of the European Free Trade Association (EFTA). This International Standard is based on EN 999:1998, published by the European Committee for Standardization (CEN).

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

1 Scope

This International Standard provides parameters based on values for hand/arm and approach speeds and the methodology to determine the minimum distances from sensing or actuating devices of protective equipment to a danger zone.

These specific devices are:

- a) trip devices as defined in EN 292-1:1991, 3.23.5 (specifically electro-sensitive protective equipment, pressure sensitive mats), including those used additionally to initiate operation;
- b) two-hand control devices as defined in EN 292-1:1991, 3.23.4 and covered by ISO 13851.

NOTE For the purposes of this International Standard, hold-to-run controls, which are designed to be actuated with one hand, are not considered to be protective equipment.

This International Standard does not apply to protective equipment which is intended to be moved, without tools, nearer to the danger zone than the calculated distance, e.g. pendant two-hand control devices.

The minimum distances derived from this International Standard do not apply to protective equipment 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 normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO/TR 12100-1:1992, *Safety of machinery — Basic concepts, general principles for design — Part 1: Basic terminology, methodology*

ISO/TR 12100-2:1992, *Safety of machinery — Basic concepts, general principles for design — Part 2: Technical principles and specifications*

ISO 13851¹⁾, *Safety of machinery — Two-hand control devices — Functional aspects and design principles*

ISO 13852:1996, *Safety of machinery — Safety distances to prevent danger zones being reached by the upper limbs*

ISO 14121:1999, *Safety of machinery — Principles of risk assessment*

IEC 61496-1:1997, *Safety of machinery — Electrosensitive protective equipment — Part 1: General requirements and tests*

1) To be published.

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO/TR 12100-1 and ISO/TR 12100-2 and the following apply.

3.1

actuation

(of protective equipment) physical initiation of the protective equipment when it detects movement of the body or a part of the body

3.2

overall system stopping performance

T

time or travel occurring from the actuation of the sensing function to the cessation of hazardous motion, or to the machine assuming a safe condition, comprising a minimum of two phases:

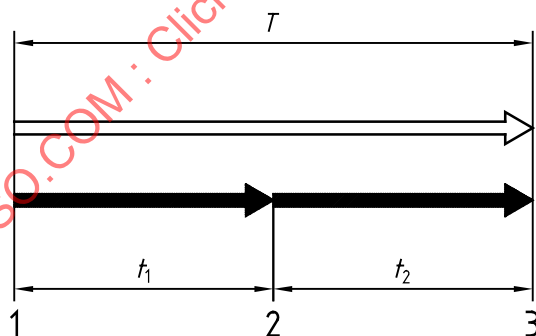
$$T = t_1 + t_2$$

where

- t_1 is the maximum time between the actuation of the sensing function and the output signal switching devices being in the off state,
- t_2 is the maximum response time of the machine, i.e. the time required to stop the machine or remove the risks after receiving the output signal from the protective equipment. t_2 is influenced by various factors, e.g. temperature, switching time of valves, ageing of components.

[IEC 61496-1:1997, 3.20]

NOTE The relationship of t_1 and t_2 is given in Figure 1. t_1 and t_2 are functions of the protective equipment and the machine respectively and are determined by design and measurement.



Key

- 1 Actuating of protective equipment
- 2 Operation of protective equipment
- 3 Elimination of risk

Figure 1 — Relationship between t_1 and t_2

3.3

detection capability

d

sensing function parameter limit specified by the supplier that will cause actuation of the electro-sensitive protective equipment (ESPE)

[IEC 61496-1:1997, 3.6]

3.4

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 and output signal switching devices

[IEC 61496-1:1997, 3.1]

4 Methodology

Figure 2 provides a schematic representation of the methodology for determining the correct position of sensing or actuating devices of protective equipment in accordance with this International Standard, which is as follows.

- a) Identify the hazards and assess the risks (see ISO/TR 12100-1 and ISO 14121).
- b) If a Type-C standard exists for the machine, select one of the specified types of protective equipment from that machine-specific standard, and then use the distance specified by that European standard.
- c) If there is no Type-C standard or if the Type-C standard does not specify any minimum distances, then use the formulae in this International Standard to calculate the minimum distance for the protective equipment selected. The selection of the appropriate type of protective equipment should be made in accordance with the relevant Type-A and Type-B standards.
- d) Incorporate the distance in the machine design.
- e) Ensure that the device has been installed in such a manner that access to the danger zone will not be possible without detection by the device.
- f) Check if the determined position will allow persons to be between the sensing devices of the protective equipment and the danger zone without being detected. In this case, supplementary measures may be required depending on the risk.

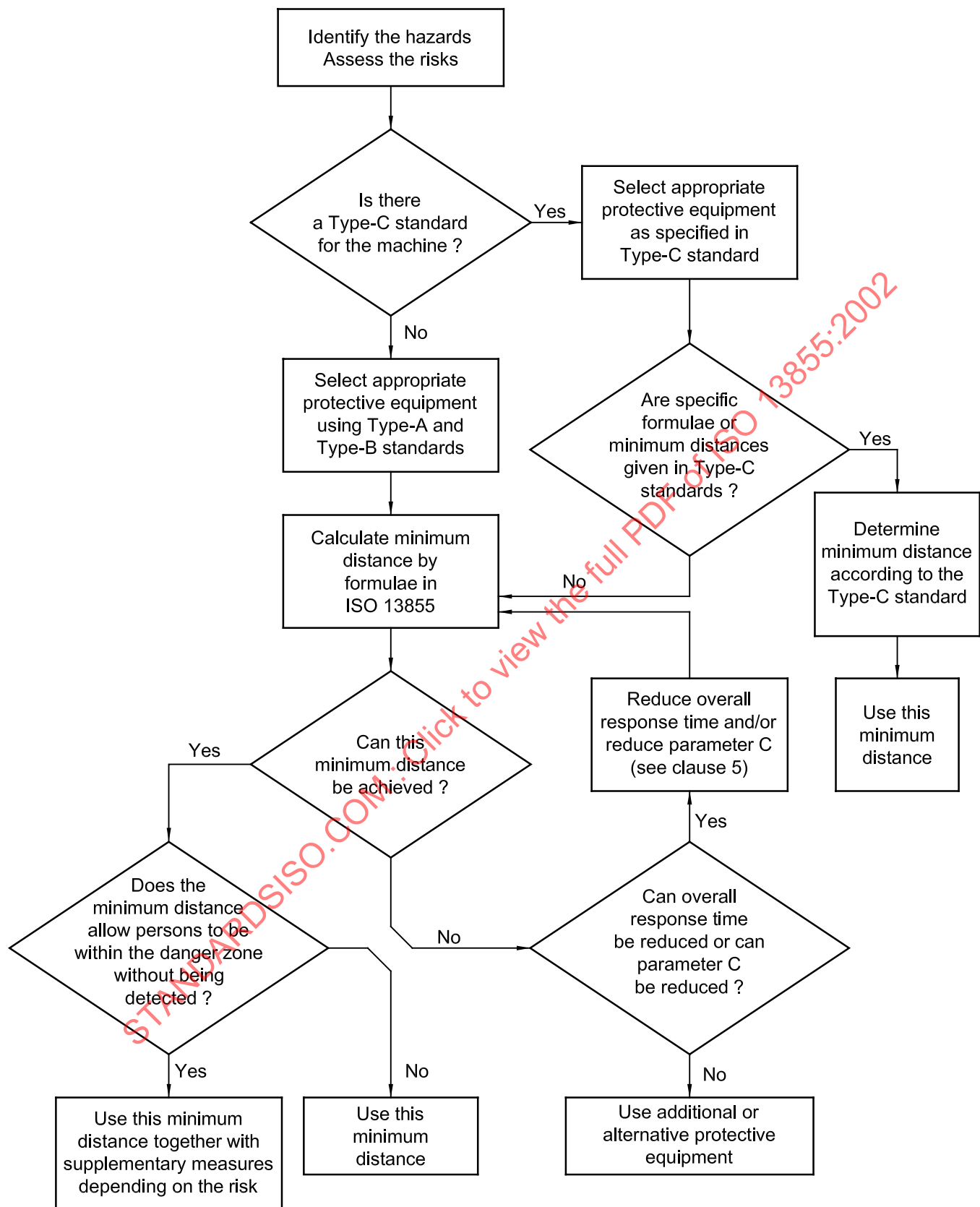


Figure 2 — Schematic of methodology

5 General formula for the calculation of minimum distances

The minimum distance, in millimetres, from the danger zone to the detection point, line, plane or zone shall be calculated by using the following general formula:

$$S = (K \times T) + C \quad (1)$$

where

- K is a parameter in millimetres per second, derived from data on approach speeds of the body or parts of the body (see also annex B);
- T is the overall system stopping performance in seconds (see 3.2);
- C is an additional distance in millimetres, based on intrusion towards the danger zone prior to actuation of the protective equipment.

For worked examples see annex A.

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

Users of this International Standard shall select and use electro-sensitive protective equipment for a machine in accordance with the appropriate Type-C standard for that particular machine. If no Type-C standard exists, they shall undertake a risk assessment according to ISO 14121.

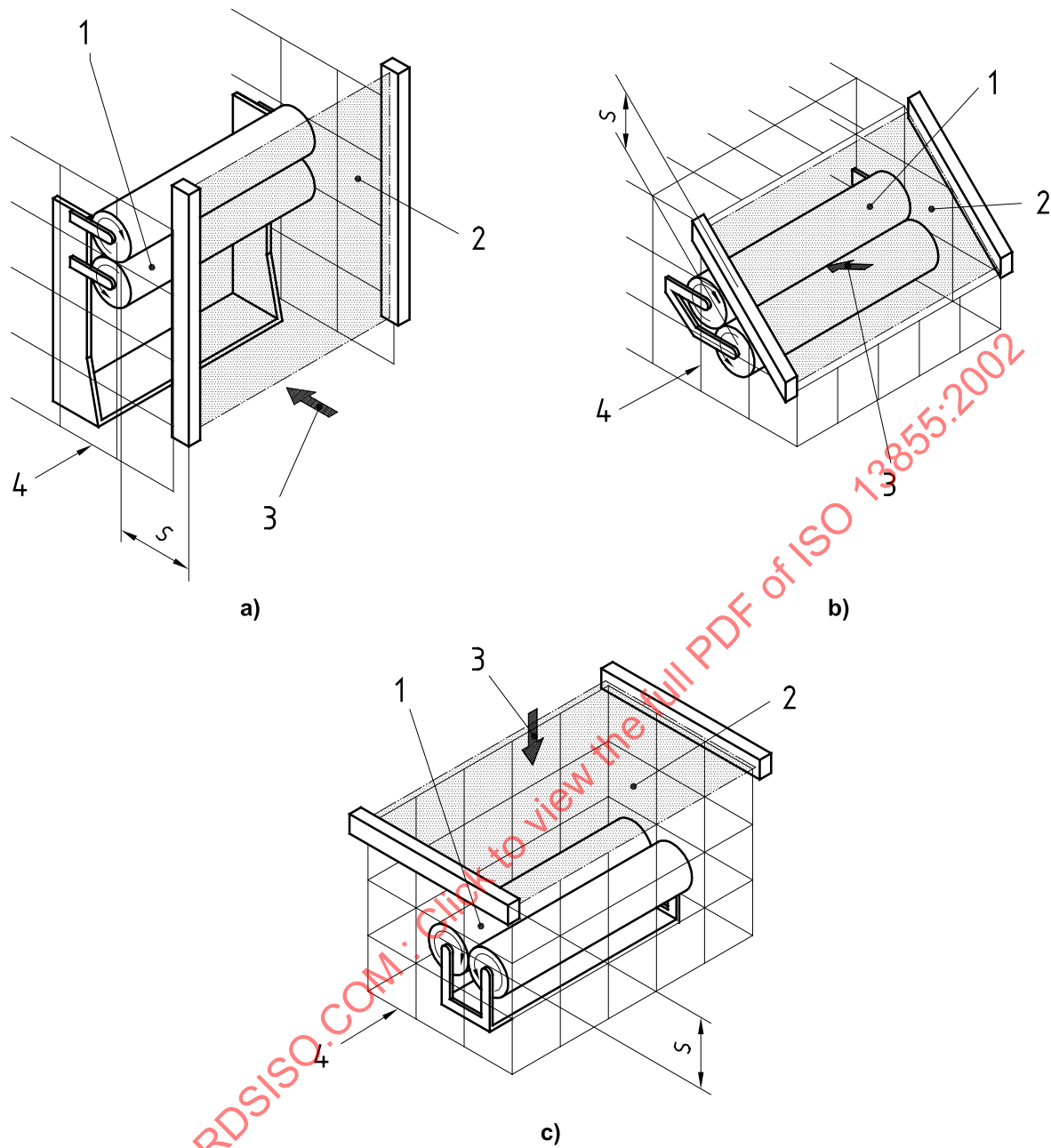
This clause considers three main applications based on the direction of approach to the detection zone²⁾:

- a) normal approach (see Figure 3);
- b) parallel approach (see Figure 4);
- c) angled approach (see Figure 5).

Where it is foreseeable that any gaps adjacent to or within the detection zone of the electro-sensitive protective equipment will allow access to the danger zone, this should be taken into account in the correct positioning of the protective equipment and additional safeguards considered.

Access to the danger zone by reaching over or round the electro-sensitive protective equipment, together with any other protective equipment and additional safeguards, shall be prevented.

2) For the definition of detection zone, see IEC 61496-1.



Key

- S Minimum distance
- 1 Danger zone
- 2 Detection zone
- 3 Direction of approach
- 4 Fixed guard

Figure 3 — Three examples of normal approach

6.1 Direction of approach normal to the detection zone

6.1.1 Electro-sensitive protective equipment employing active opto-electronic protective devices

The minimum distance from the detection zone to the danger zone shall not be less than that calculated using the following formula:

$$S = (2\,000 \text{ mm/s} \times T) + 8 (d - 14 \text{ mm}) \quad (2)$$

by substituting in formula (1) (see clause 5):

$$K = 2\,000 \text{ mm/s};$$

$$C = 8 (d - 14 \text{ mm}), \text{ but not less than } 0,$$

where d is the detection capability of the device in millimetres.

This formula 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.

If S is found to be greater than 500 mm using formula (2), then the following formula can be used:

$$S = (1\,600 \text{ mm/s} \times T) + 8 (d - 14 \text{ mm}) \quad (3)$$

by substituting in formula (1) (see clause 5):

$$K = 1\,600 \text{ mm/s};$$

$$C = 8 (d - 14 \text{ mm}), \text{ but not less than } 0.$$

In this case, the minimum value of S shall not be less than 500 mm.

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 calculated with formula (2) shall be increased by at least 75 mm. It shall be noted that in such cases formula (3) is not applicable.

6.1.2 Electro-sensitive protective equipment employing active opto-electronic protective devices used for reinitiation of machine operation

Electro-sensitive protective equipment employing active opto-electronic protective devices used for reinitiation of machine operation shall have a detection capability equal to or less than 30 mm, formula (2) (see 6.1.1) shall apply and the minimum distance S shall be greater than 150 mm.

If the detection capability is equal to or less than 14 mm, formula (2) shall apply and the minimum distance S shall be greater than 100 mm.

NOTE 1 Conditions for using electro-sensitive protective equipment in the reinitiation of machine operation are given in ISO/TR 12100-1 and ISO/TR 12100-2³⁾ and relevant Type-C standards

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

3) These requirements are under preparation and will be contained in the revision of ISO/TR 12100-1 and ISO/TR 12100-2.

6.1.3 Electro-sensitive protective equipment employing active opto-electronic protective devices with detection capability greater than 40 mm and less than or equal to 70 mm

Such pieces of equipment will 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 danger zone is in part dependent on the part of body to be detected and shall be calculated using the following formula:

$$S = (1\,600 \text{ mm/s} \times T) + 850 \text{ mm} \quad (4)$$

by substituting in formula (1) (see clause 5):

$$K = 1\,600 \text{ mm/s};$$

$$C = 850 \text{ mm}.$$

The risk of inadvertent access shall be taken into account during the risk assessment stage but, in all cases, the height of the uppermost beam shall be greater or equal to 900 mm and the height of the lowest beam shall be smaller or equal to 300 mm.

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 smaller or equal to 200 mm.

6.1.4 Multiple separate beams

Multiple separate beams, for example a combination of 2, 3 or 4 separate beams, are often used to detect intrusion of the whole body rather than parts of the body.

If the risk assessment indicates that separate beams are appropriate, they shall be positioned at a minimum distance from the danger zone in accordance with formula (4) (see 6.1.3).

During risk assessment, methods which can possibly be used to bypass such equipment shall be taken into account, 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.

The heights for 2, 3 and 4 beams given in Table 1 have been found to be the most practical in application.

Table 1 — Heights for beams

Dimensions in millimetres

Number of beams	Heights above reference plane, for example the floor
4	300, 600, 900, 1200
3	300, 700, 1100
2	400, 900

6.1.5 Single height 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.

Where the risk assessment allows a single height beam to be used alone then the minimum distance shall be calculated using the following formula:

$$S = (1\,600 \text{ mm/s} \times T) + 1\,200 \text{ mm} \quad (5)$$

A height of 750 mm from the ground or reference plane (see ISO 13852:1996, 4.1.1) has been found in industry to be a practical solution to the problems of inadvertent access from stepping over or bending under the beam.

6.2 Direction of approach parallel to the detection zone

This minimum distance shall be calculated using the following formula:

$$S = (1\,600 \text{ mm/s} \times T) + (1\,200 \text{ mm} - 0,4 H) \quad (6)$$

by substituting in formula (1) (see clause 5):

$$K = 1\,600 \text{ mm/s};$$

$$C = 1\,200 \text{ mm} - 0,4 H, \text{ but not less than } 850 \text{ mm, where } H \text{ is the height of the detection zone above the reference plane, for example the floor, in millimetres.}$$

For this type of protective equipment, 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.

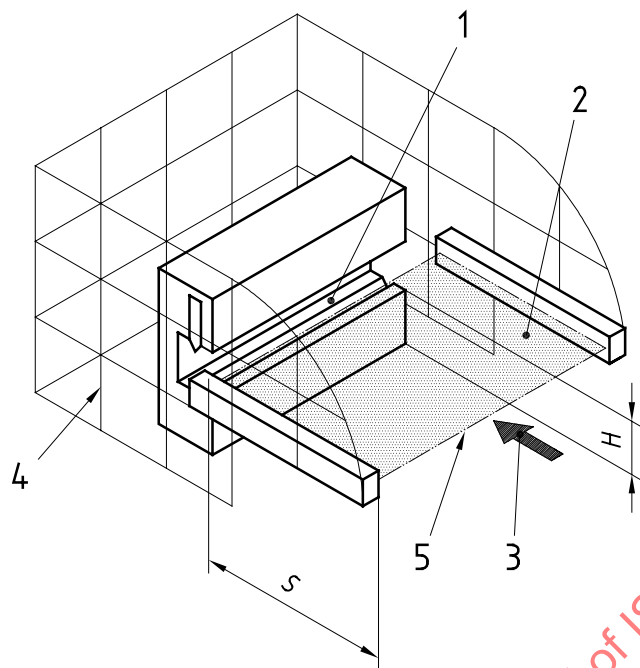
The lowest allowable height of the detection zone shall be calculated using the following formula:

$$H = 15 (d - 50 \text{ mm}) \quad (7)$$

Thus, for a given height of the detection zone, the corresponding detection capability d shall be calculated using the following formula:

$$d = \frac{H}{15} + 50 \text{ mm} \quad (8)$$

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

**Key**

- H Height of detection zone above reference plane
 S Minimum distance
 1 Danger zone
 2 Detection zone
 3 Direction of approach
 4 Fixed guard
 5 Beginning of the detection zone

Figure 4 — Parallel approach to the detection zone

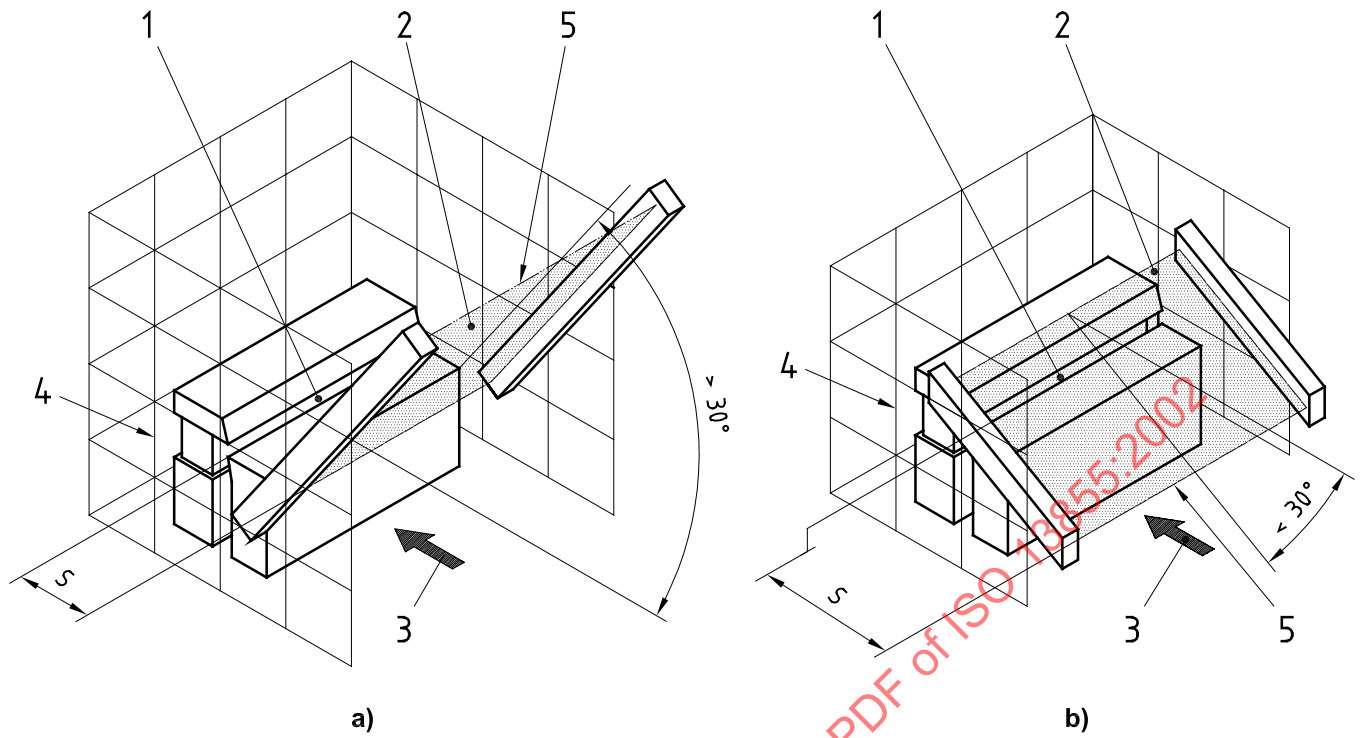
6.3 Direction of approach angled to the detection zone

If the protective equipment has been installed so that the angle of approach to the detection zone is within $\pm 5^\circ$ of their designed approach (either normal or parallel), then it need not be considered as an angled approach detection zone and the relevant formulae will apply (see 6.1, 6.2 and 6.4).

For detection zones which are positioned at angles greater than $\pm 5^\circ$ to the direction of approach, account shall be taken of the risks associated with the foreseeable methods of approach and the most appropriate formula used.

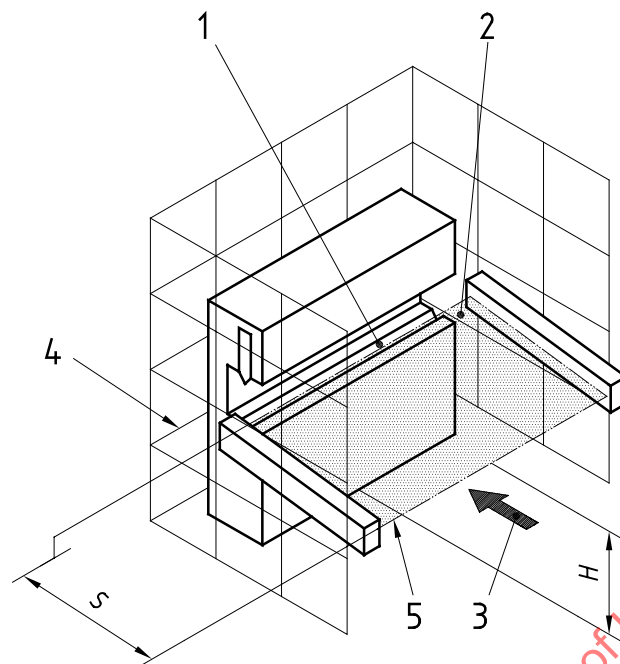
Foreseeable angles of approach greater than 30° should be considered normal approach [see 6.1 and Figure 5a)] and foreseeable angles of approach less than 30° should be considered parallel approach [see 6.2 and Figure 5b)].

When angled approach detection zones are considered as parallel approach, then formula (7) linking H and d in 6.2 shall apply to the lowest beam or the beam closest to the reference plane (see H in Figure 6). In the case of parallel approach, the formula to derive the minimum distance S shall apply to the beam furthest from the danger zone. This beam may be used up to a maximum height of the detection zone of 1 000 mm.

**Key**

- S Minimum distance
- 1 Danger zone
- 2 Detection zone
- 3 Direction of approach
- 4 Fixed guard
- 5 Beginning of the detection zone

Figure 5 — Angle of approach to the detection zone

**Key**

- H Height of the detection zone (lowest beam)
 S Minimum distance
 1 Danger zone
 2 Detection zone
 3 Direction of approach
 4 Fixed guard
 5 Beginning of the detection zone

Figure 6 — Height of the detection zone (lowest beam)

6.4 Dual position equipment

When the detection zone can be readily converted to a position either normal or parallel to the direction of approach, then the minimum distances for both directions of approach shall be applied (see example 3 in A.4).

The axis of rotation of the detection zone shall be at a point where both requirements can be achieved. This need not necessarily be the last beam.

When in position normal to the direction of approach (vertical detection zone), the minimum distance S shall be calculated using formula (2) (see 6.1.1) up to $S \leq 500$ mm.

If S is found to be greater than 500 mm using formula (2), then formula (3) (see 6.1.1) may be used but with a minimum distance of 500 mm.

When in position parallel to the direction of approach (horizontal detection zone), the minimum distance S shall be calculated using formulae (6), (7) and (8) (see 6.2) up to a maximum height of 1 000 mm.

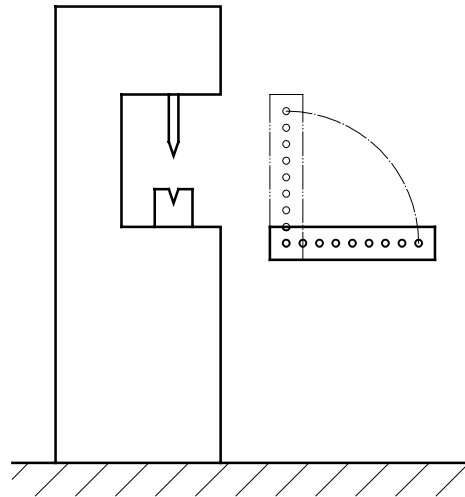


Figure 7 — Dual position equipment

7 Method of calculating the minimum distances for ground level trip devices

7.1 General method

The selection and use of ground level trip devices actuated by the feet is dependent on the appropriate Type-C standard or a risk assessment in accordance with ISO 14121 if no Type-C standard exists.

Examples of ground level trip devices include pressure sensitive mats, pressure sensitive floors and active opto-electronic protective devices.

The minimum distances derived in this clause for ground level trip devices assume that the approach speed to the danger zone will be at walking speed. Regarding the risk of stepping over the detection zone, see annex B.

The minimum distance shall be calculated using formula (6) (see 6.2):

$$S = (1\,600 \text{ mm/s} \times T) + (1\,200 \text{ mm} - 0,4 H) \quad (9)$$

where

S is the minimum distance in millimetres in a horizontal plane from the danger zone to the detecting edge of the device furthest from the danger zone;

H is the distance above the reference plane, for example floor, in millimetres (see 7.3).

7.2 Floor mounting

In most situations, the trip device will be fitted directly onto the floor, i.e. H is equal to zero. Therefore the minimum distance for trip devices installed on the floor shall be calculated using formula (9) derived from formula (6) (see 6.2).

$$S = (1\,600 \text{ mm/s} \times T) + 1\,200 \text{ mm} \quad (10)$$

7.3 Step mounting

If the trip device is mounted onto 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.

8 Two-hand control devices

The minimum distance from the nearest actuator to the danger zone shall be calculated using the following formula:

$$S = (1\,600 \text{ mm/s} \times T) + 250 \text{ mm} \quad (11)$$

by substituting in formula (1) (see clause 5):

$$K = 1\,600 \text{ mm/s};$$

$$C = 250 \text{ mm}.$$

If the risk of encroachment of the hands or part of the hands towards the danger 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. Measures described there are not adequate in all applications to prevent encroachment of the hands or parts of the hands towards the danger zone.