भारतीय मानक

Indian Standard

IS 16502 (Part 4/Sec 3) : 2024
IEC TS 61496-4-3 : 2022

मशीनों की सुरक्षा — इलेक्ट्रो-सेंसिटिव रक्षात्मक उपकरण

भाग 4 विज़न आधारित रक्षात्मक डिवाइसेस (वीबीपीडी) का उपयोग करने वाले उपकरणों के लिए विशेष अपेक्षाएँ

अनुभाग 3 स्टीरियो विज़न तकनीकों (वीबीपीडीएसटी) का उपयोग करते समय अतिरिक्त अपेक्षाएँ

(पहला पुनरीक्षण)

Safety of Machinery — Electro-Sensitive Protective Equipment

Part 4 Particular Requirements for Equipment Using Vision Based Protective Devices (VBPD)

Section 3 Additional Requirements When Using Stereo Vision Techniques (VBPDST)

(First Revision)

ICS 13.110; 29.260.99

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Safety of Machinery — Electrotechnical Aspects Sectional Committee, ETD 44

NATIONAL FOREWORD

This Indian Standard (Part 4/Sec 3) (First Revision) which is identical to IEC TS 61496-4-3 : 2022 'Safety of machinery — Electro-sensitive protective equipment — Part 4-3: Particular requirements for equipment using vision based protective devices (VBPD) — Additional requirements when using stereo vision techniques (VBPDST)' issued by the International Electrotechnical commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Safety of Machinery — Electrotechnical Aspects Sectional Committee and approval of the Electrotechnical Division Council.

This standard was first published in 2021 identical to IEC TS 61496-4-3 : 2015. This revision has been brought out to align this standard with the latest version of IEC/TS 61496-4-3.

The text of the IEC standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appears referring to this standard, they should be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker, while in Indian Standards the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 61496-1 : 2020 Safety of machinery — Electro-sensitive protective equipment — Part 1: General requirements and tests	IS 16502 (Part 1) : 2023/IEC 61496-1 : 2020 Safety of machinery electro-sensitive protective equipment: Part 1 General requirements and tests	Identical
IEC 62471 : 2006 Photobiological safety of lamps and lamp systems	IS 16108 : 2012/IEC 62471 : 2006 Photobiological safety of lamps and lamp systems	Identical
ISO 13855 : 2010 Safety of machinery — Positioning of safeguards with respect to the approach speeds of parts of the human body	IS 16815 : 2019/ISO 13855 : 2010 Safety of machinery — Positioning of safeguards with respect to the approach speeds of parts of the human body	Identical
ISO 20471 : 2013 High visibility clothing — Test methods and requirements	IS 15809 : 2017 High visibility warning clothes — Specification (*first revision*)	Technically equivalent

The Committee has reviewed the provisions of the following International Standards referred in this adopted standard and has decided that they are acceptable for use in conjunction with this standard:

International Standard	*Title*
IEC 60825-1 : 2014	Safety of laser products — Part 1: Equipment classification and requirements

(*Continued on third cover*)

CONTENTS

INTRODUCTION

An electro-sensitive protective equipment (ESPE) is applied to machinery presenting a risk of personal injury. It provides protection by causing the machine to revert to a safe condition before a person can be placed in a hazardous situation.

The working group responsible for drafting this document was concerned that, due to the complexity of the technology, there are many issues that are highly dependent on analysis and expertise in specific test and measurement techniques. In order to provide a high level of confidence, independent review by relevant expertise is recommended. They considered that if this high level of confidence could not be established these devices would not be suitable for use in safety related applications.

Indin Standards

SAFETY OF MACHINERY — ELECTRO-SENSITIVE PROTECTIVE EQUIPMENT

PART 4 PARTICULAR REQUIREMENTS FOR EQUIPMENT USING VISION BASED PROTECTIVE DEVICES (VBPD)

SECTION 3 ADDITIONAL REQUIREMENTS WHEN USING STEREO VISION TECHNIQUES (VBPDST)

(First Revision)

1 Scope

Replacement:

This document specifies requirements for the design, construction and testing of non-contact electro-sensitive protective equipment (ESPE) designed specifically to detect persons or parts of persons as part of a safety-related system, employing vision-based protective devices (VBPDs) using stereo vision techniques (VBPDST) for the sensing function. Special attention is directed to features which ensure that an appropriate safety-related performance is achieved. An ESPE can include optional safety-related functions, the requirements for which are given in Annex A of IEC 61496-1:2020 and this document.

NOTE "Non-contact" means that physical contact is not required for sensing.

Where this document does not contain all necessary provisions, IEC TS 62998-1 applies.

It is also possible, for those aspects not considered in this document, to use provisions from IEC TS 62998-1 additionally.

This document does not specify the dimensions or configurations of the detection zone and its disposition in relation to hazardous parts for any particular application, nor what constitutes a hazardous state of any machine. It is restricted to the functioning of the ESPE and how it interfaces with the machine.

The detection principle is based on the evaluation of images from different viewing points (stereoscopic view) for the determination of distance information. This distance information is used to determine the position of an object(s).

- This document is limited to vision based ESPEs with fixed distances (stereo base) and fixed directions of the optical axes using a fixed focal length.
- It is limited to vision based ESPEs that do not require human intervention for detection.
- It is limited to vision based ESPEs that detect objects entering into or being present in a detection zone(s).
- It is limited to VBPDSTs employing radiation at wavelengths within the range 400 nm to 1 500 nm.
- This document does not address those aspects required for complex classification or differentiation of the object detected.
- This document does not consider the aspects of a moving ESPE installation.

Additional requirements and tests can apply in the following cases:

- Use of multi-spectral (colour) techniques;
- Setups other than as shown in Figure 2 and Figure 3 (e.g. changing backgrounds, horizontal orientation of the optical axis with respect to the floor);

– Intended for outdoor applications.

This document is relevant for VBPDSTs having a stated detection capability up to 200 mm.

This document can be relevant to applications other than those for the protection of persons or parts of persons like arm or fingers (in the range 14 mm to 200 mm), for example the protection of machinery or products from mechanical damage. In those applications, additional requirements can be necessary, for example when the materials that are to be recognized by the sensing function have different properties from those of persons.

This document does not deal with EMC emission requirements.

2 Normative references

Addition:

IEC 60825-1:2014, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 61496-1:2020, *Safety of machinery – Electro-sensitive protective equipment – Part 1: General requirements and tests*

IEC 62471:2006, *Photobiological safety of lamps and lamp systems*

ISO 13855:2010, *Safety of machinery – Positioning of safeguards with respect to the approach speeds of parts of the human body*

ISO 20471:2013, *High visibility clothing – Test methods and requirements*

3 Terms and definitions

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

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

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

This clause of IEC 61496-1:2020 is applicable except as follows:

Replacement:

3.3
detection capability
ability to detect the specified test pieces (see 4.2.13) in the specified detection zone

Note 1 to entry: Detection capability is measured by the size of an object that can be detected. An increase in detection capability means that a smaller object can be detected.

[SOURCE: IEC 61496-1:2020, 3.3, modified – The text has been changed to make it more relevant to vision based sensors and Note 1 has been added.]

3.4
detection zone, <of a VBPDST>
three-dimensional volume within which a specified test piece will be detected by the VBPDST

Note 1 to entry: Example for three-dimensional volume are a pyramid or a cone

3.5
electro-sensitive protective equipment
ESPE

Addition:

Note 3 to entry: Illumination unit(s), if applicable, is/are part(s) of the sensing device.

Addition:

3.4301
minimum detection zone
lowest dimension of the detection zone for a test piece moving with maximum speed

Note 1 to entry: This is the lowest dimension that ensures the integrity of the detection capability.

3.4302
evaluation images, pl
set of images which are used by the detection algorithms

SEE: Figure 1.

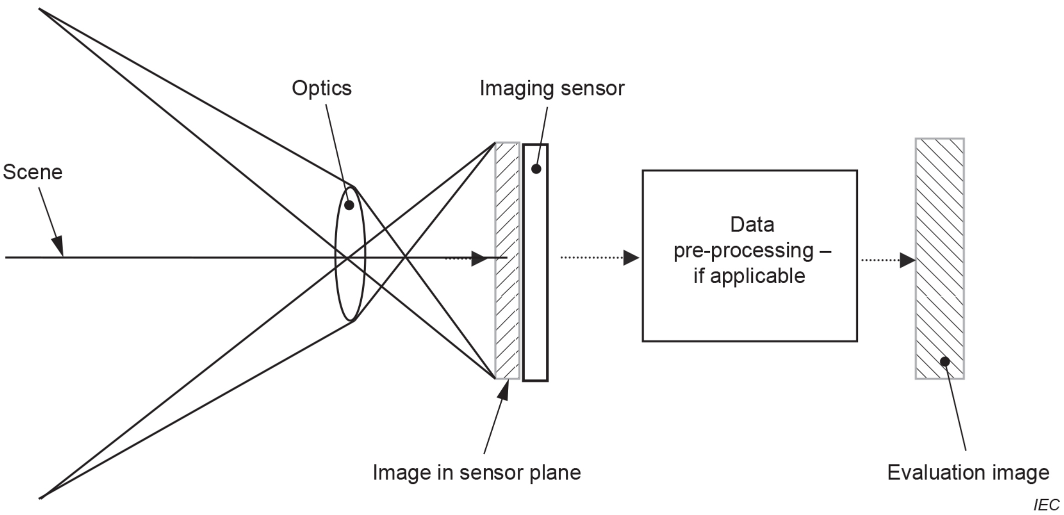


Figure 1 – Image planes in imaging device of a VBPDST

3.4303
Image
<of a VBPDST>
snapshot representation of the scene in different planes of the VBPDST in form of a two dimensional pixel matrix

3.4304
vision-based protective device
VBPD
ESPE using an imaging sensor, operating in the visible and near infrared light spectrum to detect an object in a defined field of view

Note 1 to entry: This note applies to the French language only.

3.4305
vision based protective device using stereo vision techniques
VBPDST
VBPD with two or more imaging devices using stereo vision techniques and with or without active illumination

3.4306
imaging sensor
opto-electronic device which produces electrical signals representing the characteristics of an image

SEE: Figure 1.

3.4307
imaging device
combination of an imaging sensor, optics and the processing unit (if applicable)

SEE: Figure 1.

Note 1 to entry: The imaging devices are part of the sensing device.

3.4308
operating distance
distance measured along the z-axis of the sensing device coordinate system

3.4309
Pixel
<of a sensor>
smallest light sensitive element of an imaging sensor

3.4310
Pixel
<of an image>
area of the smallest element that can be distinguished from its neighbouring elements

3.4311
ambient illumination technique
AIT
technique that relies on scene lighting for illumination and contrast to obtain range measurements

3.4312
pattern projection technique
PAPT
technique that uses a special projection to enhance the contrast of a scene

3.4313
sensing device coordinate system
coordinate system oriented to the sensing device

Note 1 to entry: Typically, the z-axis is parallel to the optical axis of one imaging device.

3.4314
tolerance zone
zone outside of and adjacent to the detection zone within which the specified test piece is detected with a probability of detection lower than the required probability within the detection zone

Note 1 to entry: The tolerance zone is necessary to achieve the required probability of detection of the specified test piece within the detection zone. For explanation of the concept of probability of detection and the tolerance zone, see Annex BB.

3.4315
user coordinate system
coordinate system that may be configured by the user

3.4316
zone with limited detection capability
volume between the detection zone and the front of the sensing device in which the stated detection capability is not achieved

3.4317
stereo base
distance between the centres of the entrance pupils of two imaging devices

Note 1 to entry: The expression baseline is often used as synonym for stereo base.

3.4318
position accuracy
accuracy in three dimensions of the position of an object as measured by VBPDST

Addition:

Abbreviated terms

AIT	Ambient illumination technique
BTP	Black test piece
GB	Grey background
GTP	Grey test piece
lx	Lux
LC	Low contrast
OD	Operating distance
P1	Position 1 of the light source
P2	Position 2 of the light source
PAPT	Pattern projection techniques
PTZ	Tolerance zone related to probability
RRTP	Retro-reflective test piece
STZ	Tolerance zone related to systematic influences
TTC	Typical test condition (test condition for normal operation tests)
TI	Typical illumination (illumination used for normal operation tests)
VBPDST	Vision based protective devices using stereo vision techniques
WTP	White test piece

4 Functional, design and environmental requirements

This clause of IEC 61496-1:2020 is applicable except as follows:

4.1 Functional requirements

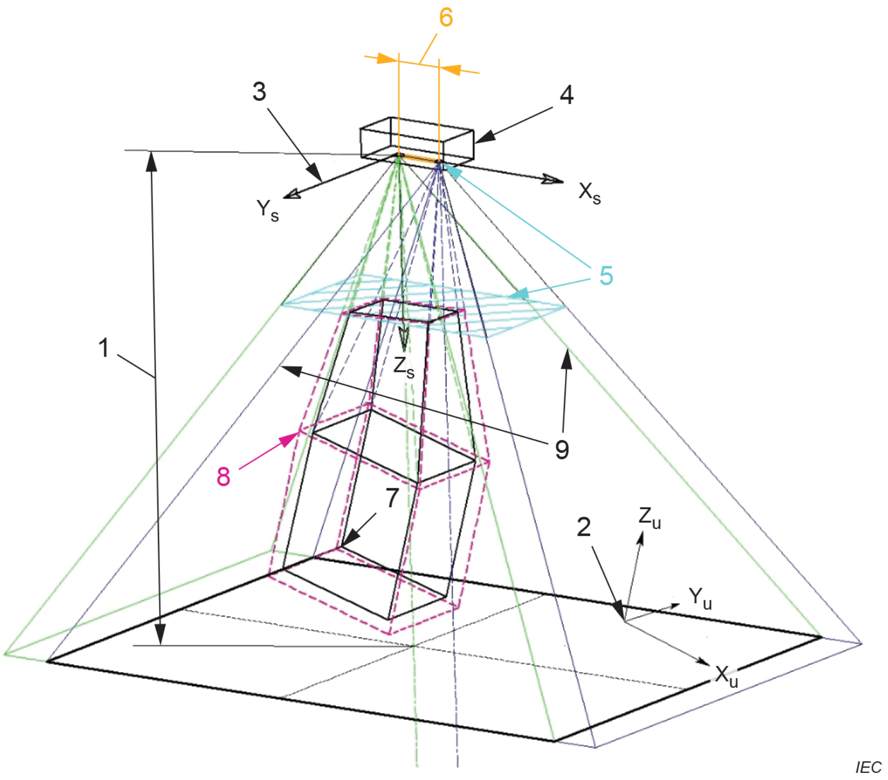
Replacement:

4.1.2 Sensing function

4.1.2.1 General

The detection zone shall begin at the border of the zone with limited detection capability and end within the maximum operating distance (see Figure 2 and Figure 3).

Object(s) in the zone with limited detection capability shall not reduce the detection capability within the detection zone. Any reduction of the detection capability shall be detected and the VBPDST shall go to lock-out condition (see 4.2.2.4).

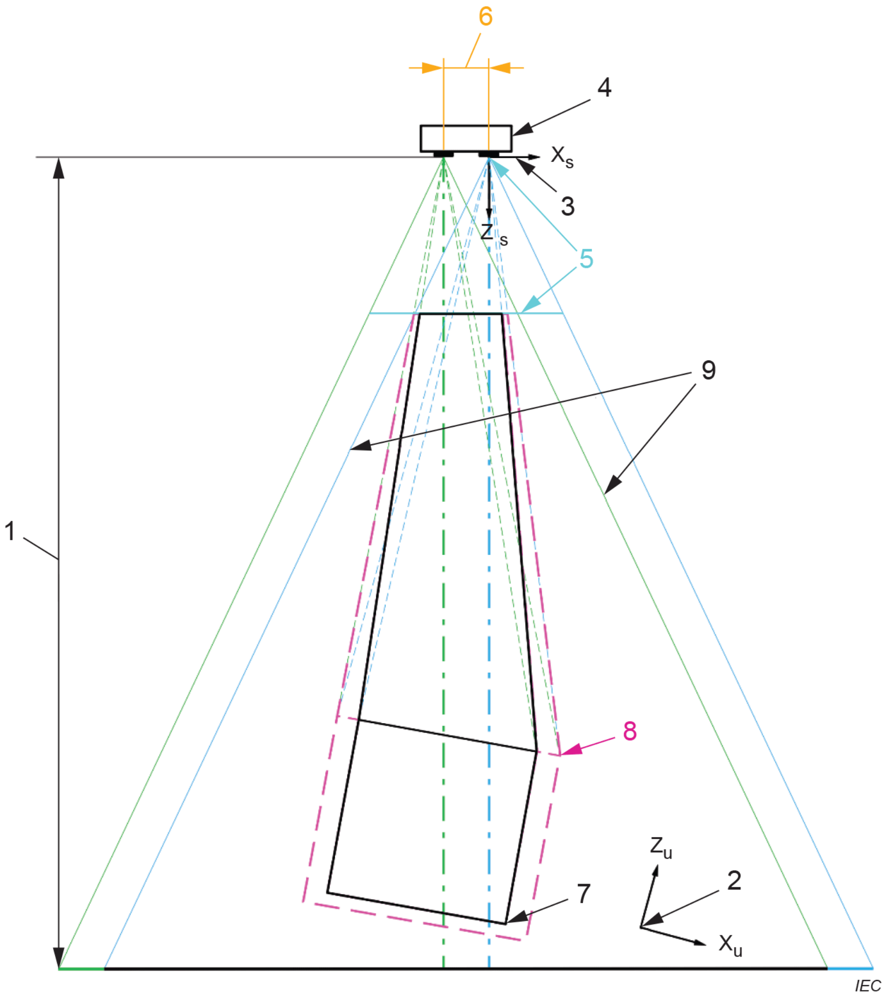


Key

1 – Maximum operating distance
2 – User coordinate system
3 – Sensing device coordinate system
4 – Sensing device
5 – Zone with limited detection capability
6 – Stereo base
7 – Detection zone
8 – Tolerance zone
9 – Stereo field of view

NOTE The figure shows a system with the sensing device coordinate system parallel to the stereo base and a maximum operating distance on a plane perpendicular to the sensing device coordinate system axis.

Figure 2 – 3D view of a vision based protective device using stereo vision techniques (VBPDST)



Key

1 – Maximum operating distance
2 – User coordinate system
3 – Sensing device coordinate system
4 – Sensing device
5 – Zone with limited detection capability
6 – Stereo base
7 – Detection zone
8 – Tolerance zone
9 – Stereo field of view

NOTE The figure shows a system with the sensing device coordinate system parallel to the stereo base and a maximum operating distance on a plane perpendicular to the sensing device coordinate system axis.

Figure 3 – 2D view of a vision based protective device using stereo vision techniques (VBPDST)

4.1.2.2 Additional functional requirements

The sensing function shall be effective over the detection zone. No adjustment of the detection zone or detection capability shall be possible without the use of a security measure (e.g. key, keyword, or tool).

The VBPDST shall respond by giving appropriate output signal(s) when a test piece is present anywhere within the detection zone whether static or moving with respect to the VBPDST.

The supplier shall specify the limits of detection capability. The supplier shall take into account worst case scenario considering all influences listed in this document including, for example:

– signal-to-noise ratio;
– light intensity in the image in sensor plane (see Figure 1);
– contrast on the image in sensor plane;
– position of the image in sensor plane.

4.1.2.3 Optical performance

The VBPDST shall be designed and constructed to:

a) limit the possibility of malfunction during exposure to extraneous radiation in the range of 400 nm to 1 500 nm;
b) limit the effects of environmental influences (temperature, vibration and shocks, dust, moisture, ambient light, extraneous reflections, changing illumination, shadows on background, background reflectivity);
c) limit the misalignment at which normal operation is possible.

4.1.3 Types of ESPE

Replacement:

In this document, only a type 3 ESPE is considered. It is the responsibility of the machine supplier and/or the user to specify which type is required for a particular application.

A type 3 ESPE shall fulfil the fault detection requirements of 4.2.2.4.

In normal operation, the output circuit of each of at least two output signal switching devices (OSSDs) of the type 3 ESPE shall go to the OFF-state when the sensing device is actuated, or when the power is removed from the ESPE.

When a single safety-related data interface is used to perform the functions of the OSSD(s), then the data interface and associated safety-related communication interface shall meet the requirements of 4.2.4.4 of IEC 61496-1:2020. In this case, a single safety-related data interface can substitute for two OSSDs in a type 3 ESPE.

Addition:

4.1.6 Zone with limited detection capability

A zone between the optical window and the beginning of the detection zone is referred to as a zone with limited detection capability. In order to ensure that no hazard can arise in a particular application due to the presence of objects in the zone between the optical window and the detection zone, its dimensions and appropriate information for use shall be provided by the supplier.

4.2 Design requirements

4.2.2 Fault detection requirements

4.2.2.2 Particular requirements for a type 1 ESPE

This subclause of IEC 61496-1:2020 is not applicable.

4.2.2.3 Particular requirements for a type 2 ESPE

This subclause of IEC 61496-1:2020 is not applicable.

4.2.2.4 Particular requirements for a type 3 ESPE

Addition:

EXAMPLE of deterioration of the VBPDST detection capability include:

- increase of the minimum detectable object size;
- increase in the minimum detectable contrast;
- decrease of position accuracy.

4.2.2.5 Particular requirements for a type 4 ESPE

This subclause of IEC 61496-1:2020 is not applicable.

4.2.12 Integrity of the ESPE detection capability

Replacement:

4.2.12.1 General

The design of the VBPDST shall ensure that the detection capability is not decreased below the limits specified by the supplier and in this document by any of, but not limited to, the following:

a) low contrast between an object and background on the evaluation images;
b) the position of the object within the detection zone;
c) the number of objects within the detection zone;
d) the size of object(s) within the detection zone;
e) auto-adjustment of optical and electrical characteristics;
f) properties/limitations of optical and electrical components;
g) accuracy of object position in image(s);
h) at the limits of alignment and/or adjustment;
i) ageing of components;
j) performance and limitations of the optical components;
k) component tolerances;
l) changing of internal and external references to ensure the detection capability;
m) environmental conditions specified in 4.3.

4.2.12.2 Detection zone(s) and tolerance zone(s)

The supplier shall define values up to 200 mm as the minimum detectable object size of the VBPDST within the detection zone. The minimum detectable object size may be distance dependent.

The test pieces (see 4.2.13) shall be detected with a minimum probability of detection of $1 - 2,9 \times 10^{-7}$ throughout the detection zone(s). To achieve this minimum probability of detection, the tolerance zone has to be considered in addition to the detection zone. The tolerance zone depends on position accuracy composed of systematic (STZ) and random influences (PTZ). Even if a measured distance value of a test piece falls into the tolerance zone, this test piece will be determined as detected (see Annex BB for further Information). If a part of the position error does not result in failure to danger, then it does not need to be included in the tolerance zone.

NOTE 1 Under the assumption that errors are normally distributed, the PTZ will be 5 times the standard deviation of the error distribution (5 sigma).

NOTE 2 Within the tolerance zone there is no requirement for maintaining a minimum probability of detection.

NOTE 3 The dimensions of the tolerance zone in the three axes can be different.

NOTE 4 An example to determine the tolerance zone is given in Annex BB.

The supplier shall specify the tolerance zone(s) and take into account worst-case considerations according to the influences listed in 4.2.12.7.

When using reference markers or parts of the environment such as walls or the floor during setup, errors in determining the correct distance and position of these references shall be taken into account when specifying the tolerance zone(s).

NOTE 5 The dimension of the tolerance zone can be influenced by the method of approach (for example walking, crawling, sliding along a wall). If such information is used to calculate the tolerance zone, then appropriate analysis or tests can be required.

NOTE 6 If the required probability of detection can be satisfied by partial intrusion of an object into the detection zone, then a smaller tolerance zone can be used for safety distance determination. Further details can be found in Annex AA.

4.2.12.3 Response time

Objects of the minimum detectable size that are either stationary or moving within the detection zone at any speed up to 1,6 m/s shall be detected by the ESPE within the specified response time. The supplier shall specify the maximum response time. The supplier shall take into account worst case conditions.

EXAMPLES for worst case conditions for maximum response time are

– frame rate;
– evaluation time;
– minimum diameter of the test piece;
– maximum speed of the test piece;
– number of objects in the detection zone;
– values of the minimum detection zone;
– environmental influences.

Where the supplier states that a VBPDST can be used to detect objects moving at speeds greater than 1,6 m/s, the requirements shall be met at any speed up to and including the stated maximum speed.

4.2.12.4 Object detection at low contrast

At low contrast the test piece shall be detected when the VBPDST is in normal operation.

NOTE A physical contrast results in a difference of intensity that is detected. For more information, see Annex CC.

4.2.12.5 Object detection at high contrast

At high contrast the test piece shall be detected when the VBPDST is in normal operation.

NOTE A high contrast results from a big difference of the coefficient of diffuse reflection and/or lighting variation between the background and the test piece. The contrast could be higher than the dynamic range of the imaging sensor.

4.2.12.6 Minimum detection zone

The supplier shall specify the minimum detection zone(s). The supplier shall take into account worst case conditions including, for example:

– response time;
– minimum diameter of the test piece;
– maximum speed of the test piece.

4.2.12.7 Position accuracy

When determining the position accuracy, the following influences shall be taken into account if applicable, but not limited to:

a) the calibration of the sensing device;
b) characteristics of the optical/imaging sensor, such as
   1) the number of pixels and pixel size
   2) signal-to-noise ratio
   3) modulation transfer function of the optics
c) algorithmic influences, such as:
   1) smoothing algorithm
   2) feature based detection algorithm, e.g. edge detection algorithm
   3) template matching
   4) colour sensor and algorithm
   5) global algorithms, e.g. cluster algorithm
   6) optical flow analysis algorithm
   7) object tracking algorithm
   8) stereo algorithm
d) synchronization between imaging sensors;
e) characteristics of the test piece;
f) limits of illumination;
g) Ageing and tolerances of components and references.

4.2.12.8 Pattern projection techniques (PAPT)

If pattern projection techniques are used to enhance the contrast in the scene, then the pattern projector shall be considered as part of the VBPDST. This illumination module shall have the capability to project sufficient contrast onto the scene anywhere within the specified detection zone such that the system fulfils the requirements of this document. The detection capability shall not be decreased below the limits specified by the supplier by any influences, including but not limited to the following:

a) contrast between projected pattern elements;
b) contrast changes within projected pattern elements;
c) size and differentiation of projected pattern elements and number of projected pattern elements used for contrast enhancement;
d) size of pixels and numbers of pixels compared to used projected pattern elements;
e) automatic adaptation of algorithm/routines;
f) size, shape, colour, reflectivity, position and surface structure of object and scene compared to projected pattern;
g) resulting superposition of natural object/scene contrast and contrast produced by pattern projection;
h) position and location of pattern projector.

4.2.12.9 Influence of periodic surface structures on the background

Periodic surface structures on the background shall not lead to a failure to danger.

Periodic surface structures resulting in a complete loss of the stated VBPDST detection capability shall cause the ESPE to go to the OFF-state and remain in it as long as the periodic structure is present.

Periodic surface structures resulting in a deterioration of the stated VBPDST detection capability shall cause the ESPE to go to the OFF-state within a time period of 5 s following the occurrence of periodic surface structures and remain in it as long as the periodic structure is present.

These requirements are verified by the tests of 5.2.1.5.

4.2.13 Test piece

Replacement:

4.2.13.1 General

The test pieces shall be provided by the supplier for use in the type tests of Clause 5. They shall be marked with a type reference and identification of the VBPDST with which they are intended to be used.

The test pieces shall be opaque. Different test pieces can be required for different phases of the test procedures.

The characteristics of the test piece which shall be considered are:

a) size;
b) shape;
c) colour;
d) reflectivity;
   – at the wavelength of the illumination for VBPDST with PAPT
   – at the wavelength of maximum sensitivity of the sensor for VBPDST with AIT
e) contrast with background;
f) texture.

When defining the characteristics of the test piece, protection against camouflage with the background shall be taken into account. Unless the analysis shows that other test pieces are appropriate the following test pieces shall be used.

4.2.13.2 Cylindrical test piece

The test piece shall be cylindrical if the VBPDST is intended to be used for finger detection. The cylindrical test piece shall have a diameter of 14 mm and a length for ease of use.

4.2.13.3 Conical test pieces

The test piece shall be a truncated cone if the VBPDST is intended to be used for hand detection. The test piece starts with a diameter of 20 mm increasing up to 40 mm over a length of 160 mm.

The test piece shall be a truncated cone in combination with a cylinder if the VBPDST is intended to be used for arm detection. The test piece starts with a diameter of 40 mm increasing up to 55 mm as a cone over a length of 180 mm and continues as a cylinder with a diameter of 55 mm to an overall length of 440 mm.

The test piece shall be a truncated cone if the VBPDST is intended to be used for leg detection. The test piece starts with a diameter of 50 mm increasing up to 117 mm over a length of 1 000 mm.

If the VBPDST is intended to be used for detection of different parts of a body, the selection of the most appropriate test pieces shall be dependent on the analysis of the design and intended application. In some cases, all test pieces can be required or their combination to represent more realistic the human body.

4.2.13.4 Spherical test piece

If the VBPDST is intended to be used for whole body detection, then the test piece shall be a sphere with a maximum diameter of 200 mm attached to a cylinder with a maximum diameter of 50 mm and a length selected for ease of use.

NOTE A spherical test piece with a diameter of 200 mm is intended to represent the thickness of a body.

4.2.13.5 Grey test piece (GTP)

The test piece shall have a coefficient of diffuse reflection of 27 % to 33 %.

4.2.13.6 Black test piece (BTP)

The test piece shall have a coefficient of diffuse reflection of less than 5 %.

4.2.13.7 White test piece (WTP)

The test piece shall have a coefficient of diffuse reflection of more than 70 %.

4.2.13.8 Retro-reflective test piece (RRTP)

The test piece shall have a retro-reflective surface that complies with the requirements for separate performance retro-reflective material of ISO 20471 or equivalent.

NOTE Table 4 of ISO 20471:2013 defines the minimum coefficient of retro-reflection for separate performance retro-reflective material as 330 cd · lx–1 · m–2 with an entrance angle of 5° and an observation angle of 0,2° (12').

Addition:

4.2.14 Wavelength

VBPDSTs shall operate at a wavelength within the range 400 nm to 1 500 nm.

4.2.15 Radiation intensity

If the emitting element(s) of the PAPT device uses LED technology, the radiation intensity generated and emitted by the VBPDST shall meet the requirements of the exempt group in accordance with IEC 62471.

NOTE Exempt group is equal to risk group zero (IEC 62471).

If the emitting element(s) of the PAPT device uses laser technology, the radiation intensity generated and emitted by the VBPDST shall not exceed the maximum power or energy levels for a class 1M laser in accordance with IEC 60825-1 (even in the presence of a component failure). The marking as class 1 or class 1M laser shall be carried out as required in 5.2 of IEC 60825-1:2014.

4.2.16 Mechanical construction

When the detection capability can be decreased below the limit stated by the supplier as a result of a change of position of its components, the fixing of those components shall not rely solely on friction.

NOTE The use of oblong mounting holes without additional means could lead for example to a change of the position of the detection zone under mechanical interference such as shock.

4.3 Environmental requirements

4.3.5 Light interference

Addition:

The VBPDST shall not fail to danger when subjected to:

– illumination fading to 0 lx;
– direct sunlight.

Based on the technologies and algorithms used and the analysis of 5.2.9, additional tests can be necessary.

4.3.6 Ambient light intensity

The VBPDST shall continue in normal operation within a range of illumination from 100 lx to 1 500 lx incandescent light at backgrounds defined in 5.1.2.4. If the supplier specifies limits outside this range, the tests shall be performed at the specified limits. Outside the limits, the VBPDST shall not fail to danger.

Addition:

4.3.7 Pollution interference

4.3.7.1 Effects on optical window

Pollution on the optical window shall not lead to a failure to danger.

Pollution resulting in a complete loss of the stated VBPDST detection capability shall cause the OSSDs to go to the OFF-state within the specified response time.

Pollution resulting in a deterioration of the stated VBPDST detection capability shall cause the OSSDs to go to the OFF-state within a time period of 5 s following the occurrence of the pollution interference.

4.3.7.2 Effects within the detection zone

Pollution within the detection zone or the zone with limited detection capability shall not lead to a failure to danger.

Pollution resulting in a complete loss of the stated VBPDST detection capability shall cause the OSSDs to go to the OFF-state within the specified response time.

Pollution resulting in a deterioration of the stated VBPDST detection capability shall cause the OSSDs to go to the OFF-state within a time period of 5 s following the occurrence of the pollution interference.

4.3.8 Manual interference

It shall not be possible to reduce the stated detection capability or modify the detection zone:

– by covering one or more of the optical windows of the housing of the VBPDST or other parts (if applicable);
– by placing objects within the zone with limited detection capability.

If the manual interference would result in a failure to danger condition, then the VBPDST shall respond by giving (an) appropriate output signal(s) within 5 s. The appropriate output signal(s) shall remain until the manual interference is removed.

4.3.9 Optical occlusion (eclipsed by small object)

The VBPDST detection capability shall be maintained if moving or static objects or parts of a machine which are smaller than the detection capability and are present in the detection zone or in the zone with limited detection capability, which can block the view of the object to be detected. If the detection capability cannot be maintained, then the OSSDs shall go to the OFF-state and shall remain in the OFF-state until the optical occlusion is removed. This shall be verified by analysis and by a test according to 5.4.9.

NOTE Software filtering algorithms are sometimes provided to disregard small objects, for example, to increase reliability of operation.

4.3.10 Drift or ageing of components

Drift or ageing of components that would reduce the detection capability below the stated value shall not cause a failure to danger of the ESPE. The drift or ageing shall be detected within a time period of 5 s and lead to a lock-out condition.

If a reference object is used for monitoring ageing and drift of components, variations in the properties of the reference object (for example reflection) shall not cause a failure to danger of the ESPE. If a reference object is used to monitor ageing and drift of components, it shall be considered to be part of the VBPDST and shall be provided by the supplier of the VBPDST.

5 Testing

This clause of IEC 61496-1:2020 is applicable except as follows:

5.1 General

5.1.2 Test conditions

5.1.2.1 Test environment

Addition:

– homogeneous diffuse reflectivity of the background with no visible surface structure;
– where other non homogeneous surface characteristics are shown to be critical as result of the analysis of the design, a selection of critical backgrounds shall be applied.

NOTE The background is the limiting plane or surface being present in the test laboratory

Unless otherwise stated in this document, the VBPDST shall be set up for the tests as follows:

– Typical contrast in accordance with 5.1.2.4;
– Ambient light intensity between 50 lx and 300 lx measured on the background.

The ambient light source should provide evenly distributed illumination as far as practical. In the following tests, grey background (GB) is defined as a flat surface with a coefficient of diffuse reflection in the range of 27 % to 33 % measured at:

– the wavelength of the illumination for VBPDST with PAPT;
– the wavelength of maximum sensitivity of the sensor for VBPDST with AIT.

During the tests, the fixture holding the test piece should not be visible to the sensor (as much as practical).

Addition:

5.1.2.2 Measurement accuracy

– for precision of distance/position measurements: 10 % of the stated position accuracy;

Addition:

5.1.2.4 Setup for typical test condition (TTC)

The test conditions shall be defined from the limits of detection capability specified in this document as a minimum or by the supplier, whatever is more stringent. Within these limits, the VBPDST shall operate as specified by the supplier, outside these limits the VBPDST shall not fail to danger.

The following setup shall be used:

– Grey background (GB);
– White test piece (WTP).

Ambient light intensity on the background within the range of 50 lx to 300 lx (TI).

5.1.2.5 Setup for low contrast (LC)

The following setup shall be used:

– Grey background (GB);
– Grey test piece (GTP).

Addition:

5.1.4 Test conditions and test plan

Unless otherwise stated, the tests shall be done with the minimum detection zone positioned as specified in Table 431.

5.2 Functional tests

5.2.1 Sensing function

Addition:

5.2.1.1 General

The sensing function and the integrity of the detection capability shall be tested as specified, taking into account the following:

– The tests shall verify that the specified test pieces are detected when the test piece is either static or moving into or within the detection zone at any speed from 0 m/s to 1,6 m/s . Where the supplier states that objects can be detected moving at higher speeds, the requirements shall be met at all speeds up to the stated maximum speeds.
– The tests shall verify that the specified test pieces are detected when the test piece is placed inside the stated detection zone(s) as far as the dimension of the stated detection capability.
– Tests shall be performed with the appropriate test piece inside the detection zone close to the background and close to the zone with limited detection capability and close to the tolerance zone(s). Tests at other positions can be required depending on analysis of the design and worst case considerations.
– For VBPDST with two imaging devices, the test piece shall be aligned parallel to the stereo base. This test is not applicable for the spherical test piece.
– The number, selections and conditions of the individual tests shall be such as to verify the requirements of 4.2.12.

If the detection capability depends on the direction of the movement, an analysis of the design and optical performance shall be done to identify the worst case conditions.

It shall be verified that the sensing device is continuously actuated and, where appropriate, that the OSSD(s) go to the OFF-state as described below, taking into account the operating principle of the VBPDST and, in particular, the techniques used to provide tolerance to environmental interference.

Table 431 shows an overview of the minimum tests required for the verification of detection capability requirements.

Table 431 – Verification of detection capability requirements (see also 4.2.12)

Number	Test sequence	Subclause	Test related to	Conditions	Distance between the sensing device and the test piece					
					Maximum operating distance		Middle operating distance		Minimum operating distance	
					Image centre[a]	Image corner[a]	Image centre[a]	Image corner[a]	Image centre[a]	Image corner[a]
1	B-Test	5.2.1.1	sensing function	Speed between 0 m/s and 1,6 m/s [b]	LC	LC	LC	LC	LC	LC
2	B-Test	5.2.1.1	sensing function	Speed between 0 m/s and 1,6 m/s [b]	GB, BTP	GB, BTP	GB, BTP	GB, BTP	GB, BTP	GB, BTP
3	B-Test	5.2.1.1	sensing function	Speed between 0 m/s and 1,6 m/s [b]	TTC	TTC	TTC	TTC	TTC	TTC
4	B-Test	5.2.1.1	sensing function	Speed between 0 m/s and 1,6 m/s [b]	GB, RRTP	GB, RRTP	GB, RRTP	GB, RRTP	GB, RRTP	GB, RRTP
5	Conti-nuous B-Test	5.2.1.3	Endurance test				TTC			
6	C-Test	5.2.1.5	Periodic surface structures	Based on VBPDST specific analysis			TTC			
7	B-Test	5.4.2.2	Ambient tempera-ture variation	50 °C or maximum [c] 5.4.2.2 of IEC 61496-1:2020 applies			TTC			
8	B-Test	5.4.2.2	Ambient tempera-ture variation	0° C or minimum, non-condensing [c] 5.4.2.2 of IEC 61496-1:2020 applies			TTC			
9	C-Test	5.4.2.3	Conden-sing test	5.4.2.3 applies			TTC			
10	B-Test	5.4.3	Electrical disturb-ances	4.3.2, 5.2.3.1 and 5.4.3 of IEC 61496-1:2020 apply			TTC			
11	B-Test	5.4.4.1	Vibration	5.4.4.1 applies			TTC			

Number	Test sequence	Subclause	Test related to	Conditions	Distance between the sensing device and the test piece					
					Maximum operating distance		Middle operating distance		Minimum operating distance	
					Image centre[a]	Image corner[a]	Image centre[a]	Image corner[a]	Image centre[a]	Image corner[a]
12	B-Test	5.4.4.2	Shock	5.4.4.2 applies			TTC			
13		5.4.6	Light interfer-ence	see Table 432						
14	B-Test	5.4.7	Pollution on the surface of the optical window (4.3.7.1)				TTC			
15	B-Test	5.4.7	Pollution in the detection zone (4.3.7.2)	Pollution caused by smoke and dust			TTC			
16	C-Test	5.4.8	Manual interfer-ence	Based on VBPDST specific analysis			TTC			
17	B-Test or C-Test	5.4.9	Optical occlusion	Based on VBPDST specific analysis			GB, BTP			
18		5.2.1.4	Position accuracy	-		LC				

[a] Location of image centre or image corner and the operating distance implies the location of the detection zone.

[b] Or higher if specified by the manufacture

[c] VBPDST in test chamber and view through chamber window or detection zone for test in the chamber or open test chamber – start test within 1 min.

5.2.1.2 Integrity of the VBPDST detection capability

It shall be verified that the VBPDST detection capability is continuously maintained or the ESPE does not fail to danger by systematic analysis of the design of the VBPDST, using testing where appropriate and/or required, taking into account 4.2.12.1.

5.2.1.3 Endurance test of the detection capability

It shall be verified that the detection capability is maintained by carrying out an endurance test as follows. The results of the analysis and testing according to 5.2.1.2 shall be used to determine the conditions and the appropriate test piece (see 4.2.13) to use for this test.

A limited functional test B (B test) in accordance with 5.2.3.3 of IEC 61496-1:2020 shall be carried out with the ESPE in continuous operation under the conditions determined for 96 h and with the test piece remaining in position inside the detection zone.

5.2.1.4 Position accuracy

The dimensions of the tolerance zone shall be verified in accordance with the requirements and results of 4.2.12.6 and 4.2.12.7. As a minimum, the test setup shall be in accordance with 5.1.2.5 (LC) at maximum operating distance with the test piece in the image corner.

Annex BB gives methods and information that can be used to verify tolerance zones.

5.2.1.5 Tests for the influence of periodic surface structures on the background

An analysis shall be carried out to determine whether periodic surface structures on the background (see Figure 4) or within the tolerance zone can influence the integrity of the detection capability.

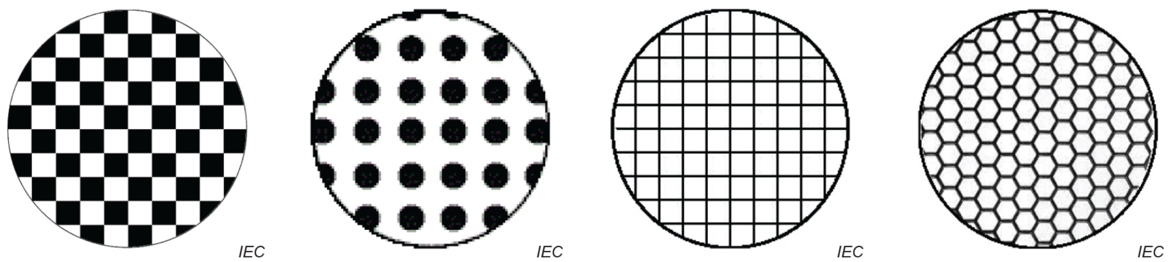
The results of the analysis of the design regarding the influence of periodic surface structures on the detection capability shall be used to determine if the requirements of 4.2.12.9 can be met and to define details of the test setup.

The limitations of the system shall be identified taking into account the stated detection capability and worst case considerations regarding the characteristics of the pattern elements, including for example:

– size;
– shape;
– contrast.

The tests covering the influence of periodic surface structures on the detection capability shall be carried out using the following test setup procedure:

a) Determination of the characteristics of the pattern elements depending on worst case considerations, especially taking into account the contrast detection and stereo algorithms.
b) Test pieces: GTP, WTP, depending on worst case considerations;
c) Test piece moving at any speed from 0 m/s to 1,6 m/s (or higher if specified by the supplier);
d) The worst case distance between test piece and periodic surface structures on the background shall be determined by measurement.



Checkerboard | **Circular pattern** | **Squared grid** | **Hexagonal grid**

Figure 4 – Examples for periodic surface structures on the background

Addition after 5.2.8.4:

5.2.9 Verification of optical performance

A systematic analysis of the electro-optical subsystem shall be carried out to:

a) verify any filtering techniques (especially software filtering algorithms) employed, and their characteristics;

b) determine the decision criteria used to determine whether or not the defined test piece(s) is detected as being inside the detection zone;
c) determine the effect of undetected faults, in accordance with 4.2.2.4, on the electro-optical characteristics;
d) determine worst case response time;
e) determine the effect of environmental influence.

The results of this analysis shall be used to determine if the requirements of 4.1.2 can be met.

5.2.10 Wavelength

The wavelength used in the VBPDST shall be verified either by inspection of the device data sheets or by measurement.

5.2.11 Radiation intensity

If the emitting element(s) of the PAPT device uses LED technology, the radiation intensity shall be verified by measurement in accordance with IEC 62471 and inspection of the technical documentation provided by the supplier.

If the emitting elements(s) of the PAPT device uses laser technology, the radiation intensity shall be verified by measurement in accordance with IEC 60825-1 and inspection of the technical documentation provided by the supplier. The marking as a class 1 or class 1M laser shall be verified for correctness.

5.3 Performance testing under fault conditions

5.3.2 Type 1 ESPE

This subclause of IEC 61496-1:2020 is not applicable.

5.3.3 Type 2 ESPE

This subclause of IEC 61496-1:2020 is not applicable.

5.3.4 Type 3 ESPE

Addition:

It shall be verified that the drift or ageing of components that influence the detection capability will be detected within a time period of 5 s according to 4.3.10.

A combination of one or more of the following is sufficient to verify the requirement to combine single faults with operating conditions/influences as required by 4.2.2.4 of IEC 61496-1:2020:

– analysis;
– simulation; and
– tests carried out in the presence of a single fault, where relevant.

5.3.5 Type 4 ESPE

This subclause of IEC 61496-1:2020 is not applicable.

5.4 Environmental tests

5.4.2 Ambient temperature variation and humidity

5.4.2.3 Condensing test procedure

Addition:

As an alternative, a systematic analysis of the design of the electro-optical subsystem of the VBPDST may be carried out in order to justify the substitution of the condensing test by a test on the optical window (see 5.4.7).

5.4.4 Mechanical influences

5.4.4.1 Vibration

Addition:

At the end of the tests, the VBPDST shall be inspected for damage including displacement of optical components and mounting brackets. It shall be verified by test that the detection zone has not changed in orientation, size or position.

5.4.4.2 Shock

Addition:

At the end of the tests, the VBPDST shall be inspected for damage including displacement of optical components and mounting brackets. It shall be verified by test that the detection zone has not changed in orientation, size or position.

5.4.6 Light interference

5.4.6.1 General

Replacement:

Tests shall be performed with the test piece inside the detection zone close to the background and close to the zone with limited detection capability and close to the tolerance zone(s). Unless otherwise stated, the distance between the detection zone and the background shall be 2 times the dimension of the tolerance zone. Tests at positions other than image centre or image corner and with other test pieces may be required depending on analysis of the design and worst case considerations.

Each test shall be carried out as specified in Table 432 and under the stated conditions as a minimum requirement.

All the tests shall be performed with the minimum detection zone. The position of the detection zone shall be as specified in Table 432.

Additional tests shall be carried out under different combinations of operating distances and environmental conditions when

– the supplier states higher immunity levels, which shall be verified by testing at those levels with appropriate light sources, and/or
– an analysis shows such tests to be necessary.

Ambient light shall be delivered by using the incandescent light source or using natural illumination. Unless otherwise stated, the ambient light intensity during light interference tests shall be within a range of 50 lx to 300 lx.

In the following test procedures, unless otherwise stated, the light intensity limits include the combination of ambient light and light contributed by the indicated light source.

Table 432 gives an overview of the light interference tests.

Table 432 – Overview of light interference tests

Number	Subclause	Test related to	Light source position [a] Test sequence	Light intensity	Test piece position		Note
					Image centre[b]	Image corner[b]	
1	5.4.6.4	Normal operation Interference on background	Incandescent P1 1	1 500 lx	Max OD [c] TTC		Figure 5
2	5.4.6.4	Normal operation Interference on background	Flashing beacon P2 1		Max OD [c] TTC		Figure 5
3	5.4.6.4	Normal operation Interference on background	Incandescent with shadow P1 1	1 500 lx bright area ≤750 lx shadow area	Max OD [c] TTC	Max OD [c] TTC	Figure 5
4	5.4.6.6	Normal operation Interference on sensing device	Incandescent - 1	1 500 lx	Max OD [c] TTC	Max OD [c] TTC	Figure 7
5	5.4.6.6	Normal operation Interference on sensing device	Line frequency fluorescent - 1	750 lx	Max OD [c] TTC		Figure 7
6	5.4.6.6	Normal operation Interference on sensing device	High frequency fluorescent - 1	750 lx	Max OD [c] TTC		Figure 7
7	5.4.6.5	Failure to danger interference on background	Incandescent P1 2	3 000 lx	Max OD [c] LC		Figure 5
8	5.4.6.5	Failure to danger interference on background	Laser beam pointer P1 2		Max OD [c] LC		Figure 5
9	5.4.6.5	Failure to danger interference on background	Direct sunlight on background - C-test only	1×10^5 lx	Analysis of the electro optical subsystem and test on component level		
10	5.4.6.7	Failure to danger Interference on sensing device	Laser beam pointer - 2	Between 0,7 mW and 1 mW	Max OD [c] LC	Max OD [c] LC	Figure 7
11	5.4.6.7	Failure to danger Interference on sensing device	Incandescent - 2	3 000 lx	Max OD [c] LC	Max OD [c] LC	Figure 7

Num-ber	Sub-clause	Test related to	Light source position [a] Test sequence	Light intensity	Test piece position		Note
					Image centre[b]	Image corner[b]	
12	5.4.6.7	Failure to danger Interference on sensing device	Line frequency fluorescent - 2	3 000 lx	Max OD [c] LC	Max OD [c] LC	Figure 7
13	5.4.6.7	Failure to danger Interference on sensing device	High frequency fluorescent - 2	3 000 lx	Max OD [c] LC	Max OD [c] LC	Figure 7
14	5.4.6.7	Failure to danger Interference on sensing device	Flashing beacon 3 meter distance 3		Max OD [c] LC	Max OD [c] LC	Figure 7
15	5.4.6.8	Normal operation Low level light during B test	- - B test only	100 lx	Max OD [c] LC		
16	5.4.6.8	Failure to danger Fading light during C test	- - C test only	<=100 lx	Max OD [c] <=100 lx LC		
17	5.4.6.5	Failure to danger Interference on background	Emitting device of PAPT of identical design - 3	-	Max OD [c] LC		Figure 6

[a] Position of the light sources (see Figure 5 or Figure 7)

[b] Location of image centre or image corner and the operating distance implies the location of the detection zone

[c] Max OD Maximum operating distance between the VBPDST sensor and the test piece in the detection zone

Addition:

5.4.6.4 Normal operation – Interference on background

The ESPE shall continue in normal operation throughout test sequence 1 in 5.4.6.3 of IEC 61496-1:2020 using light sources of 5.4.6.2 of IEC 61496-1:2020, positioned outside the detection zone and illuminate the detection zone and the background.

Tests shall be carried out in accordance with Table 432.

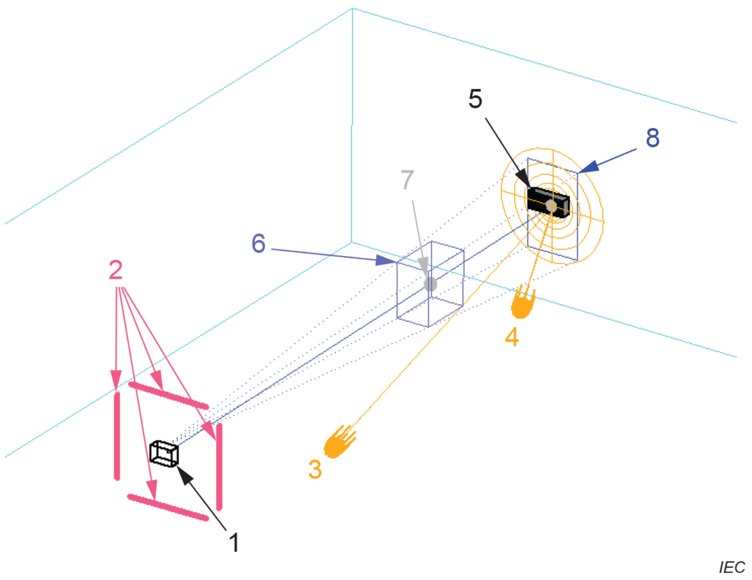
Light intensity shall be measured according to Figure 5:

a) the incandescent light source of 5.4.6.2 of IEC 61496-1:2020 placed at P1 producing a light intensity of 1 500 lx. The test shall be performed with the incandescent light source beam moved slowly at a speed between 0,1 m/s and 1,0 m/s over the background through the optical axis and the corners of the detection zone;

b) single incandescent light source of 5.4.6.2 of IEC 61496-1:2020 placed at P2 with a spherical object held in front of the light source and outside the detection zone and the tolerance zone producing a shadow on the background surface. The size of the shadow shall be larger than the detection capability but less than 50 % of the projected area on the background of the minimum detection zone. On the background the light intensity shall be 1 500 lx in the bright area and ≤ 750 lx in the shadow;

c) the flashing beacon light source of 5.4.6.2 of IEC 61496-1:2020 shall be placed at P2 outside of the detection zone and the tolerance zone but at least at 2 m in height from the background;

If the supplier states higher immunity levels than 1 500 lx for this case, normal operation up to this level and no fail to danger above shall be verified by the test above.



Key

1 – VBPDST
2 – Ambient light source
3 – Interfering light source P1
4 – Interfering light source P2
5 – Luxmeter
6 – Minimum detection zone
7 – Test piece
8 – Projected area

Figure 5 – Test setup for indirect light interference on the background

5.4.6.5 Failure to danger – Interference on background

The ESPE shall not fail to danger throughout test sequences in accordance with Table 432 using light sources positioned outside the detection zone and the tolerance zone with the background illuminated.

Light intensity measurements shall be measured according to Figure 5.

a) The incandescent light source of 5.4.6.2 of IEC 61496-1:2020 placed at P1 producing a light intensity of 3 000 lx. The test shall be performed with the incandescent light source beam moved slowly at a speed between 0,1 m/s and 1,0 m/s over the background through the optical axis and the corners of the detection zone;

b) The laser beam pointer of 5.4.6.2 of IEC 61496-1:2020 placed at P1 producing a laser beam with a maximum diameter of 5 mm on the background. The test shall be performed with the laser beam pointer moved slowly at a speed between 0,1 m/s and 1,0 m/s over the background through the optical axis and the corners of the detection zone;

c) The VBPDST with PAPT shall not fail to danger in the presence of a PAPT emitting device of identical design (see Figure 6);

d) The VBPDST shall not fail to danger by illumination of the background of 10^5 lx. This requirement shall be verified by:

– the analysis of the electro optical subsystem considering 4.2.12.1;

– or by testing at those levels with appropriate light sources.

NOTE Light intensity values are based on values given by EN 12464-1. The position and direction of the luxmeter is limited to achieve a reproducible light intensity value.

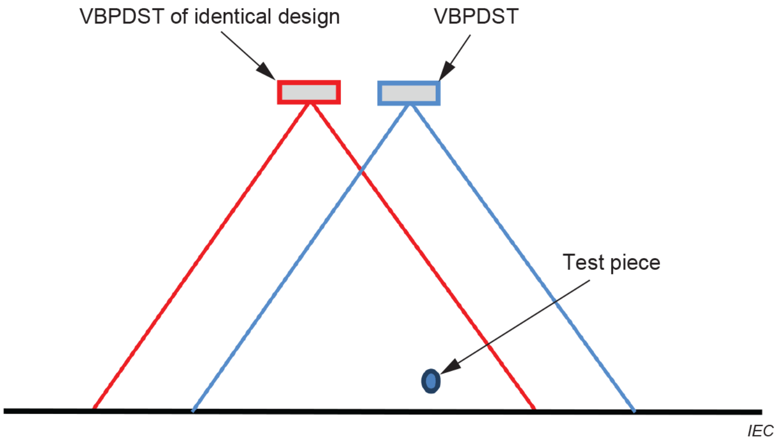


Figure 6 – Test setup for VBPDST of identical design with PAPT

5.4.6.6 Normal operation – Interference on sensing device

The ESPE shall continue in normal operation throughout test sequence 1 in 5.4.6.3 of IEC 61496-1:2020 using the light sources of 5.4.6.2 of IEC 61496-1:2020.

Tests shall be carried out in accordance with Table 432. The system shall be configured with the minimum detection zone located in the corner of the detection zone.

Light intensity measurements shall be made on the sensing device and perpendicular to the optical axis.

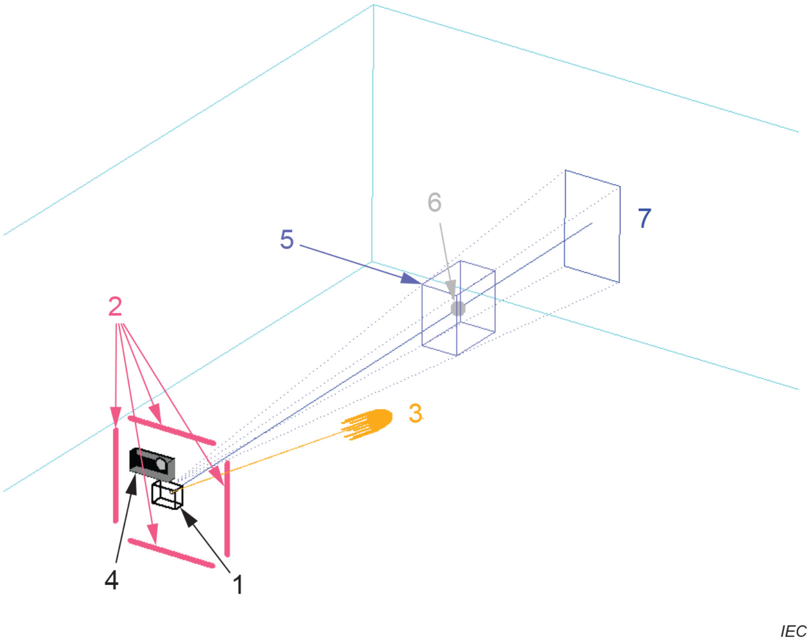
a) The incandescent light source of 5.4.6.2 of IEC 61496-1:2020 producing a light intensity of 1 500 lx and illuminating the sensing device adjacent to the field of view of all imaging sensors;

b) The line frequency fluorescent light source of 5.4.6.2 of IEC 61496-1:2020 producing a light intensity of 750 lx and illuminating the sensing device adjacent to the tolerance zone but outside the detection zone;

c) The high frequency fluorescent light source of 5.4.6.2 of IEC 61496-1:2020 producing a light intensity of 750 lx and illuminating the sensing device adjacent to the tolerance zone but outside the detection zone.

The ESPE shall not go to the ON-state when the test sequence requires it to be in the OFF-state.

The luxmeter shall be positioned on the sensing device and perpendicular to the optical axis.



Key

1 – VBPDST
2 – Ambient light source
3 – Interfering light source
4 – Luxmeter
5 – Minimum detection zone
6 – Test piece
7 – Projected area

Figure 7 – Test setup for direct light interference on the sensing device

5.4.6.7 Failure to danger – Interference on sensing device

The ESPE shall not fail to danger throughout test sequences in accordance with Table 432 using each of the light sources of 5.4.6.2 of IEC 61496-1:2020 positioned outside the detection zone and adjacent to the tolerance zone, illuminating the sensing device.

Light intensity measurements shall be made on the sensing device and perpendicular to the optical axis.

5.4.6.8 Low lighting level test

With the VBPDST in normal operation, a B test shall be carried out with an ambient light intensity of 100 lx.

With the VBPDST in normal operation, a C test shall be carried out while the intensity of ambient light is decreased until the OSSDs go to the OFF-state.

5.4.7 Pollution interference

A systematic analysis of the design of the VBPDST shall be carried out to decide which tests (if any), test methods and test conditions are appropriate to satisfy the requirements of 4.3.7. If tests are necessary to be carried out, a C test(s) shall be carried out to verify for no failure to danger.

Examples of possible pollution are:

– polluted window by particle, water-drops or dust.

5.4.8 Manual interference

Immunity against coverage shall be tested as follows:

- The objects used for simulating coverage shall be a circular opaque test spot with the diameter of 10 mm and a second test spot with the size and shape to cover the complete optical window of imaging device and emitting element(s) of the PAPT device if applicable;
- During the tests, the spot shall be placed consecutively on each optical window;
- For systems where the optical windows (or other relevant parts) have a diameter larger than 10 mm, the test spot shall be placed at a position most relevant to the detection capability of the VBPDST;
- Test for each covered part of the VBPDST whether the simulated manual interference will lead to an OFF-state of the OSSDs within a time period of 5 s or does not reduce the stated detection capability;
- Tests shall be carried out to verify that when simulated manual interference leads to an OFF-state of the OSSDs, actuation of the restart interlock (if applicable) or a new power up does not lead to an ON-state of the OSSDs. If a restart interlock is fitted, the OSSDs shall stay in the OFF-state when the covering test spot is removed.

5.4.9 Optical occlusion

Optical occlusion on the window, in the zone with limited detection capability or in the detection zone shall not reduce the stated detection capability. These tests shall be carried out to test for failure to danger.

Immunity against the effect of optical occlusion within the detection zone shall be tested as follows:

a) The object used for simulating optical occlusion shall be a cylinder with a minimum effective length of 0,3 m. The diameter of the occluding object shall be 5 mm unless determined otherwise by the analysis of 4.3.9. The surface of the occluding object shall have a coefficient of diffuse reflection of less than 20 % at:
   - the wavelength of the illumination for VBPDST with PAPT;
   - the wavelength of maximum sensitivity of the sensor for VBPDST with AIT.

b) During the test, the axis of the occluding object shall be perpendicular to the optical axis of one of the imaging devices;

c) The detection zone shall range from the minimum to the maximum operating distance, when applicable;

d) The test shall be carried out by placing the occluding object in the detection zone as near as possible to the VBPDST and in the zone with limited detection capability unless determined otherwise by the analysis of 4.3.9. A black test piece (BTP, see 4.2.13.6) and grey background (GB) shall be used. If the occluding object does not lead to the OFF-state of the OSSDs, a B test shall be performed otherwise a C test shall be performed;

e) C-tests shall be performed to verify that the stated detection capability is maintained in the presence of optical occlusion. The black test piece (BTP) shall be moved through the optical occlusion as close as possible to the occluding object and at the stated maximum detection distance;

f) Additional tests shall be carried out when the analysis of 4.3.9 shows that the following can affect the immunity to optical occlusion:
   1) distances between the VBPDST and the occluding object other than those stated above;
   2) dimensions of the detection zone other than the maximum;
   3) other distances between the occluding object and the test piece;
   4) different diameters of the occluding object at different distances from the VBPDST;
   5) different positions of the occluding object in front of the VBPDST;
   6) and/or more than one occluding object.

6 Marking for identification and for safe use

This clause of IEC 61496-1:2020 is applicable except as follows:

6.1 General

Addition:

The markings required by 6.1 b), c) and d) of IEC 61496-1:2020 may alternatively be given in the accompanying documents.

7 Accompanying documents

This clause of IEC 61496-1:2020 is applicable except as follows.

Addition:

The accompanying documents shall contain the following information where applicable:

nn) application examples showing the tolerance zone(s);

oo) dimensions of maximum and minimum detection zone(s) and tolerance zone(s) together with information about a reference point relative to the sensing device for the determination of the detection zone;

pp) information about the minimum required distance between the border of a detection zone and the surrounding environment without detecting, for example, walls or parts of machines in order to ensure reliability in operation;

qq) instructions for setting the detection zone(s) including consideration of the tolerance zone(s) and details on other optional functions of the VBPDST, described in Annex A of this document if these options are available. A clear statement shall be given when one or more zone(s) is(are) described, whether its(their) description is related to the detection zone(s) as defined in 3.4 or the combination of the detection zone(s) and the tolerance zone(s);

rr) information about the behaviour of the VBPDST in the presence of smoke and dust;

ss) information on how the detection capability can be affected if the VBPDST is used within an additional housing. For example, additional housings may have an influence on the detection capability and the detection zone;

tt) if appropriate for the application(s), an indication on the floor of the detection zone should be recommended;

uu) instructions on how to document on paper the setting of the detection zone(s) together with date, serial number of the VBPDST and identification of the person responsible;

vv) instructions to follow when the VBPDST can be influenced during normal operation by a VBPDST of identical design;

ww) potential problems not covered by the requirements of this document; especially information concerning external influences which are not covered by this document and which can decrease the stated detection capability. Examples can include weld splatter, infra-red remote control devices, different fluorescent light sources, snow, rain, pollution and thermal convection;

xx) relevant information concerning the need to check periodically the optical window(s) for damage (depending on the application);

yy) relevant information concerning the need to check periodically the mounting of the VBPDST for correctness and to check for possible misalignment of the detection zone(s) (depending on the device and the application);

zz) information as required by 4.1.6 if the VBPDST possesses one or more zone(s) with limited detection capability;

aaa) information regarding the maximum speed in the worst case direction within the detection zone of the VBPDST of an object having the minimum detectable size (see 4.2.12.5);

bbb) instruction that dimensions resulting from detection capability and object intrusion considerations shall be added to the safe distance calculations of ISO 13855. This is because response time specifications assume that the object is entirely within the detection zone before it is detected.

Annex A
(normative)

Optional functions of the ESPE

Annex A of IEC 61496-1:2020 applies except as follows.

Clause A.8 does not apply.

Addition:

A.10 Selection of multiple detection zones

A.10.1 Functional requirements

If a VBPDST has more than one safety-related detection zone, a single fault shall not lead to an unintended change from one selected zone to another zone. In cases where a single fault which does not cause a failure to danger of the VBPDST is not detected, the occurrence of further faults internal to the VBPDST shall not cause a failure to danger.

Where the input signals are derived from device(s) external to the VBPDST, the latter should meet the relevant requirements of other appropriate standards (for example ISO 13849-1, IEC 61508, IEC 62061).

Single faults that prevent an intended change from one selected zone to another or prevent the activation of an additional safety-related detection zone shall cause the VBPDST to go to a lock-out condition when a demand requires an activation of another zone or an activation of an additional zone. The specified response time(s) shall be maintained in this case.

NOTE 1 It is possible that each zone has a different response time as specified by the manufacturer.

If a detection zone is changed in size on-line for example by external inputs, the same requirement applies.

If the user sets multiple detection zones, then the user shall have the possibility to configure the sequence of activation of the detection zones which is monitored by the VBPDST. If an incorrect sequence of activation of the detection zones is detected, the VBPDST shall respond by going to a lock-out condition.

The possibility that persons may already be within a detection zone at the moment of switching between different detection zones should be considered.

NOTE 2 The automatic selection of safety-related detection zones is not a muting function (as described in Clause A.7 of IEC 61496-1:2020).

A.10.2 Verification

Verify by inspection or test that:

a) a single fault does not lead to an unintended change from one selected zone to another zone; a single fault does not prevent an intended change from one selected zone to another or prevent the activation of an additional safety-related detection zone; a further fault will not lead to a failure to danger (according to 5.3.4);
b) common-mode failures cannot lead to a deactivation or variation of the detection zones;
c) the specified response time of the VBPDST is maintained in the case of switching between different detection zones;

d) the user has the possibility to configure the sequence of activation of the detection zones which is monitored by the VBPDST;

e) the VBPDST goes to the lock-out condition when the sequence of activation differs from that configured by the user.

Annex B
(normative)

Catalogue of single faults affecting the electrical equipment of the ESPE, to be applied as specified in 5.3

Annex B of IEC 61496-1:2020 is applicable except as follows.

Addition:

B.7 Imaging sensor

Faults considered	Exclusions
Wrong line addressing	None
Wrong column addressing	None
Crosstalk between lines, columns and pixels	None
Static image (no new image)	None
Stuck at high pixel	None
Stuck at low pixel	None
Change in register settings, if applicable	None
Failure in the analog to digital converter, if applicable	None
Failure in data pre-processing, if applicable (see Figure 1)	None

Annex AA
(informative)

The positioning of VBPDST employing a volume as a detection zone in respect of parts of the human body

AA.1 Calculation of distances for electro-sensitive protective equipment employing vision based protective devices (VBPDST)

AA.1.1 General

NOTE 1 ISO 13855 provides a methodology to determine the minimum distance *S* from specific sensing or actuating devices of protective equipment to a danger zone. Clause 6 of ISO 13855:2010 details the calculation of minimum distances for electro-sensitive protective equipment employing active opto-electronic protective systems. This Annex AA adopts the given approach and extends it where necessary. It is foreseen that after some experience, the methodology will be presented to the committees preparing ISO 13855 and IEC 62046 for adoption and integration in their standards.

When calculating minimum distances, the requirements and formulae given by ISO 13855:2010, Clause 6 should be taken into account including additions given by Clauses AA.1.2 to AA.1.4.

ISO 13855 distinguishes in the calculation of the minimum distance between:

– detection zone orthogonal to the direction of approach; and
– detection zone parallel to the direction of approach.

Both cases can be applied for a three-dimensional volume; it is allowed to choose the resulting lower minimum distance *S*. Analysis has shown that the formulae for detection zones orthogonal to the direction of approach lead to a lower or equal minimum distance *S* in the cases described below. For the Formulae (AA.5) to (AA.9) it is considered that the outer shell of the three-dimensional detection zone is normal to the reference plane, e.g. floor. Other shapes such as ball-shaped or trapezoidal need further consideration. In addition, possible circumventing of a VBPDST by reaching over the detection zone has to be addressed according to ISO 13855:2010, Table 1.

To ensure that the value C_{RO} according to ISO 13855:2010, Table 1 is smaller than the value of $(C + d)$ calculated according to the formulae below independent of the height *a* of the hazard zone the height *b* of the upper edge of the detection zone of the VBPDST should be 1 400 mm as a minimum for a detection capability > 55 mm and 2 400 mm as a minimum in all other cases.

NOTE 2 A height *b* equal or greater than 1 400 mm respectively 2 400 mm means that there is no possible circumventing of an ESPE according to ISO 13855 by reaching over the detection zone.

AA.1.2 Calculation of the overall minimum distance S_0

When calculating the size or volume of a zone that is used to prevent a person reaching the hazard zone before the termination of the hazardous machine function, an overall minimum distance S_o should be calculated by Formulae (AA.1) or (AA.4) as is appropriate. Formula (AA.2) is a general formula given by ISO 13855.

$$S_o = S + S_a \qquad \text{(AA.1)}$$

$$S = (K \times T) + C \qquad \text{(AA.2)}$$

$$S_a = C_{tz} + d \qquad \text{(AA.3)}$$

$$S_o = (K \times T) + C + C_{tz} + d \quad \text{(AA.4)}$$

where:

- S_o is the overall minimum distance, in millimetres, combining the minimum distance S and an additional distance S_a;
- S is the minimum distance, in millimetres, from the hazard zone to the detection point, line, plane or zone;
- S_a is an additional distance, in millimetres, combining the effects of systematic and random influences;
- K is a parameter in millimetres per second, derived from data on approach speeds of the body or parts of the body (see ISO 13855 for details);
- T is the overall system stopping performance in seconds;
- C is an additional distance in millimetres, based on the distance, which a part of the body may be moving towards the hazard zone prior to the actuation of the protective device;
- C_{tz} is an additional distance in millimetres, based on the tolerance zone of the protective device to satisfy systematic and random influences;
- d is the sensor detection capability of the device, in millimetres (mm), i.e. the dimension of the test piece.

NOTE Protective devices employing a volume as a detection zone will normally require a test piece to be inside the detection zone with a dimension of at least its stated detection capability. This is taken into account by the corresponding test procedures (see for example Clause 5). Therefore, the dimension of the test piece (d) is part of the additional distance S_a in the Formulae (AA.3) and (AA.4). If partial intrusion (see Clause AA.1.5, Example 2) satisfies the requirements of this document, then only the relevant portion of the dimension d is used in those formulae (i.e. d_1 in Figure AA.4 to Figure AA.6).

AA.1.3 Vision based protective devices with a detection capability > 40 mm and ≤ 55 mm

The minimum distance S in millimetres should be calculated by Formula (AA.5) for VBPDST having a detection capability in the range > 40 mm and ≤ 55 mm

$$S = (K \times T) + C_{40} + C_{55} \quad \text{(AA.5)}$$

where:

- S is the minimum distance, in millimetres, from the hazard zone to the detection point, line, plane or zone;
- K is a parameter in millimetres per second, derived from data on approach speeds of the body or parts of the body (see ISO 13855 for details);
- T is the overall system stopping performance in seconds;
- C_{40} is an additional distance in millimetres, based on formulae given by ISO 13855 with C_{40} = 8 (d – 14 mm) = 8 (40 mm – 14 mm) = 208 mm;
- C_{55} is an additional distance in millimetres, based on the formula C_{55} = 12 (d – 40 mm);
- d is the sensor detection capability of the device, in millimetres (mm), i.e. the dimension of the test piece.

Then

$$S = (K \times T) + 208 \text{ mm} + 12 (d - 40 \text{ mm}) \quad \text{(AA.6)}$$

$$S = (K \times T) + 12 d - 272 \text{ mm} \quad \text{(AA.7)}$$

NOTE 1 The formula for C_{55} is derived from an estimation based on data given by B. Flügel, H. Greil, K. Sommer, Anthropologischer Atlas, Verlag Tribüne Berlin 1986, ISBN 3-7303-0042-3.

NOTE 2 For the calculation of C_{40} the value of d is 40 mm irrespective of the detection capability stated by the manufacturer. For the calculation of C_{55}, the value of d is the detection capability stated by the manufacturer.

AA.1.4 Vision based protective devices with a detection capability > 55 mm and ≤ 200 mm

The minimum distance S in millimetres should be calculated by Formula (AA.8) for VBPDST having a detection capability in the range > 55 mm and ≤ 200 mm.

$$S = (K \times T) + C \quad \text{(AA.8)}$$

where:

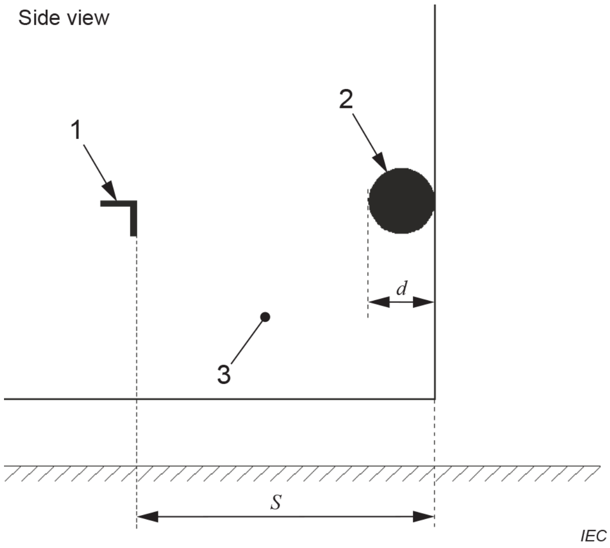
- S is the minimum distance, in millimetres, from the hazard zone to the detection point, line, plane or zone;
- K is a parameter in millimetres per second, derived from data on approach speeds of the body or parts of the body with K = 1 600 mm/s (see ISO 13855 for details);
- T is the overall system stopping performance in seconds;
- C is an additional distance of 850 mm; according to ISO 13855 this value is considered to be the standard arm reach.

Then see Formula (AA.9):

$$S = (1\,600 \text{ mm/s} \times T) + 850 \text{ mm} \quad \text{(AA.9)}$$

AA.1.5 Examples of detection zone and tolerance zone

For description of abbreviations used in Figure AA.1 to Figure AA.6, see Clause AA.1.2.



Key

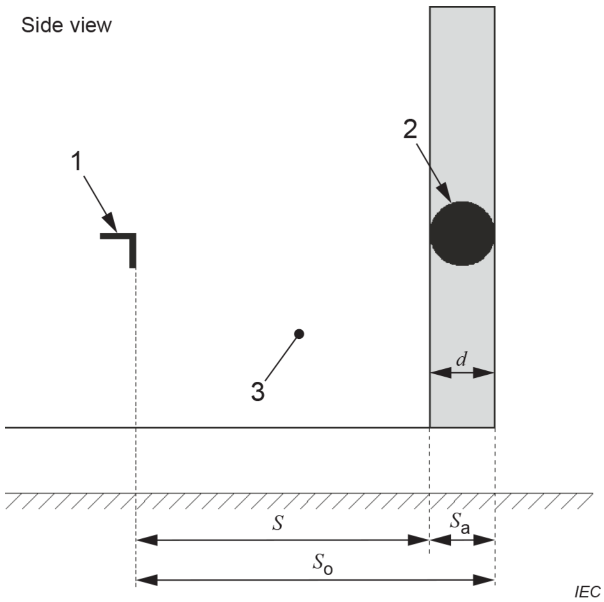
1 – Hazard zone

2 – Test piece

3 – Detection zone

Figure AA.1 – Minimum distance S – Example 1

According to the general description of the test procedure in 5.2.1.1, the test piece shall be detected when placed inside the detection zone as far as the stated detection capability d.



Key

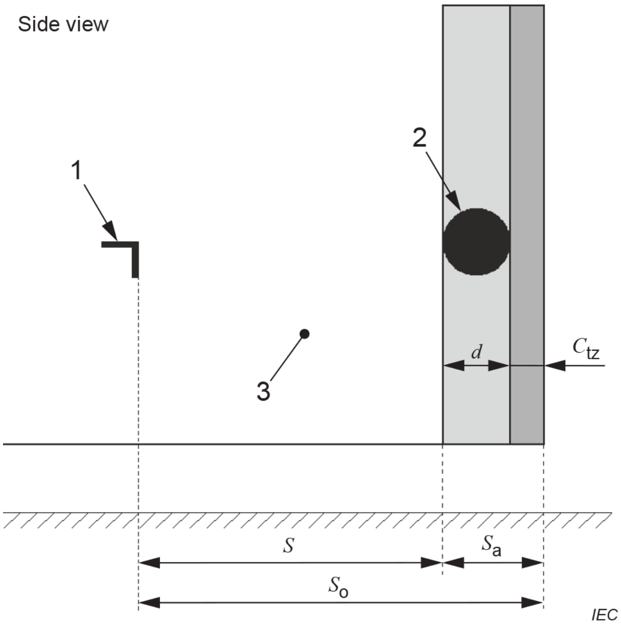
1 – Hazard zone

2 – Test piece

3 – Detection zone

Figure AA.2 – Overall minimum distance S_o without tolerance zone – Example 1

The dimension of the detection capability d shall be added to the minimum distance S to ensure the correct distance between the hazard zone and an object.



Key

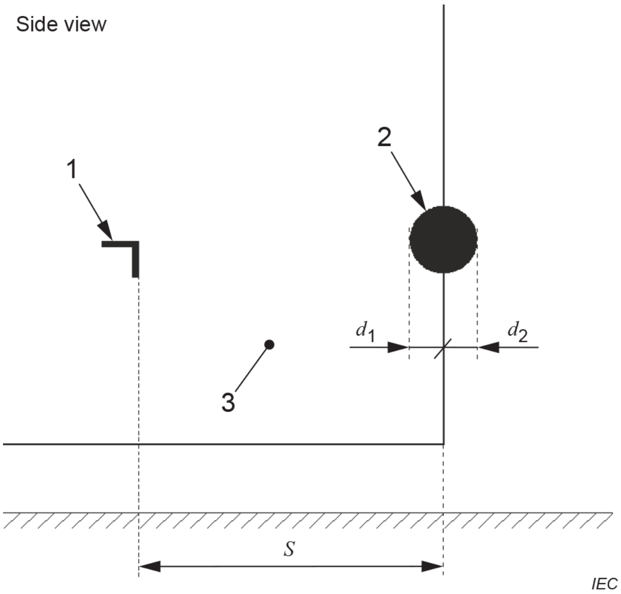
1 – Hazard zone

2 – Test piece

3 – Detection zone

Figure AA.3 – Overall minimum distance S_o including tolerance zone – Example 1

To achieve the required minimum probability of detection, the tolerance zone has to be considered in addition to the detection zone. The tolerance zone depends on position accuracy composed of systematic (STZ) and random influences (PTZ). Even if a measured distance value of a test piece falls into the tolerance zone, this test piece will be determined as detected and the OSSDs will go to the OFF-state or remain in the OFF-state.



Key

1 – Hazard zone

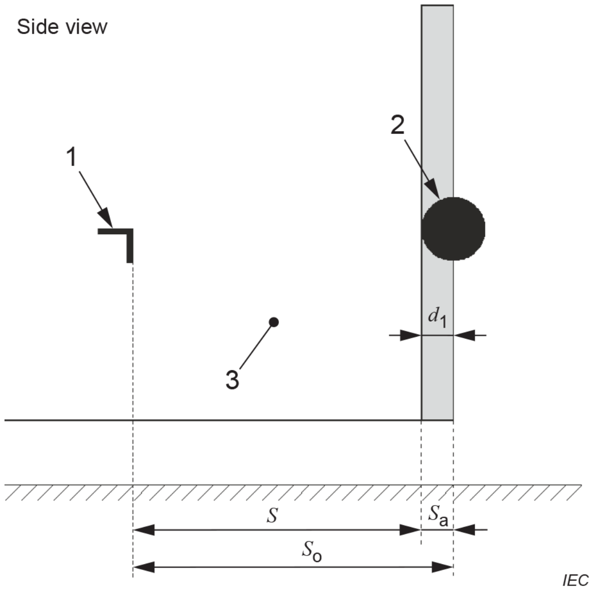
2 – Test piece

3 – Detection zone

$d = d_1 + d_2$

Figure AA.4 – Minimum distance *S* – Example 2

According to the general description of the test procedure in 5.2.1.1 the test piece shall be detected when placed inside the detection zone as far as the stated detection capability d. If partial intrusion of an object into the detection zone as shown by the dimension d_1 in Figure AA.4 leads to detection, then the dimension d_1 shall be added to the minimum distance S to ensure the correct distance between the hazard zone and an object, see Figure AA.5.



Key

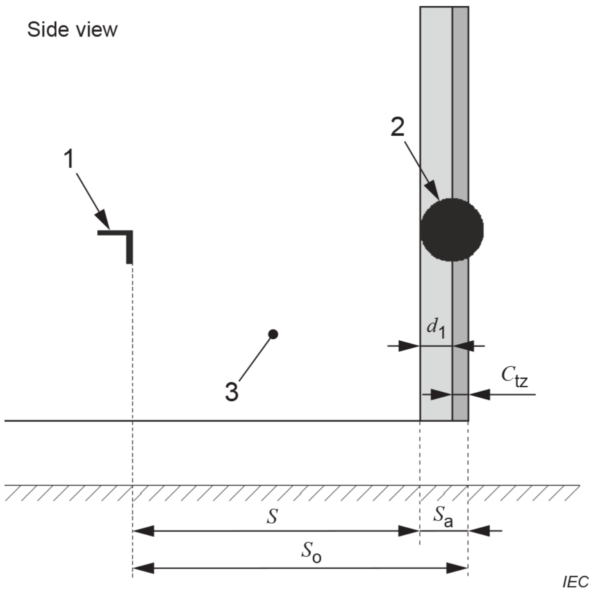
1 – Hazard zone

2 – Test piece

3 – Detection zone

d_1 – see Figure AA.4

Figure AA.5 – Overall minimum distance S_o without tolerance zone – Example 2



Key

1 – Hazard zone

2 – Test piece

3 – Detection zone

d_1 – see Figure AA.4

Figure AA.6 – Overall minimum distance S_o including tolerance zone – Example 2

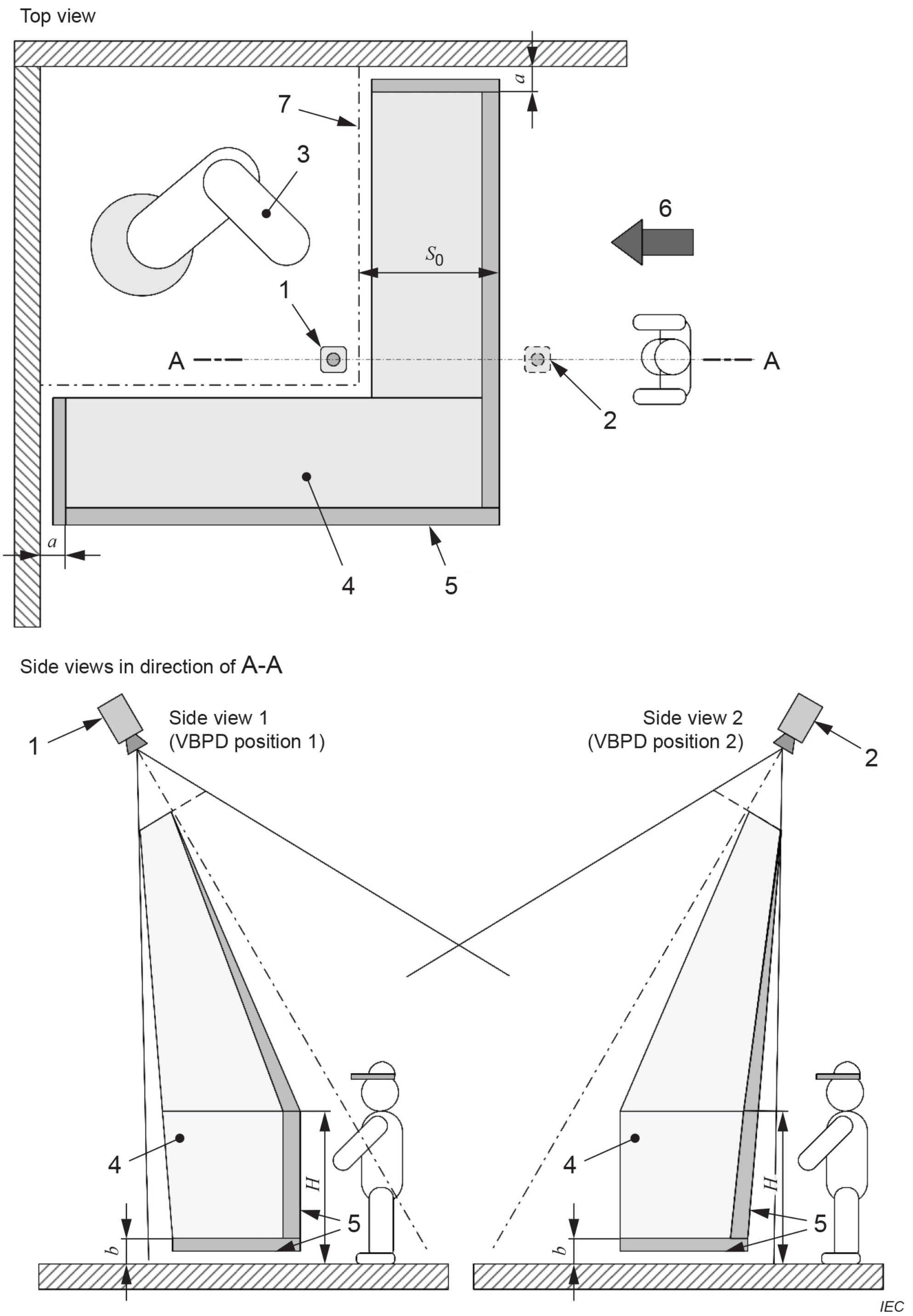
To achieve the required minimum probability of detection, the tolerance zone has to be considered in addition to the detection zone. The tolerance zone depends on position accuracy composed of systematic (STZ) and random influences (PTZ). Even if a position of a test piece falls into the tolerance zone, this test piece will be determined as detected and the OSSDs will go to the OFF-state or remain in the OFF-state.

AA.2 Application examples for body detection of a VBPDST employing a volume as a detection zone

The application example (see Figure AA.7) shows a robot working station. The entry of persons is prevented on two sides by walls or safety fences (top view). The entry from the other two sides is monitored by a VBPDST. If a person enters the detection zone, the robot stops its movement.

The safety distance S_0 should be calculated in accordance with the examples given in AA.1.5 and the VBPDST accompanying documents. Furthermore, the distance to the walls (*a*), the distance to the floor (*b*) and the height of the detection zone (*H*) should be calculated in accordance with the VBPDST accompanying documents and the risk assessment.

The VBPDST can be mounted at different positions. Side view 1 and side view 2 show two possible solutions and the shape of the resulting detection zone (4) and the adjacent tolerance zone (5).



Key

1 – VBPDST position 1	5 – tolerance zone S_a	S_o – Safety distance according AA.1.2
2 – VBPDST position 2	6 – direction of approach	H – height of detection zone over the reference plane e.g. floor
3 – robot	7 – hazard zone	a – distance to the reference plane e.g. walls
4 – detection zone		b – distance to the reference plane e.g. floor

NOTE The dimensions of a and b are according to the risk assessment.

Figure AA.7 – Application example for body detection of a VBPDST employing a volume as a detection zone

Annex BB
(informative)

Relationship between position accuracy and tolerance zones for VBPDST

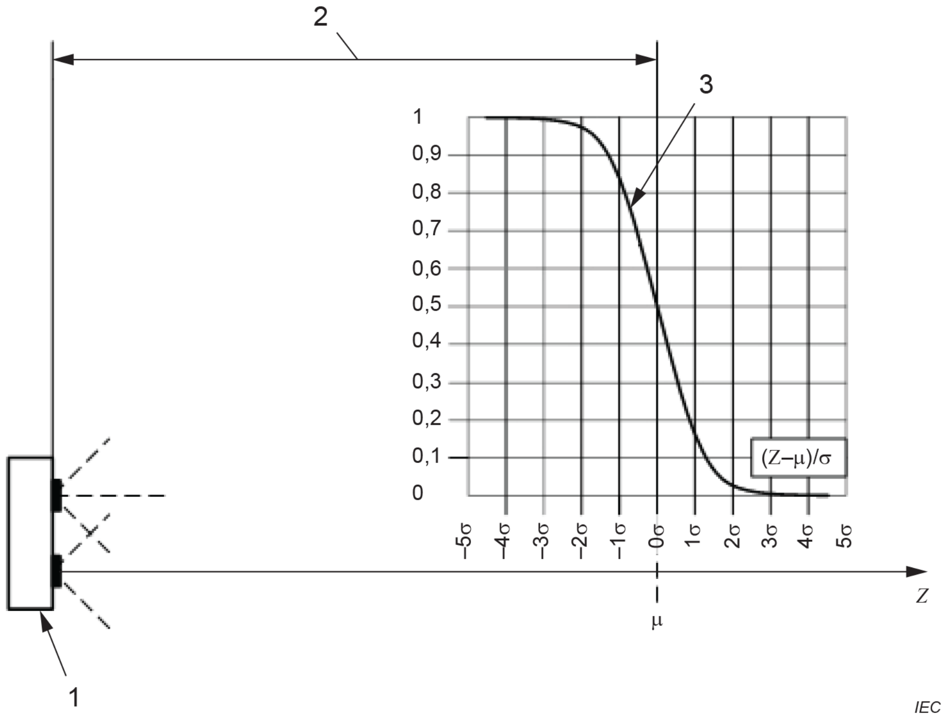
BB.1 Probability of detection

Probability of detection as used in this document is determined by the accuracy of measurement and is not related to the probability of faults. The probability with distribution function F_D that a test piece placed at the border of the detection zone is measured as being inside the detection zone can be calculated by using the normal distribution function F per Formula (BB.1).

$$F_D(\mu) = 1 - F(\mu) = 1 - \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\mu} e^{-\frac{1}{2}\left(\frac{2-\mu}{\sigma}\right)^2} dz = 0{,}5 \qquad \text{(BB.1)}$$

This calculation is based on the assumption that the measurement values follow a normal (Gaussian) distribution.

One method to measure the probability of detection is to use the detection information of the VBPDST (ON or OFF state of the OSSDs) for systems not providing object distance information. Figure BB.1 shows the relationship between test piece position and the probability of detection in one direction. Other directions may have to be considered accordingly.



Key

1 – Sensing device

2 – Detection zone

3 – Probability of detection

Figure BB.1 – Relationship between test piece position and the probability of detection

According to the relationship shown in Figure BB.1, a test piece will be measured as inside the detection zone with a probability of 0,5 at the position z = μ. Without any addition to the detection zone, the probability of detection would be unacceptably low. It is a requirement of this document that the supplier states an addition which is called the tolerance zone. Several different influences contribute to the tolerance zone as defined in this document.

BB.2 Tolerance zone related to probability

One part of the tolerance zone S_a is related to probability (PTZ). The probability that a test piece is measured as being inside the detection zone can be calculated according to Formula (BB.2).

$$F_D(\mu - 5\sigma) = 1 - \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\mu-5\sigma} e^{-\frac{1}{2}\left(\frac{z-\mu}{\sigma}\right)^2} dz = 1 - 2{,}9 \times 10^{-7} \qquad \text{(BB.2)}$$

This calculation is based on the assumption that the measurement values follow a normal (Gaussian) distribution. When configuring the detection zone, a tolerance zone related to the deviation of 5 σ should be added to the calculated safety distance (detection zone). Then the probability that it will be measured as inside the detection zone is 1 – 2,9 × 10^{-7}.

BB.3 Determination of tolerance zone for systems not providing object distance information

A practical way to measure σ is to measure the probability of detection at different positions z_i near to the outer border of a fix detection zone under worst case conditions and to recalculate σ by differentiation of the discrete probability of detection values $F(z_i)$ (as shown in Figure BB.2).

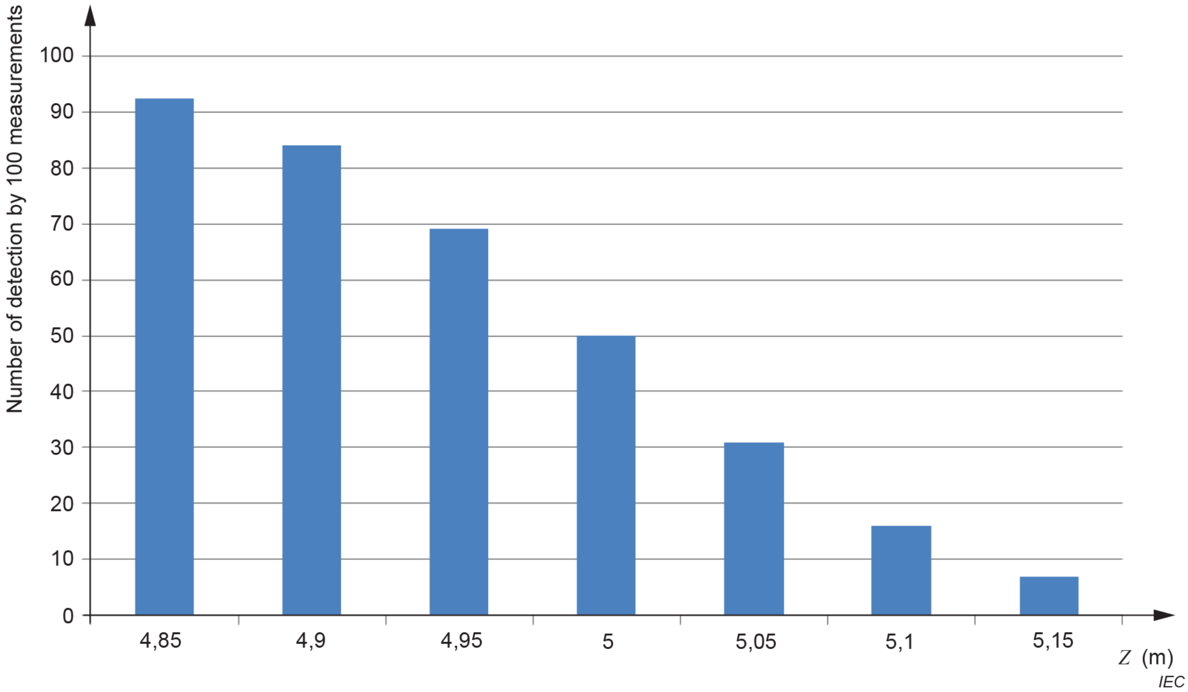


Figure BB.2 – Example for measurement of the probability of detection

The standard deviation σ of a Gaussian distribution is calculated for example by using Formula (BB.3):

$$\sigma = \sqrt{\frac{\sum_{i=2}^{n}\left(F\left(z_i\right)-F\left(z_{i-1}\right)\right)\times\left(\frac{z_i+z_{i-1}}{2}-\mu\right)^2}{F\left(z_n\right)-F\left(z_1\right)}} \quad \text{(BB.3)}$$

$F(z_i)$ is the ratio of the number of measurements with the test piece detected as being inside the detection zone to the number of all measurements at the position z_i.

μ, the maximum of the Gaussian distribution ($F(\mu)$ = 0,5) is also a numerical value calculated for example by using Formula (BB.4):

$$\mu = \frac{\sum_{i=2}^{n}\left(F\left(z_i\right)-F\left(z_{i-1}\right)\right)\times\left(\frac{z_i+z_{i-1}}{2}\right)}{F\left(z_n\right)-F\left(z_1\right)} \quad \text{(BB.4)}$$

This measurement is performed with the test piece positioned in the image corner at the maximum operating distance.

NOTE 1 The use of numerical integration techniques such as Simpson's rule could be appropriate.

NOTE 2 For determining STZ, refer to Clause BB.5.

BB.4 Determination of tolerance zone for systems providing distance information

Systems that provide a distance value to the objects in the detection zone allow a direct determination of the tolerance zones by analysis of the measurement accuracy.

The measurement accuracy can be determined by performing repetitive position measurements of a test piece and then using statistical analysis to derive the statistical and systematic measurement errors of the system. From these measurement errors the corresponding tolerance zones (PTZ and STZ) can be calculated.

The appropriate test setup for this measurement is the setup for low contrast (LC). A grey test piece (GTP) according to the specified detection capability of the sensor shall be positioned in front of a grey background (GB) with at least 50 cm between test piece and background. The distance between sensor and test piece shall be the maximum operating distance of the system. The test piece shall be positioned in the image corner and if the test piece is cylinder shaped, it shall be oriented such that its axis is perpendicular to the z-axis of the sensing device coordinate system.

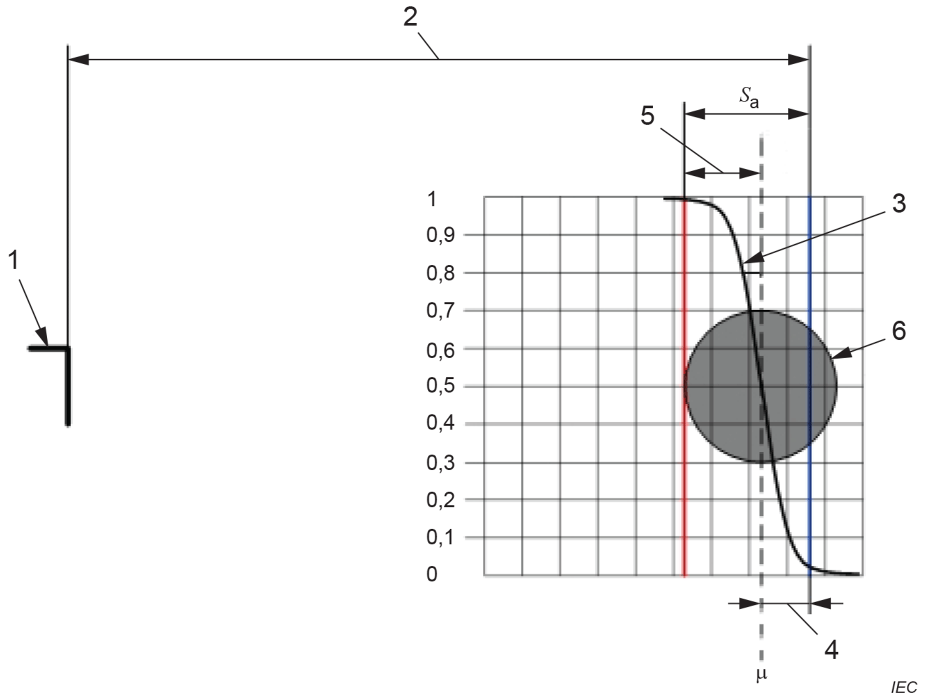
Repetitive distance measurements of the test piece in the specified test setup are performed. A set of 1 000 distance measurements can be analysed regarding mean value μ and standard deviation σ with sufficient statistical accuracy. It can now be inferred from Formula (BB.2) that the size of the PTZ is five times the standard deviation σ Furthermore, the systematic measurement error can be determined: the deviation of the mean value μ from the real test piece position is regarded as a systematic measurement error and shall be added to the size of the STZ.

It is important to note that a common distance value attributed to the test piece as a whole shall be used for the determination of the tolerance zones. The standard deviations of pixel-based distance values that are averaged, filtered or in some other way processed by a specific detection algorithm cannot be easily related to the detection probability and hence are not useful to calculate the sizes of tolerance zones.

BB.5 Tolerance zone related to systematic interferences

The tolerance zone S_a is also affected by influences that are not probabilistic. An additional systematic tolerance zone (STZ) is defined and added to PTZ (as shown in Figure BB.3).

STZ is the difference between the border of the detection zone and μ.



Key

1 – Hazard zone

2 – Detection zone

3 – Probability of detection

4 – Tolerance zone related to systematic influences (STZ)

5 – Tolerance zone related to probability (PTZ)

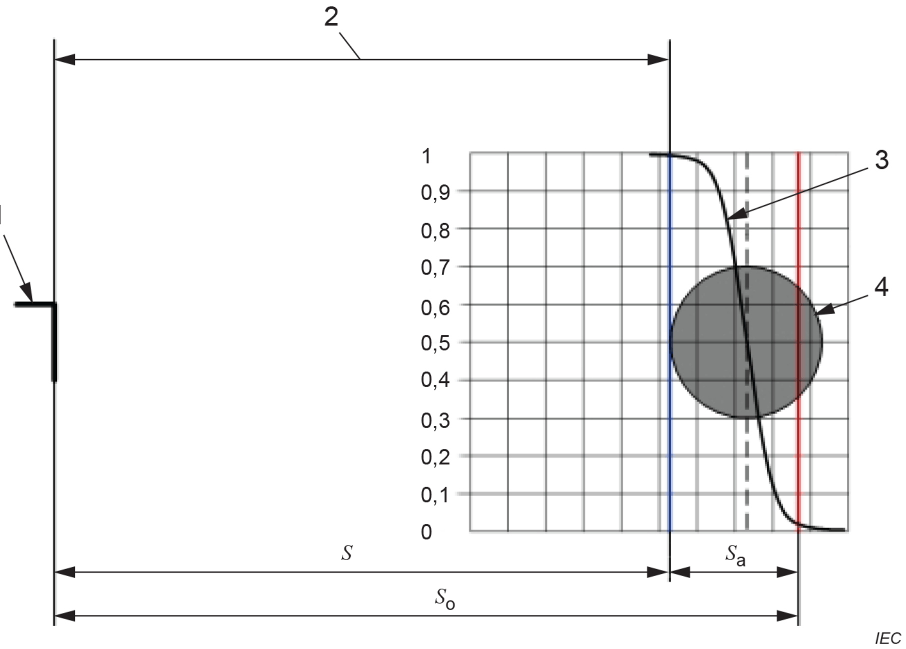
6 – Test piece

Figure BB.3 – Relationship between detection zone and tolerance zone

NOTE Clause BB.5 and Figure BB.3 describe the procedure to determine the systematic part of the tolerance zone (STZ). Therefore, the tolerance zone is shown as part of the detection zone in Figure BB.3. Clause BB.6 describes how to use the measured values.

BB.6 Adding the tolerance zone on the outer border of the detection zone

The tolerance zone S_a has to be added to the outer border of the detection zone to ensure the required probability of detection inside of the detection zone (as shown in Figure BB.4).



Key

1 – Hazard zone

2 – Detection zone

3 – Probability of detection

4 – Test piece

Figure BB.4 – Overall minimum distance S_o including tolerance zone

Annex CC
(informative)

Basic principles of physics for contrast of convex homogeneous bodies

CC.1 Illumination on a surface element

The brightness of a surface element, of any convex body with homogenous diffuse (Lambert's) reflectivity depends on the direction of illumination φ on the surface element (see Figure CC.1 and Figure CC.2) and is calculated according to Formula (CC.1).

$$I(\varphi) = I \times \cos(\varphi) \tag{CC.1}$$

In the case of a sphere illuminated by a point source (see Figure CC.1), the behaviour is as follows:

– The surface of the sphere normal to the direction of the point source (φ = 0°) is illuminated with maximum intensity;
– The surface of the sphere parallel to the direction of the point source (φ = 90°) is illuminated with minimum intensity (i.e. dark);
– The backside (φ > 90°) of the sphere not in direct view of the point source is dark.

It is possible to use a half-Ulbricht sphere model to approximate the floor-level illumination of a large, high ceiling hall with lamps densely and equally distributed.

NOTE 1 This is not a worst case under some conditions. Additional analysis can be necessary by the supplier to identify critical situations based on specified lighting requirements and operating conditions.

In the case of a test sphere placed at the center of a half-Ulbricht sphere (see Figure CC.2), the brightness varies as follows:

– The top of the sphere is illuminated with maximum intensity;
– The side of the sphere (φ = 90°) is illuminated with the half intensity;
– The back is dark.

NOTE 2 An Ulbricht sphere illumination doesn't appear in the real world. In case of any convex body illuminated from all directions (Ulbricht sphere), every surface element has the same brightness. No structure is visible, only different colours induce a contrast on the surface.

The brightness of a surface element of a spherical test piece is calculated by integrating all incidence angles of the surface element (see Figure CC.3) according to Formula (CC.2):

$$I(\varphi) = I \times \frac{(1 + \cos(\varphi))}{2} \tag{CC.2}$$

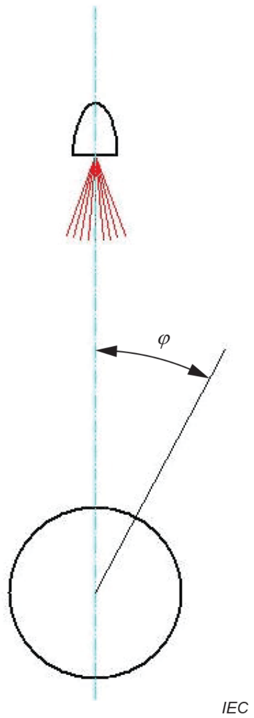


Figure CC.1 – Illumination model – Sphere illuminated by a point source

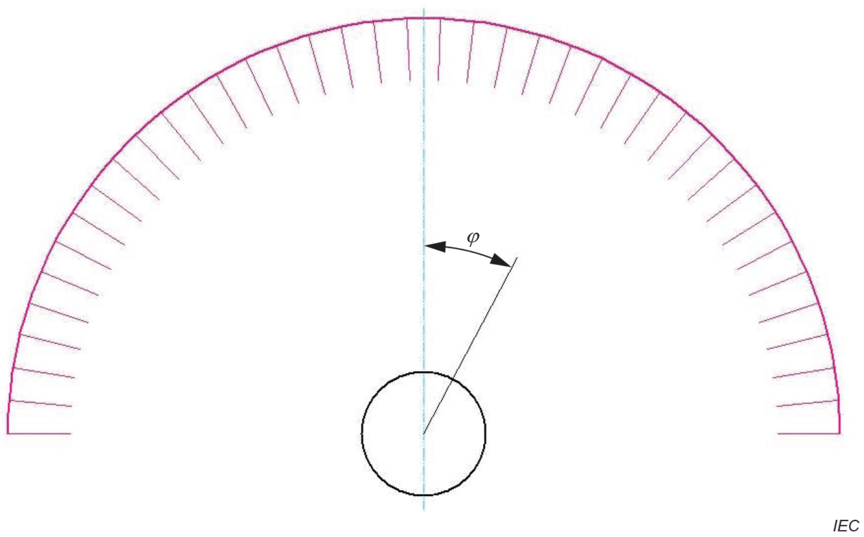


Figure CC.2 – Illumination model – Sphere illuminated by a half-Ulbricht sphere

CC.2 Brightness of a surface element

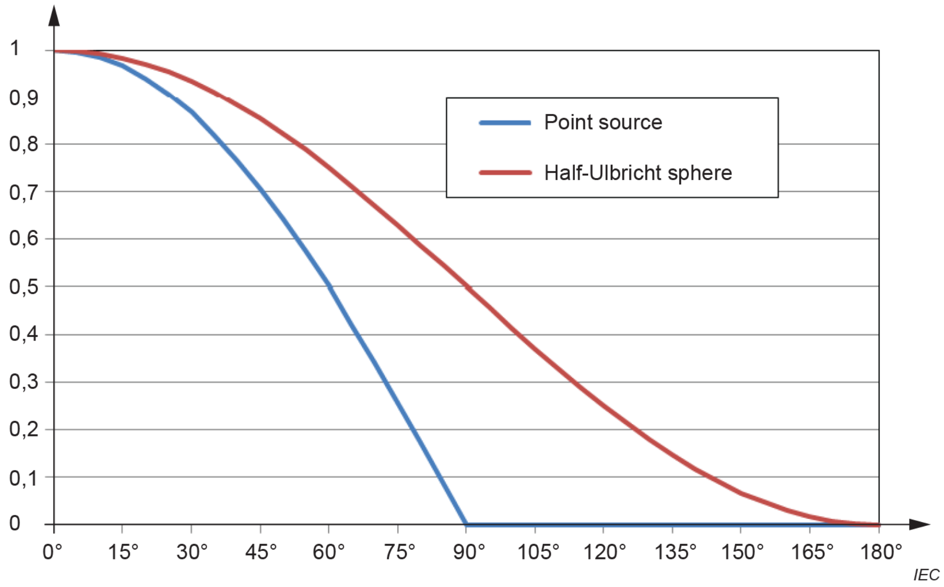


Figure CC.3 – Brightness of a surface element of a sphere in spherical coordinates

When a spherical test piece is illuminated by half of an Ulbricht sphere and projected on an image (parallel projection), the intensity profile in the image depends on the viewing direction (see Figure CC.4).

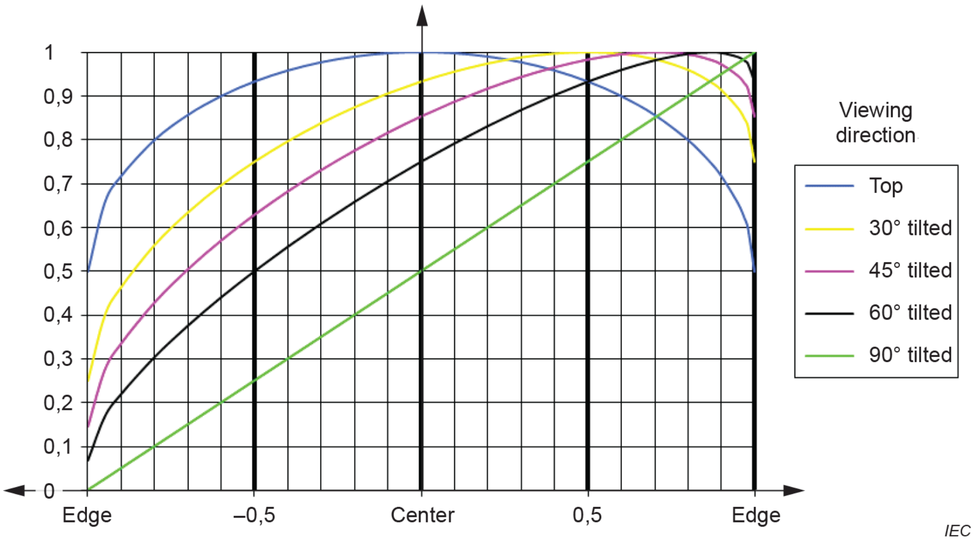


Figure CC.4 – Brightness distribution in an image of a sphere

The contrast is as low as possible when the sphere is viewed from the same direction as the illumination. The contrast in this specific lighting plan and test piece position reaches a theoretical minimum when the average grey values with or without the test piece are the same (see Figure CC.5).

NOTE A practical test setup can alternately use a test piece and background of the same reflectivity in worst case lighting conditions, as established through analysis (see 5.1.2.1, Setup for low contrast (LC)).

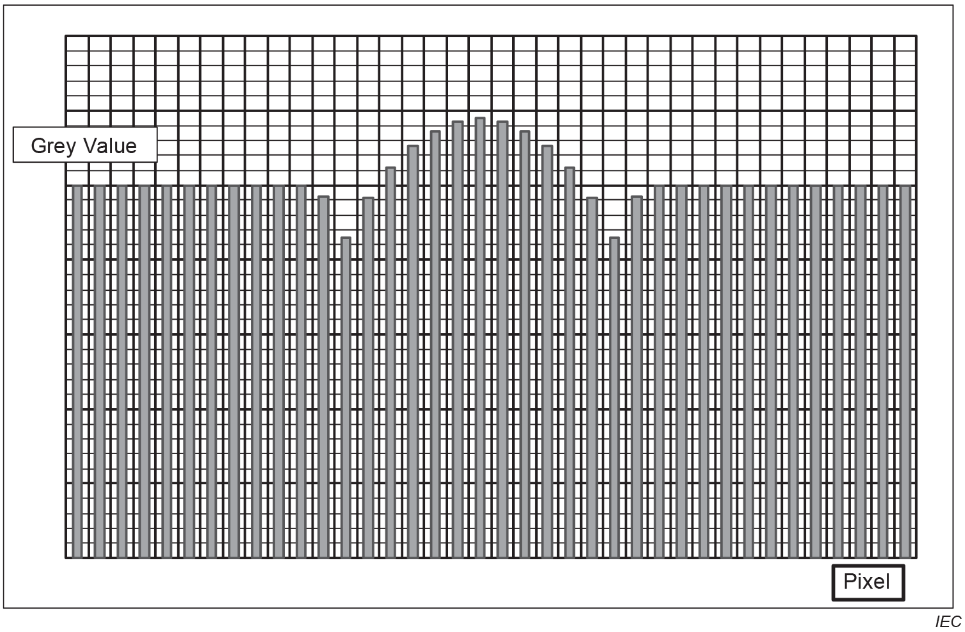


Figure CC.5 – Grey value profile over a sphere with low contrast for a typical imaging contrast (Modulation Transfer Function)

Grey value distributions shown in Figure CC.6 to Figure CC.8 have better contrast than the distribution shown in Figure CC.5.

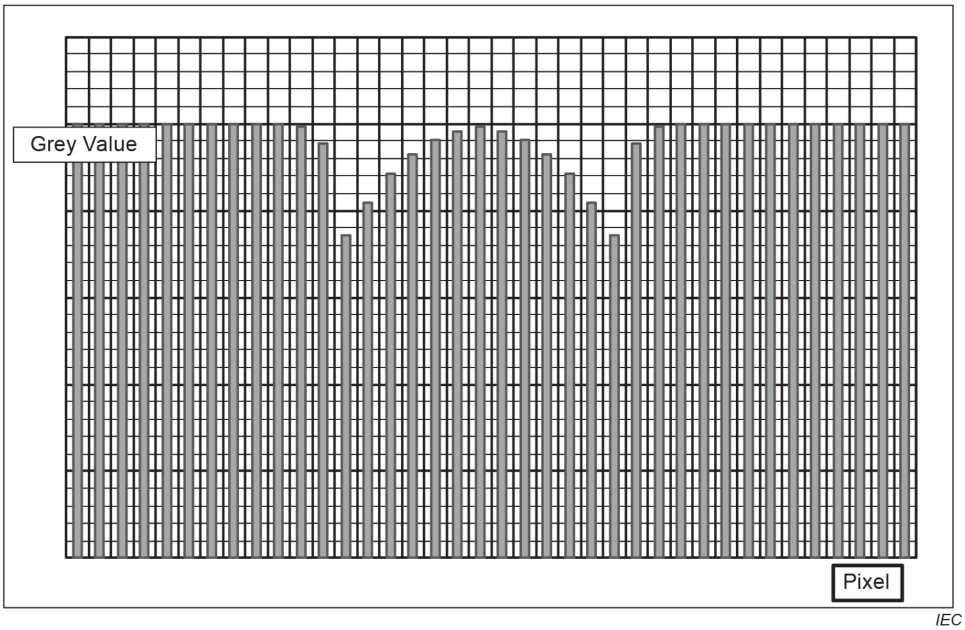


Figure CC.6 – Grey value profile over a sphere with the same colour as the background

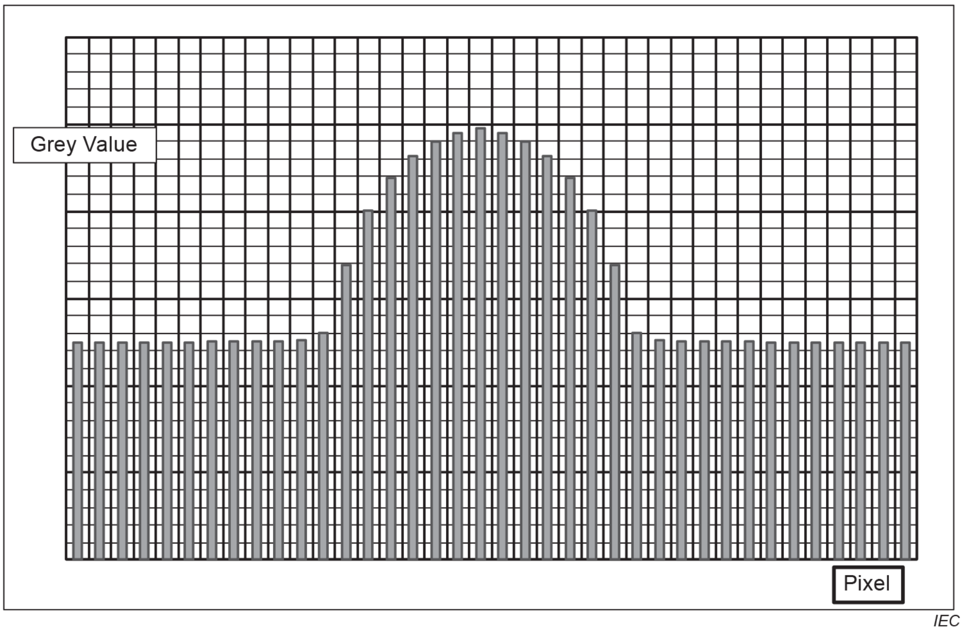


Figure CC.7 – Grey value profile over a sphere in front of a background that is half as bright

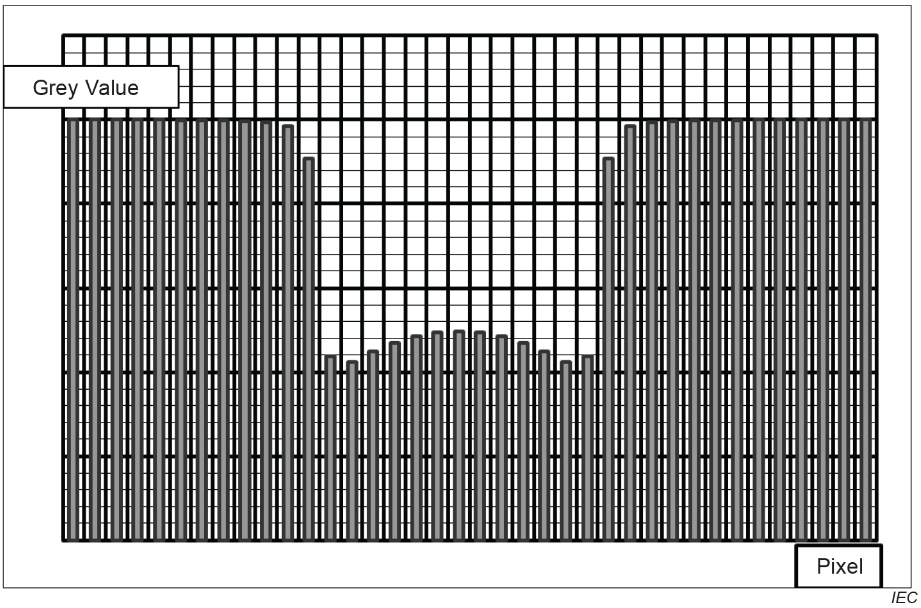
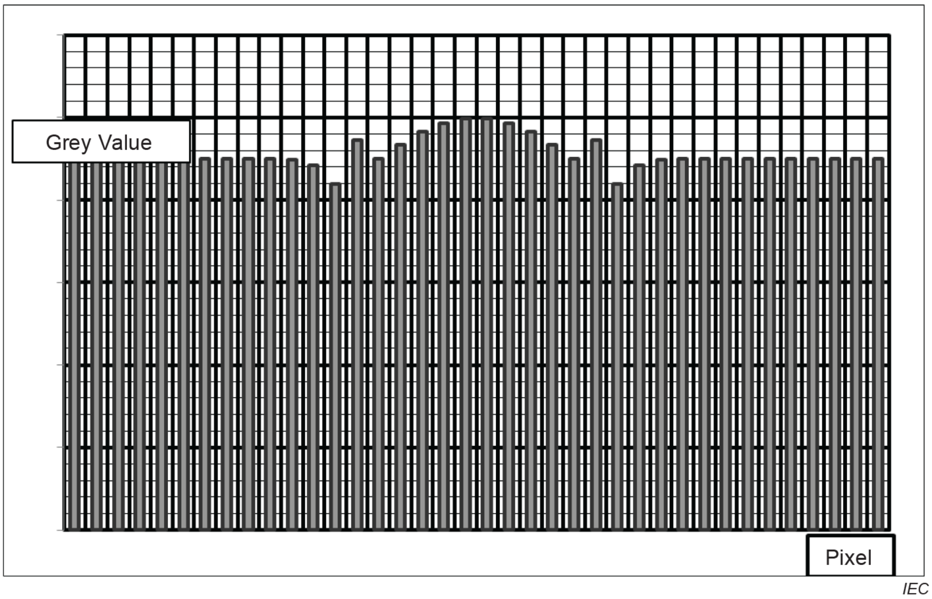


Figure CC.8 – Grey value profile over a sphere in front of a background that is twice as bright

Figure CC.9 and Figure CC.10 show two other worst case situations.



NOTE The side of the sphere is 1,2 times brighter than the top (like dark hair and white skin).

Figure CC.9 – Grey value profile over a sphere by low contrast

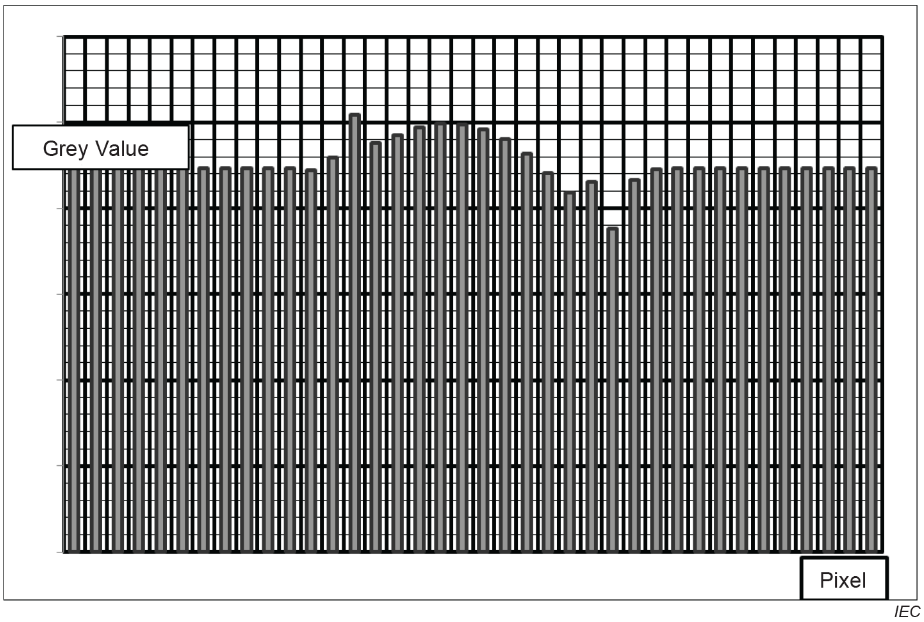


Figure CC.10 – Grey value profile over the sphere from Figure CC.9 but with the direction to the imaging device changed by 10°

Figure CC.11 shows a sphere with minimum size which leads to an object with a 5 pixel diameter in the image plane.

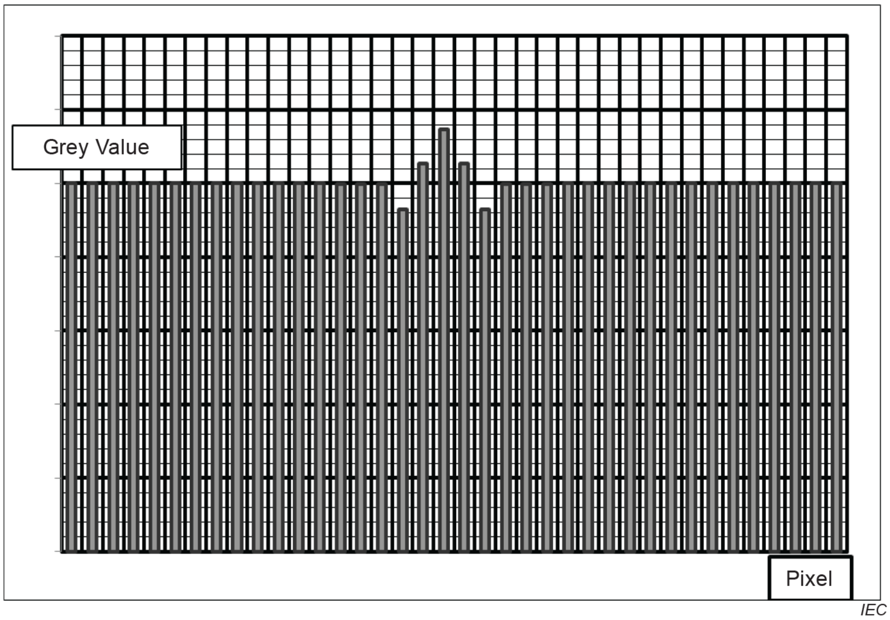


Figure CC.11 – Grey value profile over a small sphere that results in an image that is 5 pixels in diameter

Bibliography

Addition:

ISO 15534-1:2000, *Ergonomic design for the safety of machinery – Part 1: Principles for determining the dimensions required for openings for whole-body access into machinery*

ISO 15534-2:2000, *Ergonomic design for the safety of machinery – Part 2: Principles for determining the dimensions required for access openings*

ISO 15534-3:2000, *Ergonomic design for the safety of machinery – Part 3: Anthropometric data*

EN 12464-1:2021, *Light and lighting. Lighting of work places – Part 1: Indoor work places*

EN 547-3:1996, *Safety of machinery – Human body measurement – Part 3: Anthropometric data*

DIN 33402-2:2020, *Ergonomics. Human body dimensions – Part 2: Values*

B. Flügel, H. Greil, K. Sommer, Anthropologischer Atlas, Verlag Tribüne Berlin 1986, ISBN 3-7303-0042-3

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(*Continued from second cover*)

Only English language text has been retained while adopting it in this Indian Standard, and as such the page numbers given here are not the same as in the International Standard.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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