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Safety of machinery — Laser processing machines —

Part 1: Laser safety requirements

Sécurité des machines — Machines à laser —

Partie 1: Exigences de sécurité laser

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Foreword

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Laser and electro-optical systems*, in collaboration with IEC/TC 76, *Optical radiation safety and laser equipment*.

This second edition cancels and replaces the first edition (ISO 11553-1:2005), which has been technically revised with the following main changes:

— the terms "beam delivery systems", "beam path components", "beam shaping components", "beam switching components" and "fibre optic cable" and "fibre connector" were added;

— the document was restructured;

— the Title was adapted;

— other hazards than laser radiation hazards are not considered in this document but are described in Annex A;

— operating modes (automatic mode, setting mode, manual intervention mode, service mode) and the operating mode selector switch were added;

— Clause 5 is separated in requirements regarding different locations and the different modes of operation;

— in Clause 6 the verification procedures were described in more detail;

— Annex B was deleted.

A list of all the parts of ISO 11553 can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The Machinery Safety Directive issued by the European Parliament and the Council of the EC outlines essential and mandatory requirements that must be met in order to ensure that machinery is safe. In response, CEN/CENELEC initiated a programme to produce safety standards for machines and their applications. This document is one in that series.

It has been prepared as a harmonized standard to provide a means of conforming to the essential safety requirements of the Machinery Directive and associated EFTA Regulations.

This document is a type B standard as stated in ISO 12100. The provisions of this document may be supplemented or modified by a type C standard.

For machines which are covered by the scope of a type C standard and which have been designed and built according to the provision of that standard, the provisions of that type C standard take precedence over the provisions of this type B standard.

The purpose of this document is to prevent injuries to persons by

— listing potential laser radiation hazards generated by machines containing lasers,

— specifying safety measures and verifications necessary for reducing the risk caused by specific hazardous conditions,

— providing references to pertinent standards, and

— specifying the information which is to be supplied to the users so that they can establish proper procedures and precautions.

Safety of machinery — Laser processing machines —

Part 1: Laser safety requirements

1 Scope

This document describes laser radiation hazards arising in laser processing machines, as defined in 3.7. It also specifies the safety requirements relating to laser radiation hazards, as well as the information to be supplied by the manufacturers of such equipment (in addition to that prescribed by IEC 60825).

Requirements dealing with noise as a hazard from laser processing machines are included in ISO 11553-3:2013.

This document is applicable to machines using laser radiation to process materials.

It is not applicable to laser products, or equipment containing such products, which are manufactured solely and expressly for the following applications:

— photolithography;

— stereolithography;

— holography;

— medical applications (per IEC 60601-2-22);

— data storage.

2 Normative references

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

ISO 3864 (all parts), *Graphical symbols — Safety colours and safety signs*

ISO 11145:2018, *Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols*

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

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

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

ISO 13850:2012, *Safety of machinery — Emergency stop function — Principles for design*

IEC 60204-1:2016, *Safety of machinery — Electrical equipment of machines — Part 1: General requirements*

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

IEC 60825-4:2006, *Safety of laser products — Part 4: Laser guards*

IEC 62061:2005, *Safety of machinery — Functional safety of safety-related electrical, electronic and programmable electronic control systems*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11145:2018, ISO 12100:2010, IEC 60825-1:2014 and IEC 60825-4:2006 and the following apply.

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

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

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

3.1
beam delivery system
system comprised of all components, including all optical beam components and potential beam paths and enclosures, which when combined, transfer laser radiation emitted from the laser (according to definition in IEC 60825-1:2014) to the workpiece. The beam delivery system can include all elements for guiding, shaping and switching the laser beams as well as the enclosure of and support for the beam path components

[SOURCE: IEC 60825-4:2006/AMD 2:2011, G.2.1, modified — replaced "workpiece. These components may include" by "workpiece and where the components can include" and changed laser beam to laser beams.]

3.2
beam path component
optical component which lies on a defined beam path

Note 1 to entry: See IEC 60825-1:2014, 3.16.

EXAMPLE A beam steering mirror, a focus lens, a fibre optic cable or a fibre optic cable connector.

3.3
beam shaping component
optical component integrated in the beam path to transform the profile or cross-section of the laser beam by means of apertures, reflective, refractive or diffractive optical components

EXAMPLE Lens or integrating optical element for hardening applications.

3.4
beam switching component
optical component or an assembly of components introduced in the beam path to direct or divert, under external control, the beam path along (a) predetermined direction(s)

Note 1 to entry: The external control allows the beam path to be switched from one predetermined direction to another.

3.5
fibre optic cable
optical beam guiding component that enables the transfer of laser radiation along a transparent medium

Note 1 to entry: The fibre optic cable can be equipped with sensors to monitor breakage and/or temperature.

Note 2 to entry: A fibre optic cable can have a glass or another core that carries the laser radiation and is surrounded by cladding. The outside of the fibre is protected by cladding and can be further protected by additional layers of other materials such as polymer or a metal to protect the fibre from mechanical deformation, ingress of water, etc. In this document, this term also includes other forms of transmission devices such as waveguides.

3.6
fibre connector
fibre component, that connects the fibre optic cable with other components in the beam path

Note 1 to entry: The fibre connector can be equipped with sensors to monitor its position (connected/disconnected).

Note 2 to entry: Typically, fibre connectors connect the fibre with the laser and the laser processing head.

3.7
laser processing machine
machine in which (an) embedded laser(s) provide(s) sufficient energy or power to melt, evaporate, or cause a phase transition in at least a part of the workpiece, and which is ready to use in function and safety

3.8
hazard area
danger zone
space within and/or around machinery in which a person can be exposed to a hazard

Note 1 to entry: Laser hazard area, within which the beam irradiance or radiant expose exceeds the MPE including the possibility of accidental misdirection of the laser beam (see definition according to IEC 60825-1:2014).

3.9
process zone
<laser processing machines> area where the laser beam interacts with the material of the workpiece

3.10
location with controlled access
location where the hazard is inaccessible except to authorized persons who have received adequate training in laser safety and servicing of the system involved

Note 1 to entry: The access to the location is controlled by authorization systems, e.g. keys, password.

Note 2 to entry: See Table 1.

EXAMPLE Service engineers that need to work in a guarded laser hazard area, or in excess of the MPE respectively. Protective measures include, besides technical and administrative means, adequate personal protective equipment (laser protective eyewear, protective clothing).

3.11
location with restricted access
location where the hazard is inaccessible to the public but may be accessible to other observers or other personnel untrained in laser safety

Note 1 to entry: The location with restricted access, for which personnel are kept from being exposed to the laser radiation hazards by guards/walls, barriers or other methods.

Note 2 to entry: See Table 1.

EXAMPLE Performing service at a laser processing machine located in a shop floor, which is the restricted area. The laser hazard area is screened by means of vertical mobile laser guards/walls, which are labelled with safety signs respectively. Reflected laser radiation can propagate to upper floors or scaffold platforms. Personnel having access to the shop floor is trained in organizational measures, so that they follow the organizational safety measures (prohibitions/warnings).

3.12
location with unrestricted and uncontrolled access
location where access is not limited or controlled

Note 1 to entry: All people, including the public can have access to the location.

Note 2 to entry: See Table 1.

Note 3 to entry: If the machine is used under public access, servicing can take place by generating locations with restricted access or locations with controlled access.

EXAMPLE Typically, these machines are exhibited or demonstrated on fairs and exhibitions. Since the public can have access to the location, no hazards may emanate from the laser processing machine.

Table 1 — Description of locations

Location	Controlled	Restricted	Unrestricted and uncontrolled
People	Authorized and trained in laser safety	Personnel untrained in laser safety but not the public	All, including the public

3.13
automatic mode
production
<laser processing machines> operating mode, during which the machine is used as intended (normal use), including

— loading and unloading of parts and/or materials to be processed,

— processing during which the laser beam works alone or in conjunction with other tools

Note 1 to entry: During automatic mode (normal use) safeguarding equipment is closed.

Note 2 to entry: The loading/unloading can take place fully or partly automated or manual.

3.14
setting mode
<laser processing machines> operating mode, during which laser adjustments or settings are carried out by the operator

Note 1 to entry: This is required for changes e.g. of the workpiece, the processing movement paths or the process parameters. During setting mode safeguarding equipment is open, but safety measures, such as significantly reduced speed, or step-mode, reduced laser output power, allow the operator to intervene in the process.

3.15
manual intervention mode
<laser processing machines> operating mode, during which single workpieces can be laser processed and the process can be observed by the operator

3.16
service mode
<laser processing machines> operating mode, in which the machine is operated, to carry out corrective actions

EXAMPLE Fault diagnosis, equipment strip-down and repairing, cleaning of optical elements or adjustments or alignment.

3.17
operating mode selector switch
<laser processing machines> switch or another selection device, which allows the use of the laser processing machine in several control or operating modes, requiring different protective measures and/or work procedures and which can be locked in each position

Note 1 to entry: The selection device includes but is not limited to software.

3.18
modification
change to the machine, which makes it capable of processing materials in a manner which differs from the original design, or which makes it capable of processing materials differently from how it was envisaged in the original design, or which affects the safety characteristics of a machine

3.19
subassembly
constituent part needed for proper performance of the laser processing machine

Note 1 to entry: A laser processing subassembly can be of any laser class in accordance with IEC 60825-1:2014.

3.20
workpiece
material intended to be processed by laser radiation, i.e. the target of the laser beam

3.21
maximum permissible exposure
MPE
level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects

Note 1 to entry: The MPE levels represent the maximum level to which the eye or skin can be exposed without consequential injury immediately or after a long time and are related to the wavelength of the laser radiation, the pulse duration or exposure duration, the tissue at risk and, for visible and near infra-red laser radiation in the range 400 nm to 1 400 nm, the size of the retinal image. Maximum permissible exposure levels are (in the existing state of knowledge) specified in IEC 60825-1:2014, Annex A.

Note 2 to entry: The MPE values given in IEC 60825-1:2014, Annex A are informative and are provided so that the manufacturer can calculate the NOHD, perform a risk analysis and inform the user about safe usage of the product. Exposure limits for the eye and the skin of employees in the workplace and the general public are in many countries specified in national laws. These legally binding national exposure limits might differ from the MPEs given in IEC 60825-1:2014, Annex A.

[SOURCE: IEC 60825-1:2014, 3.59, modified — in Notes to entry, included IEC 60825-1:2014 before Annex A indication for clarity.]

3.22
nominal ocular hazard area
NOHA
area within which the beam irradiance or radiant exposure exceeds the appropriate corneal maximum permissible exposure (MPE), including the possibility of accidental misdirection of the laser beam

Note 1 to entry: If the NOHA includes the possibility of viewing through optical aids, this is termed the "extended NOHA".

[SOURCE: IEC 60825-1:2014, 3.64]

3.23
foreseeable exposure limit
FEL
maximum laser exposure on the front surface of the laser guard, within the maintenance inspection interval, assessed under normal and reasonably foreseeable fault conditions

[SOURCE: IEC 60825-4:2006, 3.4]

4 Hazards generated by laser radiation

4.1 General

A number of different hazards can emanate from a laser processing machine. This document is (exclusively) addressed to the specific hazards resulting from laser radiation arising in laser processing machines.

Secondary hazards, which are caused by laser beam/material interaction, such as the generation of hazardous substances (fumes, vapours, gases), fire/explosion risks or the generation of secondary radiation, e.g. UV-radiation or ionizing radiation, are not considered in this document.

Other hazards which can emanate from a laser processing machine are given in Annex A.

Particular hazards are also covered by harmonized standards (examples):

For noise reduction and noise measurement methods for laser processing machines and hand-held processing devices and associated auxiliary equipment (accuracy grade 2) see ISO 11553-3:2013, Annex A.

For assessment and reduction of risks arising from radiation (laser and ionizing radiation excluded) emitted by machinery see EN 12198-1 to EN 12198-3.

For the evaluation of the emission of airborne hazardous substances, generated during laser material processing (such as particulate and gaseous substances; e.g. fumes, vapours, gases) see EN 1093 (all parts).

For reduction of risks to health resulting from hazardous substances emitted by machinery see ISO 14123-1 and ISO 14123-2.

4.2 Laser radiation hazards/sources of laser radiation emission

Laser radiation hazards can originate from a direct laser beam or a reflected/scattered laser beam. The normal use as well as malfunctions/reasonably foreseeable fault conditions have to be considered.

Possible emission sources of a direct beam are:

a) aperture of an embedded laser source,

b) beam delivery system within a laser processing machine,

c) laser beam emitted from the processing head (to the workpiece),

d) laser beam emitted from a scanning unit (to the workpiece).

Possible emission sources of a reflected beam are:

— elements (with reflective surface) within the beam delivery system of the laser processing machine,

— the workpiece holder (if the workpiece is missing),

— elements in the processing zone,

— elements inside the housing of a machine (e.g. handling system, suction pipes, parts of guards),

— the workpiece, processed by the laser processing machine.

The optical properties (e.g. surface roughness and reflectivity) of the material exposed to the laser beam decisively determine the kind of reflection (direct/specular reflection or scattered reflection) and thus the risk level. This has impact on both the foreseeable exposure limit (FEL) at the inner surface of a machine enclosure/guard or the resulting irradiance or the radiant exposure at a machine workplace or at a certain distance to the machine.

Inadequate design or malfunctions of laser components and machinery equipment can also be the reason for laser radiation hazards/emission (or a misguided laser beam):

— damaged optical fibre cable,

— damaged passive optical elements (e.g. mirrors, lenses),

— misaligned beam path (inadequate optical elements, incorrectly positioned),

— not properly working active beam guiding and shaping elements,

— not properly working handling system or robot positioning of the laser processing head,

— gaps in the enclosure/guard of a laser processing machine, through which laser radiation can propagate,

— damage of protective enclosure/guards/screens.

NOTE Information on reasonably foreseeable fault conditions related to beam guidance is given in IEC 60825-4:2006, Annex B.

Inadequate design of safety functions, and safety related parts of control systems (SRP/CS) respectively, for the safe isolation or deactivation of the laser beam (e.g. by shutters, relays controlling power supply to the laser) can cause severe laser radiation risks. In the following, safety functions are exemplarily given:

— emergency stop;

— opening of maintenance covers or doors for workpiece input and output with access to laser radiation;

— opening of doors to enter laser cabins with access to the laser hazard area;

— disassembling (manually) of fibre connectors with access to the direct laser beam;

— active control of guards and windows with regard to damage by laser radiation.

4.3 Laser radiation hazards induced by external effects (interferences)

Power conditions and the environment in which the laser processing machine operates may cause the machine to malfunction, thus giving rise to hazardous conditions related to laser radiation and/or making it necessary for someone to intervene within hazard zones.

Environmental interferences include

— temperature,

— humidity,

— external shock/vibration,

— vapours, dust or gases from the environment,

— electromagnetic/radio frequency interference,

— source voltage interruption/fluctuation, and

— insufficient hardware/software compatibility and integrity of machine parts.

EXAMPLE Environmental conditions can cause adverse impacts on the laser beam characteristics, which can deteriorate absorption efficiency; shock/vibration can cause misalignment of optical elements and thus the laser beam.

4.4 Characteristics of laser radiation

The hazards related to laser radiation depend on the characteristics of the radiation.

For a hazard analysis and a risk assessment, the laser radiation emitted from a laser processing machine is characterized by including but not limited to the following:

— wavelength;

— operating mode (cw, pulsed);

— beam profile (mode, energy distribution);

— beam quality codes: BPP, M^2, K;

— polarization;

— foreseeable exposure limit (FEL) at the inner side of an enclosure/guard;

— irradiance/radiant exposure at a machine workplace or specified distance to the laser machine;

— maximum exposure time.

5 Safety requirements and measures

5.1 General requirements

The extent to which hazards are covered is indicated in the Scope.

Manufacturers shall ensure the safety of laser processing machines by

a) hazard identification and risk assessment,

b) implementation of safety measures to minimize risks by laser radiation,

c) verification of the safety measures, and

d) provision of appropriate information for the user.

Based on the risk assessment (see 5.2), appropriate safety measures against laser radiation shall be incorporated into the laser processing machine by design and manufacture.

5.2 Risk assessment with regard to laser radiation hazards

The accessibility to hazardous laser radiation decisively depends on the status of a laser machine. Therefore, a risk assessment with regard to laser radiation hazards shall be performed:

— for the whole life cycle of the machine, as applicable, (for examples see ISO 12100:2010);

— for all operating modes (The operating modes described in Clause 3 are only examples. The operating modes of the machine incl. terminology and content should be defined by the risk assessment of the manufacturer.);

— after each modification of the machine by the person or organization responsible for the modification; and

— for each reasonably foreseeable misuse/operation not included by the intended use.

A risk assessment includes but is not limited to:

a) hazards caused by the direct or reflected laser beam;

b) hazard zones, particularly those associated with

   1) the laser or the laser system,

   2) the laser beam path/beam delivery system,

   3) the process zone,

   4) the laser hazard area, and

   5) the area in which laser radiation can dazzle people;

c) "interferences" listed in 4.3.

The results of the risk assessment shall be duly documented. See ISO 12100:2010 for principles for risk assessment.

5.3 Implementation of risk reduction measures

5.3.1 General

Safety measures against laser radiation hazards shall be incorporated in the machine by design and manufacture as specified in 5.3.2 to 5.3.4. Safety measures against laser hazards shall follow the priority principle according to ISO 12100:2010.

5.3.2 Safety measures against laser radiation hazards in dependence of the locations

NOTE In the following, requirements for safety measures against laser radiation hazards are given in dependence of the location, where the laser processing machine operates.

5.3.2.1 Safety measures at locations with unrestricted and uncontrolled access

For laser processing machines operating in locations with unrestricted and uncontrolled access, the possibility of people being exposed to hazardous levels of laser radiation exceeding the accessible emission limit (AEL) for Class 1 according to IEC 60825-1:2014 shall be eliminated during all operating modes (production and any other operating mode).

To satisfy these requirements, the following conditions shall be met:

— Unauthorized human access to a hazard zone shall be prevented solely by engineering safety measures as stipulated in IEC 60825-1:2014 and ISO 12100:2010.

— Guarding shall be applied to protect against laser radiation.

— SRP/CS shall be used to safely isolate the laser radiation, the requirements of ISO 13849-1:2015 shall be met.

NOTE Most commonly by means of an enclosure or guards/screens as described in IEC 60825-4:2006.

EXAMPLE Typically, these machines are exhibited or demonstrated on fairs and exhibitions. Since the public can have access to the location, no hazards may emanate from the laser processing machine.

5.3.2.2 Safety measures at locations with restricted access

For laser processing machines operating in locations with restricted access, predominantly engineering safety measures specified in IEC 60825-1:2014 and ISO 12100:2010 shall be taken to prevent human access to a laser hazard area (NOHA).

To satisfy these requirements, the following conditions shall be met:

a) Engineering safety measures for guarding and for shielding of laser radiation shall reduce the irradiance below the MPE of eye and skin. SRP/CS for the safe isolation of the laser radiation shall comply with ISO 13849-1:2015.

b) In addition to engineering measures organizational measures might be necessary (e.g. for operating mode “service”) to prevent human access to hazardous laser radiation. Exposure above the MPE shall be eliminated by additional use of administrative/organizational safety measures.

Organizational safety measures shall be carried out with secondary priority in accordance with ISO 12100:2010 and IEC 60825-1:2014. The manufactures shall inform the user, how to carry out the organizational measures in order to avoid risks (exceed MPE) by laser radiation.

If the laser hazard area is shielded or partially shielded by laser guards the manufacturer shall inform the user how to determine the FEL and provide adequate laser guards (with sufficient PEL according to IEC 60825-1:2014).

If the laser safety is provided by distance the manufacturer shall inform the user how to determine the NOHA. The manufacturer shall inform the user, how to install barriers (e.g. with barrier tapes) at the respective Nominal Ocular Hazard Distances. He shall provide information how to implement the organisational measures in training/education and safety instructions.

EXAMPLE Performing service at a laser processing machine located in a shop floor, which is the restricted area. The laser hazard area is screened by means of vertical mobile laser guards/walls, which are labelled with safety signs respectively. Reflected laser radiation can propagate to upper floors or scaffold platforms. Personnel having access to the shop floor is trained in organizational measures, to follow the organizational safety measures (prohibitions/warnings). By this, the residual risk by laser radiation can be eliminated by organizational measures; here e.g. prohibition of entry to upper floors.

5.3.2.3 Safety measures at locations with controlled access

For laser processing machines operating in locations with controlled access, the possibility of people being exposed to levels of laser radiation exceeding the maximum permissible exposure (MPE_{eye} and MPE_{skin}) shall be eliminated.

To satisfy this requirement, the following conditions shall be met in addition to all safety measures related to operating modes, where 5.3.3.2 to 5.3.3.5 apply.

a) Unauthorized human access to the laser hazard zone shall be prevented predominantly by engineering safety measures as specified in IEC 60825-1:2014 and ISO 12100:2010. The manufacturer shall specify the kind of authorization control enabling/preventing access to the laser hazard zone (e.g. door with key, password/transponder).

b) If authorized access (e.g. by key or password/transponder) is necessary for laser processing machines operating in locations with controlled access (e.g. for service mode, see also 5.3.3.4) the manufacturer shall provide information on how to work safely in a laser hazard area (see IEC 60825-1:2014).

   Exposure above the MPE in the controlled area shall be eliminated by use of engineering and administrative controls, including Personal Protective Equipment (PPE). The manufacturer shall provide the following information to the user:

   — Engineering measures: Emergency stop in the laser hazard area.

   — Organizational measures: The qualification of personnel authorized to access the laser hazard zone, which means level of training and education of the personnel and on safety instructions given to the personnel.

   — PPE: The required personal protective equipment (type, level of protection).

EXAMPLE Service engineers that need to work in a guarded laser hazard area, or in excess of the MPE respectively. Protective measures include, besides technical and administrative means, adequate personal protective equipment (laser protective eyewear, protective clothing).

5.3.3 Safety measures against laser radiation hazards

NOTE In the following, design requirements for safety measures against laser radiation hazards are given.

5.3.3.1 Design requirements for safety measures

For all laser processing machines, without regard to restricted or controlled access, the following shall apply.

a) The laser machine shall be equipped with protective devices to ensure a safe isolation of the laser beam (e.g. by a safety shutter or deactivation by shutting off the power to the pumping diodes).

b) If human presence in a hazard zone is unavoidable while the machine is functioning (e.g. during service), the machine shall be equipped with an enabling switch of machine motion, laser beam direction and laser beam isolation. See 5.3.3.5.

c) The design of protective devices, such as switches, shutters, beam dissipation devices and deterring/impeding devices, shall meet the requirements specified in IEC 60825-1:2014 and ISO 12100:2010. A single protective device may be used to provide simultaneous protection against more than one hazard.

d) Protective housings (enclosures) are not subject to IEC 60825-4:2006, Annex D, but shall otherwise conform to IEC 60825-4:2006 or IEC 60825-1:2014. Laser guards (not part of a protective housing) shall comply with requirements specified in IEC 60825-4:2006, Annex D.

e) If active guards (e.g. equipped with sensors) are used within the enclosure or guarding the component shall be integrated in the safety control (SRP/CS) of the laser processing machine. Requirements on active guards are specified in IEC 60825-4:2006, Annex D. The manufacturer shall indicate the achieved PL (according to ISO 13849-1:2015) or SIL (according to IEC 62061:2005) and the system reaction time for isolating the laser beam and shall ensure that the passive laser resistance (time) of guard/windows is sufficient (longer) than the system reaction time.

NOTE 1 Passive laser guards: Laser guard which relies for its operation on its physical properties only. They are used, when the physical laser resistance of the material is sufficient for the given inspection time and FEL (see IEC 60825-4:2006).

NOTE 2 Active laser guards: If the FEL cannot be reduced to a value where common guarding materials provide adequate protection in the form of a passive laser guard, an active laser guard can be used (see IEC 60825-4:2006)

NOTE 3 IEC 60825-4:2006, Annex E provides informative guidelines on the arrangement and installation of laser guards, Annex F provides information for assessing the suitability of laser guards.

f) The beam delivery system or parts of a beam delivery system shall comply with the requirements specified in IEC 60825-4:2006, Annex G.

g) Whenever and wherever there are multiple laser sources [e.g. from a back-up laser, energy share multiplex (beam split) or time share multiplex (beam switch)] the safety controls for each respective work station, process zone or laser hazard zone shall be automatically connected or associated with each respective laser source, such that when that station's interlocks or emergency stops or other protective device sensors are activated, no hazardous laser energy can be directed to that station or zone.

NOTE 4 The laser machine can be operated in manual intervention mode under the conditions described under the modes for production, service or setting.

5.3.3.2 Protection against laser radiation hazards during production

The principal hazard zone is usually the process zone but the hazard zone shall be defined as a result of the risk assessment. The risk assessment shall indicate which type of guarding (local protection or peripheral protection) is to be used. The applicable type of guarding depends on the design of the machine and the guards respectively (see also IEC 60825-4:2006, Annex F: Guideline for assessing the suitability of laser guards).

Local protection is a method of guarding to reduce laser radiation and associated optical radiation to a safe level based on a risk assessment (e.g. by means of a nozzle or a small guard fitted close to the beam

focus at the workpiece) without totally enclosing the workpiece, the workpiece support and/or machine motion system.

EXAMPLE 1 Applied for laser marking systems being integrated in a complex packaging machine or bottling line.

Peripheral protection is a method of guarding to reduce laser radiation and associated optical radiation to a safe level based on a risk assessment by means of one or more distant guards (e.g. a protective enclosure or a laser cabin) that enclose the workpiece, workpiece support and, usually, most of the machine motion system.

EXAMPLE 2 Applied for laser cutting machines, micromachining laser machines, laser additive manufacturing.

The type of protection and the requirements on the guarding will depend on several factors, for instance (see also IEC 60825-4:2006, Annex F):

a) the power determining laser parameters, (e.g. laser power, pulse duration, pulse energy, repetition rate, wavelength);

b) the optical elements (for example, focal length), resulting in irradiance or radiant exposure at the work piece or guard;

c) the direction (fixed or variable) of beam propagation with regard to the work piece, (working with static optical elements or scanner optics);

d) the type of machining operation to be realized (cutting, welding, etc.), (e.g. handling or robot system: dimensions, number of axis, laser head);

e) the material and shape of the workpiece to be processed, (e.g. size of the workpiece, shape);

f) the workpiece support, (e.g. manually/automatically, continuous support for e.g. tubes/hoses, discontinuous support);

g) the visibility of the process zone (e.g. type of laser window: active/passive, process viewing by camera and monitor systems).

5.3.3.3 Protection against laser radiation hazards during setting mode (teaching, path programming and programme verification without processing)

During setting mode, human access to laser radiation exceeding the AEL for Class 1 shall be prevented except for laser radiation emitted in the wavelength range of 400 nm to 700 nm when human access to laser radiation shall not exceed the AEL for Class 3R.

NOTE Exposure limits for the eye and the skin of employees in the workplace and the general public are in many countries specified in national laws. The legally binding national exposure limits might differ from the MPEs used in this standard. Therefore, radiation emitted in the wavelength range of 400 nm to 700 nm when human access to laser radiation might be limited to the AEL for Class 2.

5.3.3.4 Protection against laser radiation hazards during service mode

During service mode, human access to laser radiation exceeding the AEL for Class 1 is sometimes unavoidable. Machines shall therefore be designed, and appropriate safety measures provided, with respect to the following four situations (listed in order of preference):

a) servicing takes place outside the laser hazard area (according to IEC 60825-1:2014); no further protection is necessary.

b) servicing takes place in a laser hazard area to which access is controlled in the same manner as during production; protective measures in c) apply.

c) servicing takes place in a laser hazard area (e.g. with open guards that are normally closed during production) but accessible laser radiation does not exceed the AEL for Class 1.

Exposure above AEL for class 1 shall be predominantly prevented by engineering safety measures described in IEC 60825-1:2014, e.g. protective equipment to detect the presence of persons e. g. opto-electronic protective devices (Laserscanner). If parts are integrated in a safety control, requirements specified in ISO 13849-1:2015 and/or ISO 62061:2005 shall be met.

Administrative safety measures (lock-out/tagout: LOTO), e.g. to lock-out (e.g. with a padlock) a laser cabin door so that the door/interlock is open and therefore exposure above AEL for class 1 is prevented by SRP/CS, shall be used as subordinated measure.

d) servicing takes place in hazard zones, for example because opening of guards (normally closed during production) is necessary. In this case accessible laser radiation exceeds the AEL for Class 1. If servicing takes place in the laser hazard area the requirements of 5.3.2.3 shall be met.

The manufacturer shall indicate the effective class of accessible laser radiation as indicated by the AEL when in the service mode and recommended safety procedures for each of these situations.

5.3.3.5 Protection against laser radiation hazard by operating mode selector switch

The operating mode selector switch enables the selection of machine functions characterized by different risk levels with regard to laser radiation hazards; e.g. normal use/automatic mode vs. service mode.

On the basis of the risk assessment the manufacturer shall define requirements on the operating mode selector switch and the authorization control for the operating mode selector switch.

If the mode selection can give rise to unsafe operation of the machine (e.g. by unauthorized or wrong selection of service mode resulting in hazardous accessible emission level (AEL) of laser radiation), the operating mode selector switch shall be lockable and integrated in the safety control of the machine. The requirements on the operating mode selector switch (here PL_r) shall be determined in accordance with ISO 13849-1:2015 and ISO 12100:2010.

NOTE If appropriate, an operating mode selector switch can be applied to avoid manipulation (see also ISO 14119:2013).

5.3.4 Engineering control measures

In the following, engineering control measures with regard to design and controls are listed:

— The manufacturer shall follow general principles for design, risk assessment and risk reduction for laser processing machines explained in ISO 12100:2010.

— The general requirements for the safety of the electrical equipment of laser processing machines described in IEC 60204-1:2016 shall be observed.

— The start/stop controls of a laser processing machine shall comply with the requirements specified in ISO 60204-1:2016 and ISO 13849-1:2015.

— The emergency stop controls shall be designed according to the requirements specified in ISO 13850:2012 and IEC 60204-1:2016.

— Safety related parts of control systems of laser processing machines shall comply with the requirements given in IEC 60825-1:2014, IEC 60204-1:2016, ISO 13849-1:2015, or ISO 62061:2005. A risk assessment shall be performed according to ISO 12100:2010.

— This risk estimation for damage to sight leads at least to a required Performance Level PLr = c or in a Safety Integrity Level SIL = 1. If the accessible irradiance or the radiant exposure exceeds ten times the AEL of laser class 1 as defined in IEC 60825-1:2014, then a Performance Level PLr = d is required.

— Provisions for the safe isolation of the laser beam shall be designed in compliance with IEC 60825-1:2014, 4.3 (reasonably foreseeable single fault condition for normal operation).

6 Verification of the safety requirements and risk reduction measures

The manufacturer shall verify the following.

The verification of the safety requirements and risk reduction measures for the laser processing machine and the validation of the design and the function of the laser processing machine shall be carried out in accordance with relevant standards, see Table 2.

The risk assessment shall be verified to ensure that all reasonably foreseeable hazards and reasonably foreseeable fault conditions are identified and, if necessary, corrective measures have been taken.

The verification and validation of the safety requirements and risk reduction measures includes following measures, but are not limited to

a) visual inspection,

b) practical inspection/functional tests,

c) measurements,

d) observation during operation,

e) Verification of application-specific schematics, circuits layouts and design document,

f) Verification of safety-related application specific hardware and software or software documentation (SRP/CS),

g) Verification of the risk assessment, (incl. evaluations, calculations),

h) Verification of the detailed description, the layout drawings and mounting description,

i) Verification of specification values and information to user.

NOTE See Table 2.

Verification of risk reduction measures against laser radiation hazards is related to different technical issues. Table 2 provides information on the safety requirement/measure, the method of verification/validation and gives reference to applicable standards.

Table 2 — Methods for verification of safety requirements/measures

Subclause	Safety requirements and/or measures	Method for Verification and/or Validation									Reference (Standard)
		a)	b)	c)	d)	e)	f)	g)	h)	i)	
5.1	**Laser classification of machine**										
5.3	Indication of the laser class for every operating mode			x				x		x	IEC 60825-1:2014
5.3.3	Realization of access control to laser hazard area				x	x		x		x	IEC 60825-1:2014
5.3.2.3	Authorization control measures	x	x					x		x	IEC 60825-1:2014
5.3.3	**Safety related performance of guards**										
5.3.3.2	Foreseeable exposure limit (FEL)							x			IEC 60825-4:2006 Or IEC 60825-1:2014

Table 2 *(continued)*

Subclause	Safety requirements and/or measures	Method for Verification and/or Validation									Reference (Standard)
		a)	b)	c)	d)	e)	f)	g)	h)	i)	
5.3.3.2	Protective exposure limit (PEL)			x	x	x					IEC 60825-4:2006 Or IEC 60825-1:2014
5.3.3.2	Design of enclosure/guards free of gaps	x		x	x						IEC 60825-4:2006 Or IEC 60825-1:2014
5.3.4	**Safety related electrical equipment**										
5.3.4.	Design of electric equipment	x	x			x					IEC 60204-1:2016
5.3.4.	Design of stop functions and indication of stop categories		x		x	x					IEC 60204-1:2016
5.3.4.	Emergency stop	x	x			x					IEC 60204-1:2016
5.1 — 5.3.3.5	**Safety related performance of SRP/CS**										
5.3.3.2	Indication of required performance level PL_r and achieved PL (each safety function for isolation of laser radiation)		x			x	x	x		x	IEC 60825-4:2006 Or IEC 60825-1:2014 ISO 13849-2:2012
5.3.3.5	Realization of operating mode selection		x			x	x	x			IEC 60825-4:2006 Or IEC 60825-1:2014 ISO 13849-2:2012
	Safety Labelling										
8	Labelling of Safety signs	x				x		x		x	IEC 60825-1:2014 ISO 3864

7 Information for use

The manufacturer shall follow the requirements of ISO 12100:2010, 6.4, preparing the chapter "information for use".

The manufacturer should consider IEC/IEEE 82079-1:2019.

The information for use (manual) of the laser machine shall at least include the following laser radiation hazards related issues.

The manufacturer shall:

— define the normal use of the machine and all other operating modes intended for the laser processing machine.

— describe the residual risks or the hazards related to laser radiation respectively for all phases of machine life and for every applicable operating mode and shall indicate the level of accessible laser radiation or the laser class (according to IEC 60825-1:2014) respectively.

— advise users of known potential laser radiation hazards by providing a prominently placed warning statement in the user instructions and/or operator's manual.

— include information on laser safety requirements for all operating modes, including if applicable for the setting mode, the manual intervention mode and service mode. This information shall include general notes on

  — technical protective measures,

  — organizational protective measures,

  — personal protective measures, or personal protective equipment, respectively,

— if necessary, specify requirements on the required protective equipment and refer to respective standards; e.g.

  — technical and organizational laser protective measures: IEC 60825-1:2014,

  — laser guards: IEC 60825-4:2006,

  — SRP/CS for safe isolation of the laser radiation: ISO 13849-1:2015, ISO 13849-2:2012 (and/or IEC 62061:2005),

  — laser protective eyewear: EN 207:2017.

— provide sufficient and adequate information how to operate the laser processing machine in other operating modes than the normal use without being exposed to laser hazards; especially if safety equipment is removed or overridden instructions for the use of adequate protective measures including personal protective equipment shall be given.

— define which authorization measures (to enter the laser hazard area) are comprised and have to be followed if access to hazardous laser radiation can be possible.

— if necessary, define the level of qualification of personnel (related to laser safety), gained by training and education and instructions, which is required to select specified operating modes and/or which is required according to the accessible laser radiation or the location (see Table 1), in which the laser processing machine is operated.

8 Labelling

Laser processing machines shall be labelled regarding laser radiation hazards as following:

a) Each laser processing machine shall be equipped with labelling in accordance with ISO 3864 (all parts).

  — Safety signs (prohibition/warning/mandatory signs);

  — Colours, sizes and print styles of the labels shall comply with the design principles for product safety labels according to ISO 3864 (all parts);

  — Laser radiation labels shall be as described in IEC 60825-1:2014.

b) The location of labels shall satisfy the following requirement:

  — the size and location of the labels shall be such as to make the appropriate labels legible from outside the hazard zones without exposing anyone to any of the laser hazards listed in Clause 4.

— if different operation modes make different sets of safety signs necessary (e.g. for normal use and service), it shall clearly be indicated for which operating mode which set of safety signs is applicable.

NOTE In addition to the labelling required by IEC 60825-1:2014, the laser processing machine can, if necessary according to the risk assessment, carry other pertinent cautionary and warning labels (e.g. warning signs about harmful substances or incoherent radiation).

Annex A
(informative)

Potential hazards

A.1 General

This annex gives examples of hazards other than laser-related hazards, which may well need to be considered. The list is not comprehensive.

The requirements of ISO 12100:2010 are applicable to all the hazards listed.

A.2 Inherent hazards emanating from a laser processing machine, but are not subject of this standard:

a) mechanical hazards;

b) electrical hazards;

c) thermal hazards;

d) vibration hazards;

e) electromagnetic field hazards;

f) secondary radiation hazards, such as

   1) hazards generated by ionizing radiation (X-rays),

   2) hazards generated by incoherent collateral (UV, microwave, etc.) radiation produced, for example, by flash lamps, discharge tubes or RF-power sources, and

   3) hazards generated by secondary radiation due to beam effect (the wavelength of the secondary radiation may be different from that of the beam);

g) hazards generated by neglecting ergonomic principles in machine design;

h) noise hazards.

A.3 Examples of laser processing by-products

A.3.1 General

The following are examples of some of the more common by-products of material processing using lasers. These examples are provided for information only and are not comprehensive.

A.3.2 Processing ceramics

Oxides of aluminium (alumina), magnesium, calcium and silicon.

Beryllium oxide (highly toxic).

A.3.3 Processing silicon materials

Airborne Si and SiO debris (respirable; can cause silicosis).