INTERNATIONAL STANDARD

ISO 11553

First edition
1996-09-01

Safety of machinery — Laser processing machines — Safety requirements

Sécurité des machines — Machines à laser — Prescriptions de sécurité

Reference number
ISO 11553:1996(E)

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International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

Foreword

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

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

International Standard ISO 11553 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 9, *Electro-optical systems*, in collaboration with CEN/TC 123, *Lasers and laser related equipment*, and was correlated with IEC/TC 76.

Annex A forms an integral part of this International Standard. Annexes B, C and D are for information only.

Introduction

The Machinery Safety Directive issued by the Council of the EEC 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 International Standard is one in that series.

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

The extent to which hazards are covered is indicated in the scope. Machinery should comply as appropriate with ISO/TR 12100 for hazards which are not covered by this International Standard.

It is applicable to machines using laser radiation to process materials. The purpose of this International Standard is to prevent injuries to persons

— by listing potential hazards generated by machines containing lasers;

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

— by providing references to pertinent standards;

— by 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 — Safety requirements

1 Scope

This International Standard describes hazards generated by laser processing machines, as defined in 3.2, and specifies the safety requirements relating to radiation hazards and hazards generated by materials and substances. It also specifies the information to be supplied by manufacturers of such equipment.

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 601-2-22);

— data storage.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 3864:1984, *Safety colours and safety signs.*

ISO 11252:1993, *Lasers and laser-related equipment — Laser device — Minimum requirements for documentation.*

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

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

IEC 204-1:1992, *Electrical equipment of industrial machines — Part 1: General requirements.*

IEC 825-1:1993, *Safety of laser products — Part 1: Equipment classification, requirements and user's guide.*

3 Definitions

For the purposes of this International Standard, the definitions given in ISO/TR 12100-1 and IEC 825-1 and the following definitions apply.

3.1 machine: Assembly of linked parts or components, at least one of which moves, with the appropriate actuators, control and power circuits, etc., joined together for a specific application, in particular for the processing, treatment, moving or packaging of material. [ISO/TR 12100]

3.2 laser processing machine: Machine in which (an) embedded laser(s) provide(s) sufficient energy/power to melt, evaporate, or cause a phase transition in at least a part of the workpiece, and which machine has the functional and safety completeness to be ready-to-use.

3.3 (preventive) maintenance: Performance of those adjustments or procedures specified in user information, which are intended to be performed by the user for the purpose of assuring the intended performance of the product.

NOTE 1 Examples include replenishment of consumables and cleaning.

3.4 manufacturer: Individual or organization that assembles the laser processing machine. Where a laser processing machine is imported, the importer assumes the duties of the manufacturer. An individual or organization that is responsible for modification of a machine is regarded as a manufacturer.

3.5 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 different from what was envisaged in the original design, or which affects the safety characteristics of a machine.

3.6 process zone: Area where the laser beam interacts with the material of the workpiece.

3.7 production: Phase during which the machine is used as intended, including the following operations:

— loading and unloading of parts and/or materials to be processed; this loading/unloading can be fully or partly automated or manual;

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

3.8 service (corrective maintenance): Performance of those procedures or adjustments described in the manufacturer's service instructions which may affect any aspect of a product's performance.

NOTE 2 Examples include fault diagnosis, equipment strip-down and repairing.

3.9 subassembly: Constituent part needed for proper performance of the laser processing machine. A laser processing subassembly can be of any laser class in accordance with IEC 825-1.

3.10 workpiece: The material intended to be processed; the target of the laser beam.

4 Hazards

The following subclauses outline areas of concern associated with materials processing with lasers.

4.1 Inherent hazards

The following hazards (see ISO/TR 12100) may be generated by a laser processing machine:

— mechanical hazards;

— electrical hazards;

— noise hazards;

— thermal hazards;

— vibration hazards;

— radiation hazards; examples include

  hazards generated by direct or reflected laser beam,

  hazards generated by ionizing radiation,

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

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

— hazards generated by materials and substances; examples include

  hazards due to products which are used in the machine (for example laser gases, laser dyes, lasing gases, solvents),

  hazards resulting from interaction between the beam and the material (for example fumes, particles, vapours, debris),

  fire or explosion,

  hazards from associated gases (see for example 5.3.3) used to assist laser target interactions and from any fumes that are produced; these hazards include explosion, fire, toxic effects and oxygen depletion;

— hazards generated by neglecting ergonomic principles in machine design.

4.2 Hazards created by external effects (interferences)

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

Additional environmental interferences include:

— temperature;

— humidity;

— external shock/vibration;

— vapours, dust or gases from the environment;

— electromagnetic/radio frequency interference;

— source voltage interruption/fluctuation;

— insufficient hardware/software compatibility and integrity.

4.3 Hazards covered by this International Standard

Only radiation hazards, and hazards generated by the laser interaction with materials and substances are dealt with in this International Standard. Information concerning other hazards is given in annex B.

5 Safety requirements and measures

5.1 General requirements

Manufacturers shall ensure the safety or laser processing machines by:

— hazard identification and analysis;

— implementation of safety measures;

— certification and verification of the safety measures;

— provision of appropriate information for the user.

Based on the hazard identification (see 5.2), appropriate safety measures shall be incorporated into the laser processing machine by design and manufacture.

The following requirements shall be satisfied:

a) each manufacturer shall comply with the safety requirements and measures stipulated in this clause;

b) the manufacturer of an installed machine shall be responsible for the compliance of the whole machine, including subassemblies.

NOTE 3 These requirements apply even if the manufacturer and the customer/user are the same legal entity.

These measures shall take into account each hazard listed in clause 4, the results of the hazard analysis and information in annexes B, C and D.

5.2 Risk assessment

A risk assessment shall be performed

a) for all phases of machine "life" (as applicable); for examples see ISO/TR 12100-1;

b) after each modification of the machine by the person or organization responsible for the modification.

A risk assessment includes but is not limited to

a) hazards listed in 4.1 and 4.2;

b) danger zones, particularly those associated with

the laser system,

the laser beam path/beam delivery system,

the process zone;

c) "interferences" listed in 4.2.

The results of the risk assessment shall be duly documented.

5.3 Implementation of corrective measures

Safety measures shall be incorporated in the machine by design and manufacture as specified in 5.3.1 to 5.3.3.

5.3.1 Protection against laser radiation hazards

5.3.1.1 General

The possibility that people be exposed to levels of laser radiation exceeding the accessible emission limit (AEL) for Class 1 shall be eliminated during production (normal or otherwise). Access to radiation in excess of AEL for Class 3A shall be eliminated for mainten-

ance. To satisfy this, the following requirements shall be met.

a) Unauthorized human access to a danger zone shall be prevented by engineering measures as stipulated in IEC 825-1 and ISO/TR 12100.

b) If human presence in a danger zone is unavoidable while the machine is functioning (for example during servicing), the machine shall be equipped with means for direct control of machine motion, beam direction and beam stop (see 5.3.2.5).

c) The design of protective devices, such as shutters, guards, beam dissipation devices, trip devices and deterring/impeding devices shall meet the requirements specified in IEC 825-1 and ISO/TR 12100. In cases of ambiguity or difference of interpretation between ISO/TR 12100 and IEC 825-1, the first two sentences of 5.3.1.1 shall be definitive.

d) One and the same protective device may be used to provide simultaneous protection against more than one hazard.

In addition to the requirements of c), guards shall comply with requirements specified in annex A[1].

5.3.1.2 Protection during production

The principal danger zone is usually the process zone.

At the process zone, one or more guards shall prevent human access during normal production to levels of laser radiation higher than the AEL for Class 1.

The hazard analysis shall indicate which type of guarding — local protection or peripheral protection — is to be used.

Local protection is a method of guarding to reduce laser radiation and associated optical radiation to a safe level — for example 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.

Peripheral protection is a method of guarding to reduce laser radiation and associated optical radiation to a safe level by means of one or more distant guards (for example a protective enclosure) that enclose the workpiece, workpiece support and, usually, most of the machine motion system. The sort of protection will depend on several factors, for instance:

— the direction (fixed or variable) of beam propagation with regard to the workpiece;

— the type of machining operation to be realized (cutting, welding, etc.);

— the material and shape of the workpiece to be processed;

— the workpiece support;

— the visibility of the process zone.

5.3.1.3 Protection during service

During service procedures, 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 danger zones.

b) Servicing takes place in danger zones to which access is controlled in the same manner as during production (for example interlocked cover).

c) Servicing takes place in a danger zone (for example with open guards that are normally closed during production) but accessible laser radiation does not exceed the AEL for Class 1.

d) Servicing takes place in danger 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. [See 5.3.1.1 b).]

The manufacturer shall indicate the class of accessible laser radiation and recommended safety procedures for each of these situations (as applicable).

5.3.1.4 Protection during teaching, programming and program verification

During teaching, path programming and program verification, human access to laser radiation exceeding the AEL for Class 3A should be prevented. If this condition cannot be met, the same requirements as for servicing shall apply.

5.3.2 Control means and circuits

Control means and circuits shall comply with IEC 204-1.

1) Annex A is valid until a standard on guards prepared by IEC/TC 76 is published.

5.3.2.1 Start/stop controls

The machine stop control shall stop the machine (i.e. switch off actuators) and either isolate the laser beam or deactivate laser beam generation. The laser stop control shall deactivate beam generation.

Separate control devices may be provided for the laser system and the rest of the machine.

5.3.2.2 Emergency stop control

The emergency stop control shall comply with IEC 204-1.

The emergency stop control shall

— deactivate laser beam generation and automatically position the laser beam stop;

— deactivate the machine (i.e. actuator power off), and

— switch off the laser power supply and discharge all stored energy.

If a laser device is used for several machines which work separately from one another, the emergency stop control located on one of the machines shall work as above, or

— deactivate the relevant machine (i.e. actuator power off), and

— isolate the laser beam optical path leading to the relevant machine.

5.3.2.3 Interlocks and guard control

When guards (per ISO/TR 12100) are opened or displaced, or safety interlocks are defeated, automatic operation of the machine shall be impossible.

If the design of the machine requires occasional procedures to be carried out with one or more guards open (normally closed during production) and with power supplied to the machine actuators, then an operating mode shall be provided to make overriding of the guard(s) possible.

The selection of this operating mode shall

a) be by means of a lockable mode selector;

b) automatically isolate the laser beam;

c) prevent automatic operation of the machine.

A key-operated switch may be used as the mode selector.

Discrete, deliberate, interlock override mechanisms on removable access panels with safety interlocks (defeatable safety interlocks) shall meet the requirements of IEC 825-1 for such override mechanisms.

The operation mode selected shall be clearly signalled. After this operation mode has been selected it shall be possible to override the beam isolation (i.e. "open" the beam stop) for service procedures.

5.3.2.4 Provisions for isolation of the laser beam

Isolation of the laser beam shall be achieved by blocking and/or deviating the laser beam to prevent it from entering the beam delivery system.

Beam isolation shall be accomplished using a fail-safe laser beam stop (shutter) located inside or immediately outside the laser. A position indicator shall show when the beam stop is in the closed position (i.e. preventing the beam from proceeding).

Suitable easily accessible means shall be provided for locking the laser beam stop in the closed position. A key-control shall be permitted for this purpose.

Additional beam stops may be provided by the machine manufacturer, for example in the following situations:

a) when there are maintenance/cleaning areas present along the beam path (beam delivery system);

b) when one laser device supplies more than one beam path, and there is a need for human intervention in one path while the beam is pursuing one of the other paths.

5.3.2.5 Device for protection when people are inside a danger zone

As stated in ISO/TR 12100-2:1992, subclause 4.1.4, for situations (except production) when human presence in a danger zone is necessary, the machine shall be provided with a device for control of machine motion and laser beam emission, to be operated by the person inside the danger zone. The following requirements shall apply to this device:

— the device shall be provided with a hold-to-run control which, when released, prevents access to radiation in excess of AEL for Class 3A;

— when placed under the control of this device, all machine motions and laser beam emission shall be controllable only from this device;

— if it is possible to enter the danger zone through a door, then it shall be possible to start laser emission using this device only after closing such doors.

5.3.3 Protection against hazards generated by materials and substances

The manufacturer shall inform the customer/user of the materials that are intended to be processed with the machine. The manufacturer shall supply suitable means for capturing the fumes and airborne particles from these materials. The manufacturer shall provide information on the limit values for these materials and for the fumes and particulate matter generated by machining these materials.

NOTE 4 The safe removal and disposal of fumes and particulate matter from the machine according to local, national or regional Threshold Limit Values are the responsibility of the customer/user.

Due regard shall be given to the hazards from associated gases (for example oxygen) used to assist laser/workpiece interactions and from any fumes that are produced. Related hazards include explosion, fire, toxic effects, oxygen excess and oxygen depletion.

Additional information is given in annex B.

6 Verification of safety requirements and measures

General conformance with the requirements of this International Standard, particularly those relating to the presence and positioning of guards and control devices, shall be confirmed by visual inspection.

Correct functioning of control devices shall be verified according to functional tests specified by the manufacturer.

Verification procedures relating to laser radiation levels shall conform to IEC 825-1:1993, clause 9.

7 Information for user

In addition to the requirements of IEC 825-1, IEC 204-1, ISO 11252 and ISO/TR 12100-2, the following requirements shall be satisfied.

a) The manufacturer shall supply pertinent safety-related documentation and data, including correct maintenance and servicing procedures to the customer/user.

b) The manufacturer shall inform the user as to the responsibilities of the user relating to the removal and/or disposal of fumes and particulate material from the machine.

c) The manufacturer shall provide information on the limit values for the materials intended to be processed and for the fumes and particulate matter generated by machining these materials. The manufacturer shall also provide general information about equipment for removal of fumes and particulate matter.

d) The manufacturer shall make available suitable safety-related training to the user.

e) The manufacturer shall advise users of known potential hazards by providing a prominently placed warning statement in the user instructions and/or operator's manual.

The following items should be considered for inclusion in the user's instructions and/or operator's manual:

1) IEC 825-1 specifies protective measures for the primary laser radiation.

The minimum requirement, in the case of potential exposure by a class 3B and class 4 product, is to wear protective eyewear rated for the laser power and wavelength.

2) Some operations, for example welding, may produce intense UV and visible radiation.

The minimum requirement, in the case of potential exposure to this kind of radiation, is to wear appropriate protective eyewear (for example a welding mask).

3) Most material processing applications produce fumes and particles. When processing metals, heavy metal vapours may be produced. These can harm body tissues and organs. When processing plastics, toxic or lethal by-products can be produced.

The minimum requirement, before starting the process, is to

— be familiar with the material to be processed, know what by-products may result, assess their risk to health and

determine what precautions are necessary;

— employ appropriate measures to prevent or control the risk; such measures will normally require positive exhaust of fumes from the process zone and adequate purification before exhaust gases are returned to the atmosphere away from personnel;

— inform, instruct and train operators about the risks, and the precautions to be taken;

— where necessary, monitor the exposure of operators and carry out an appropriate form of surveillance of their health in compliance with local regulations;

— consult a pertinent authority to find out what national, state and/or local regulations must be satisfied before exhaust gases are returned into the atmosphere.

4) Dangerous voltage/current is used to power the laser and its associated equipment. Power supplies can contain capacitor banks which may remain charged for some time after switching the equipment off.

The minimum requirements in the case of repair is to follow the rules for electrical safety practices.

8 Labelling

Local or regional laws for labelling shall be adhered to.

The machine shall be labelled to indicate

— the name and address of the laser processing machine manufacturer;

— the manufacturing date;

— the series or type of machine (if appropriate) and serial number (if any).

The labels shall satisfy the following requirements:

— colours, sizes and print styles of laser radiation warning labels shall be as described in IEC 825-1;

— in addition to the labelling required by IEC 825-1, the laser processing machine shall, after installation, carry other pertinent cautionary and warning labels (for example: "TOXIC FUMES/PARTICLES MAY BE GENERATED BY THIS MACHINE"). The size and location of the labels shall be such as to make the appropriate labels legible from outside the danger zones without exposing anyone to any of the hazards listed in clause 4.

The colour, size and print style of the labels shall comply with the requirements of ISO 3864.

Annex A
(normative)

Guards

NOTE 5 IEC/TC 76 is currently preparing a more complete standard on laser guards.

A.1 Passive guards

A passive guard shall be designed and manufactured from a material making it possible to prevent human access to laser radiation exceeding AEL for Class 1 under worst case conditions for a length of time sufficient for the operator to actuate the Emergency Stop control.

A.2 Active guards

An active guard consists of a guard and a detection device which causes laser emission to stop when impact of the laser beam on the guard is detected or when other phenomena linked to beam impact on the guard are detected.

If the guard is exposed to levels of radiation that can destroy the guard, the system shall be shut off within a time shorter than the destruction time of the guard (i.e. shut-down shall occur before accessible laser radiation exceeds the AEL for Class 1).

Annex B
(informative)

Potential hazards

B.1 Examples of processing by-products

The following are examples of some of the more common by-products of materials processing using lasers.

These examples are provided for information only, and are not comprehensive.

B.1.1 Ceramic processing

Al_2O_3, Mg-, Ca- and Si-oxides; BeO (highly toxic).

B.1.2 Silicon processing

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

B.1.3 Machining metals

From the medical point of view, at least the following metals and their compounds are relevant: Mn, Cr, Ni, Co, Al, Zn, Cu, Be, Pb, Sb.

Medical effects are as follows:

toxic	Cr^{6+}, Mn, Co
allergies, metal fume fever	Zn, Cu
lung fibrosis	Be
carcinogenic	Cr^{6+}, NiO

Beryllium is very dangerous. Heavy metal fumes are created especially when cutting aerospace alloys or Zn-bearing metals.

B.1.4 Cutting plastics

A great variety of potentially hazardous substances can be emitted. At low temperatures aliphatic hydrocarbons are produced, whereas higher temperatures result in an increase of aromatic hydrocarbons (such as benzene, PAH) and polyhalogenated polynuclear hydrocarbons (for example dioxins, furanes). Particular materials can lead to emissions of cyanides, isocyanates (polyurethanes), acrylates (PMMA) and hydrogen chloride (PVC).

Medical effects include:

— toxic: cyanides, CO, benzene derivatives;

— allergens/irritants: isocyanates, acrylates;

— irritation of airways: formaldehyde, acrolein, amines;

— carcinogenic: benzene, some PAHs.

B.1.5 Welding metals

General fume emission is low compared to metal cutting. Heavy metal vapours can be expected.

See B.1.3.

B.1.6 Heat treatment

Generally no significant by-products but some heavy metal vapours may be generated.

B.1.7 Soldering and brazing

Heavy metal vapours, flux vapours and by-products can be expected.

B.1.8 Cutting paper and wood

Standard cellulose by-products, esters, acids, alcohols, benzene.

B.2 Examples of secondary radiation hazards

Secondary radiation hazards include optical radiation from the welding zone, bringing about

— degradation of polymers and emission of poisonous fumes and gases, particularly ozone;

— fire or explosion hazards posed by flammable materials and substances;

— X-rays from plasmas;

— hazard to people from the emitted UV-radiation and bright visible light.

B.3 Examples of mechanical hazards

B.3.1 Moving machine parts

B.3.2 Robots

Robots can punch a hole in a protective housing, damage the laser or the beam delivery system, and point the laser beam at an operator/enclosure wall/viewing window.

B.4 Examples of electrical hazards

B.4.1 Primary hazards

High voltages, stored energy, high current capability.

B.4.2 Secondary hazards

Production of ozone or X-rays from unshielded components under very high voltage.

B.5 Examples of design deficiencies

Poor design or positioning of interlock switches, switch assemblies, interlock circuits, gas lines and gas valves.

Inadequate shielding from the laser radiation of cabling and gas lines.

Annex C
(informative)

Protection against other hazards

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/TR 12100 are applicable to all the hazards listed.

C.1 Mechanical hazards

See the standards from ISO/TC 199, *Safety of machinery*.

C.2 Electrical hazards

The requirements of IEC 204 are applicable.

C.3 Thermal hazards

See EN 563.

C.4 Noise

See ISO 3744, ISO 9614, ISO 11201 and ISO 12001.

C.5 Vibration

See ISO 2631.

C.6 Hardware/software compatibility and integrity

Special requirements may be applicable.

C.7 Protection against secondary radiation

See EN 165-171, EN 207 and EN 208.

Annex D
(informative)

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2) To be published.