Műszaki Tudományos Közlemények vol. 21. (2024) 61–66.
DOI: Hungarian: https://doi.org/10.33895/mtk-2024.21.09
English: https://doi.org/10.33894/mtk-2024.21.09

SAFETY QUESTIONS CONCERNING MANUAL LASER WELDING

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Abstract

Manual laser welding equipment is increasingly used in industry. Unfortunately, the safety regulation of this equipment is not yet fully developed, and in this paper, the authors have attempted to provide a summary study of the safety classes and current standards for laser welding equipment. The harmful effects of laser radiation on the human body (skin, eyes) and the environment are described. The authors also provide protection recommendations on the need to signal the dangers and how to avoid them and summarise the most important rules in ten points.

Keywords*: laser welding, laser safety, diffuse radiation, normal optical hazard distance (NOHD).*

1. Introduction

Today, there are several laser technologies optimised for a wide range of tasks. In some cases, the harmful effects of radiation can be neglected (class 1 and 2 lasers), but in industrial environments with high power densities, the indirect radiation (reflection) in the machining area must be taken into account **[1–5]**. Radiation has been classified, safety requirements have been laid down in standards (EU: IEC 60825-1; USA: ANSI Z136) and compliance with these requirements is required by law **[6]**. The radiation safety requirements for lasers are laid down in several standards, and only the requirements of these standards can be applied **[4, 7, 8]**.

The first laser (Theodore Maiman, Hughes Kuta Lake Institute, California, 1960) was a solid-state laser that excited chromium ions in ruby, which contaminated the corundum (Al_2O_3) with photons. Two years later, the first gas laser (William R. Bennett, Don Herriott and Alfonso Arons Hughes Kuta Lake Institute, California, 1961) was born, in which a He-Ne gas mixture was the laser medium, which was raised to higher energy levels by electrical discharge **[9, 10]**.

Soon after the first lasers appeared, the need arose to study the wavelengths and properties of different laser beams and types. These He-Ne lasers operate in the visible red-light range and were relatively easy to study (using optical prisms), but considerable spectroscopic knowledge was needed to detect the wavelength of each laser. By 1976, in the USA, this knowledge had led to the classification of lasers into categories (ANSI Z136.1: Safe Use of Lasers): four main classes were defined. This American standard was sufficiently permissive that in 1994, in response, the IEC 60825-1 standard was created based on the same classification.

2. Security classes

2.1. Classification according to Standards

The IEC 60825-1 standard takes the following factors into account when classifying laser devices: radiation power (W, mW), wavelength (nm, μm), exposure time (s), type of radiation (continuous mode, pulsed mode). In addition to the four main classes, subclasses are distinguished by a special letter (M).

Class 1 laser devices include those whose wavelength range is not hazardous to human health and which are generally of the closed system type (e.g. CD reader).

Class 1M includes laser devices with wavelengths from 302.5 to 400 nm, which are not dangerous to humans without optical amplification (e.g. laser pointers).

Class 2 includes low power (1 mW) laser devices with wavelengths between 400 and 700 nm. Without optical amplification, they do not require protective equipment, since the automatic blink reflex of the human eye (0.25 s) provides sufficient protection (e.g. laser pointer), the requirements of Class 1 apply.

For Class 2M, the Class 2 guidelines apply, but with the interposition of an optical device, it becomes dangerous to the human eye (e.g.: marking lasers).

Class 3R (3A) laser systems operate at powers between 1 and 5 mW in the visible light wavelength (400–700 nm). During short exposure times (< 0,25 s), they do not endanger the human eye, but they can damage the eye through the collecting lens by maintaining the interaction for longer periods. Warning signs and stickers should be placed on such equipment or in the vicinity of the equipment used, and the use of protective goggles is recommended (e.g., medium-power laser cutting machines).

Class 3B is already markedly harmful to the eyes, even in the case of scattered radiation. It is true for these devices that they operate continuously at power levels between 5 mW and 500 mW (e.g.: industrial/medical laser irradiation). The use of protective goggles is mandatory!

Class 4 laser products can cause eye and skin damage and are even a potential fire hazard. Devices exceeding the limits of the previous class are included here, and the use of protective equipment is mandatory (e.g. industrial material processing lasers) [4, 7, 8, 11].

In order to ensure safe operation, it is necessary to become familiar with the properties of the different laser beam properties. We highlight two main groups of lasers for industrial applications: solid-state lasers (in our case, transistors) and gas lasers (usually CO_2 lasers). The formation of the laser beam is schematically illustrated in Figure 1.

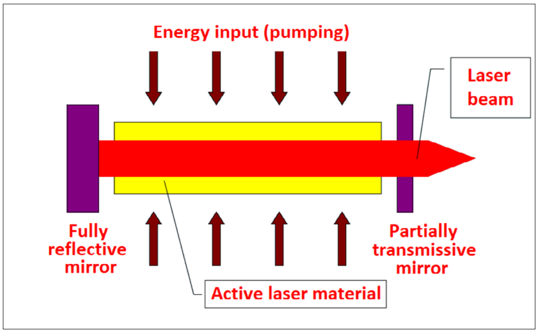

Fig. 1. *Schematic representation of the creation of a laser beam.*

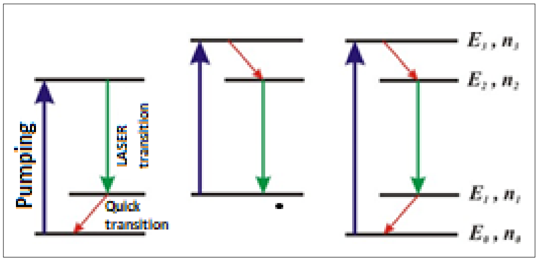

Fig. 2. *Schematic representation of three- and four-level energy systems.* [12]

2.2. Classification by Wavelength

2.2.1. Solid-state laser

This type of laser uses as a laser medium, a rod, a disc or a glass fiber, which are crystals with excellent refractive index ($Y_3Al_5O_{12}$/YAG: yttrium aluminium garnet, YVO_4: yttrium orthovanadate) doped with constituents (neodymium, erbium, ytterbium, etc.). Two energy sources are not sufficient for population inversion to occur since the excited particle immediately tends to reach rest, so systems with 3 and 4 energy sources are typical at the population scale (Figure 2). To date, it is true that this type of lattice is usually equipped with Nd: YAG crystals, in which neodymium ions (Nd^{+3}). are excited to the highest energy level of the system by diode lattices emitting at 808 nm. This is followed by a radiation-free transition, during which the vibrational energy of the crystal lattice is much lower than the energy of the system, resulting in a typical photon beam with a wavelength of 1064 nm. In order to maintain the laser radiation as a circular flux, the neodymium ions have to be brought from the lower energy level of the emission to the so-called hegemonic state in order to bring the active laser beam back down to the highest energy level of the system [1, 5, 10].

2.2.2. CO_2 lasers

In industrial machining, an airy laser medium can be used, usually carbon dioxide (CO_2) for high power density requirements. The gas medium is contained in a quartz glass tube and is excited by an electric field (DC high-frequency excitation). The CO_2 laser operates between the vibration levels of the carbon dioxide molecule. It is the most powerful gas laser and has the highest efficiency (15-20%). The laser medium is a mixture of CO_2, N_2, He or H_2O vapour in a ratio of about 1:1:8. Four-energy arc system: a large number of N_2 molecules is excited by gas discharge, enriched in a long-lived, metastable state, and then energy is transferred to the carbon dioxide molecules by collision. A laser transition is created between their two vibrational states, typically with a wavelength of 10600 nm that can be coupled. Helium gas or water vapour helps to empty the lower laser nozzles during energy transfer (collisional energy transfer) [1, 10].

The excitation induces electromagnetic radiation of different wavelengths depending on the laser beam, which may pose a hazard to human health if the operator is inside the work area. In the following, only protection against scattered radiation will be discussed.

3. Risk areas

3.1. Eyes

The eye is the most sensitive organ of the human body to radiation, and suitable protective equipment must be provided during work. Figure 3 shows how the eye reacts to certain types of radiation.

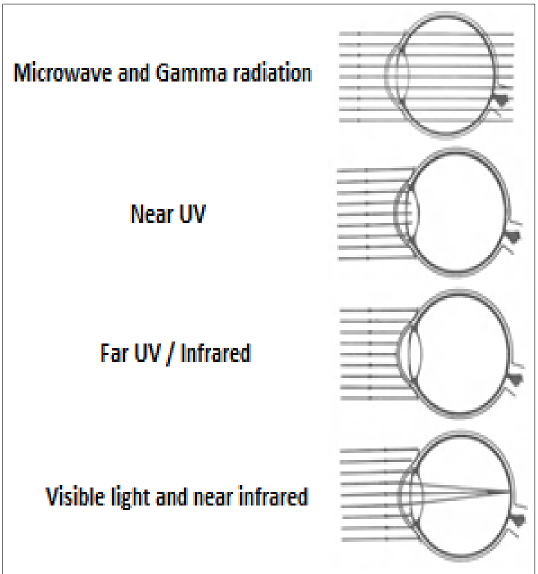

Fig. 3. *Behaviour of the human eye to certain types of radiation, schematic diagram.*

General case:

$$NOHD = \sqrt{\frac{4 \cdot P \cdot \alpha}{\pi \cdot MPE \cdot \omega_0^2}} = (m) \qquad (1)$$

In the case of multimode optical fiber:

$$NOHD = \sqrt{\frac{1{,}79}{NA}} \cdot \sqrt{\frac{P}{\pi \cdot MPE}} = (m) \qquad (2)$$

where:

- P is the laser power (W),
- α is the beam divergence (rad),
- ω_0 is the initial beam radius (m),
- MPE is the maximum permissible exposure (W/m^2),
- NA is the numerical aperture .

Glasses with different refractive index lenses have been designed to protect the eye depending on the wavelengths to which it is exposed. The most widely used standard for such products is MSZ EN 207:2020, but there is an American equivalent (AISI Z136.3), but this standard only specifies the optical density of the glasses, the European one is much stricter. It can be said that there is no product on the market that can be used safely at all wavelengths, so the protective device must be selected for the specific laser machine. In order to ensure protection, it is necessary to be able to determine the safety class of the glasses.

Such devices are tested before they are put on the market, in order to determine the most important metric, the optical density, which indicates their effectiveness against radiation. It is true that the higher this value, the more effective the protection against the radiation, but it is worth determining the minimum safety level, as the cost increases with the optical density. Knowledge of the wavelength, power, beam diameter and mode of operation is required. With this in mind, we can use the table in EN 207:2020 to work out the minimum safety level required to ensure safe operation. In the documentation for safety goggles, there is a diagram showing the transmittance and optical density at each wavelength, so safety equipment must be chosen accordingly. It is advisable to define the normal danger distance (NOHD), which should be communicated to the operator and enforced (1), (2) [2, 7].

3.2. Skin

Human skin protects us from the dangers of the environment, but it is less effective against this artificial exposure. Radiation at different wavelengths can penetrate deeper into human skin, and these will have their own specific damage mechanisms. As shown in Figure 4, there are two cases where there is a big difference: the wavelength of the CO_2 laser penetrates the epithelium, our skin is damaged by thermal conduction, can overheat and possibly coagulate (irreversible).

The small wavelengths of radiation from solid-state lasers reach the deepest layers of our skin, where they evaporate the water in our skin. In addition to the water in the capillaries, there is also iron in our blood, which readily absorbs this wavelength (Figure 5). The superheated iron atoms explode and the 'slag' in the bloodstream can then clog capillaries (particularly in the eyes, which have the thinnest vessels).

In order to avoid these hazards, all parts of the body must be covered and the protective clothing material must absorb the radiation present without damage. Because of the long wavelength of CO_2 laser light, conventional welding clothing (cowhide) provides sufficient protection, while other special materials (composites) must be used to protect against solid-state laser radiation. It is essential to make sure that protective equipment is able to perform its function [3].

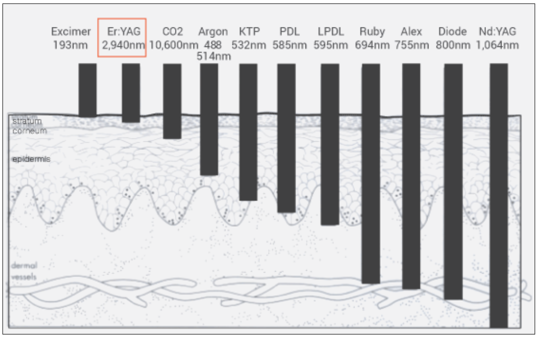

Fig. 4. *Schematic representation of penetration depths of various laser beams into human skin.* [14]

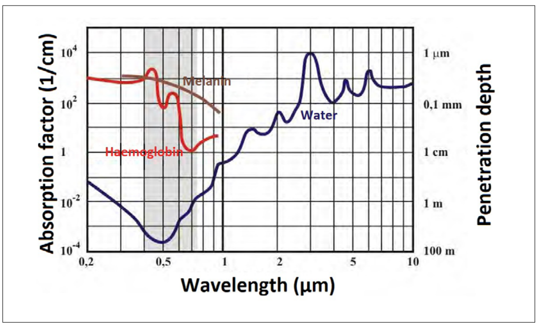

Fig. 5. *Behaviour of fluids in the human body (skin) under various laser radiation types.* [15]

3.3. Environment

Aware of the damaging effects of laser light, the work area must be insulated from the outside world, and suitable materials must be chosen depending on the wavelength of the radiation. The aim is to prevent radiation from escaping: either reflection or absorption of the radiation can be the basic principle. If the latter is chosen, since the device is used indoors, Plexiglas (PMMA) offers protection against CO2 lasers but is transparent to near-infrared waves. For this wavelength, special enclosures, special sandwich panels (graphite between Al-plates), and reflective building elements coated with an absorbing layer on the inside (painting, coating, fixing of other material panels) can be used as a cost-effective solution. Special attention must be paid to the absorption of radiation from the area towards which the light source is directed (thicker light absorbing layer). It is advisable to choose a door design that can operate a safety switch, because only in an enclosed space can laser light be coupled. For safety reasons, anyone outside the work area should be able to see into it in case of a possible complication during the operation of the laser source. For this purpose, windows are available in a similar way to spectacles, for which the control principles for the choice of the spectacle lens apply. The extraction of airborne metal in the environment must be ensured. For material handling reasons, it is advisable to follow LEAN principles to avoid mechanical injuries, and hazard warnings and obligations (e.g. wearing protective clothing) should be displayed (Figure 6) [6].

Fig. 6. *Pictograms representing obligations and hazards.*

4. Safety Recommendations in the NIR Range

The Bánki Donát Faculty of Mechanical and Safety Engineering at Óbuda University plans to install a handheld laser welding machine, which is a fiber laser welding device, with the support of CLOOS Hungary Crown International Kft. Its most important characteristic is that the laser medium is a solid-state material with an increased specific surface area (thin fiber), a maximum power of 2000 W, and it operates at a wavelength in the near-infrared range (1080 nm, or 1070±20 nm) according to the manual). This wavelength range can be dangerous for the machine operator, as 17% of the radiation can penetrate the deepest layer of human skin (the hypodermis), potentially causing the damages discussed previously. What exacerbates the problem is that this radiation can "burn out" the optic nerves of the human eye, creating blind spots for the operator (an irreversible process). Because of these dangers, individual and environmental safety must be ensured. As a solution, safety goggles with a specific safety factor will be selected from specialists, as it is not advisable to economize on this because the brightness of our eyes can be at stake, e.g. Laservision, UVEX, and NoIR **[16, 17]**. In terms of clothing, fabrics containing metal fibers (stainless steel, silver) should be chosen, which are also ergonomic. Jackets and trousers from ISA Technology are recommended, as they protect against radiation and heat effects **[18]**. Gloves made of white-pigmented materials are popular due to the reflectivity of titanium dioxide (TiO_2) **[2, 7]**. The product named "Guide 70" is widely used by those engaged in handheld laser welding **[20]**. In terms of footwear, safety work shoes can be applied. The environment can be designed in a cost-effective way, with sliding doors being used to operate the safety interlock. Lasers operating in the near-infrared range typically release metal vapours; in this respect, industrial ventilation and air purification systems are sufficient.

5. Conclusion

Nowadays, the increasingly popular handheld laser devices pose a danger to the machine operator, as they are in the same enclosed space. Even industrial lasers have their work areas enclosed to protect the operator. When using handheld units, those within the working area are protected by safety clothing, while those outside the area are safeguarded by hermetically sealed enclosure elements. Such devices are "cheap" and easy to acquire, capable of performing multiple tasks (such as cleaning lasers); however, the belief that they are risk-free is a misconception. We must familiarize ourselves with these devices and perform risk assessments of the hazards to ensure, with high expertise, the safe operation of laser equipment. Finally, we must strive to comply with the rules shown in Figure 7 to avoid injuries.

1. **Never look directly into the laser beam.**
2. **Never aim the beam at another person.**
3. **Do not view Class 3R or higher-powered lasers through optical instruments.**
4. **Operate lasers only in designated areas.**
5. **Position the beam path well above or below eye level for both standing and seated positions.**
6. **Always use diffuse reflective beam guards.**
7. **Remove all reflective objects, such as jewelry or tools, from the beam path.**
8. **Only authorized personnel may enter areas with Class 3B and 4 lasers.**
9. **Always wear laser safety glasses when exposed to Class 4 invisible radiation.**
10. **Always implement safe configurations.**

Fig. 7. *Principles for Injury-Free Laser Operation.* **[21]**

References

[1] Christopher Dawes: *Laser Welding*. Abington Publishing, Cambridge, 1992.

[2] David Sliney, Myron Wolbarsht: *Safety with Lasers and Other Optical Sources*. Springer Science+Business Media, New York, 1980.

[3] Halász G.: *Kézi lézeres berendezések biztonságos használata*. Hegesztéstechnika, 35/1. (2024), 41–47.

[4] Bagyinszki Gy.: *Lézerek alkalmazásának technológiai és biztonságtechnikai szempontjai*. XI. Nemzeti és IV. GTE-MHtE-DVS hegesztési Konferencia, Budapest, 2004, 14 –30.

[5] Bitay E.: *Lézeres felületkezelés és modellezés*. Erdélyi Múzeum-Egyesület, Kolozsvár, 2007. https://doi.org/10.36242/mtf-04

[6] 2012. évi I. törvény a munka törvénykönyvéről: 51. § és 86. §
[7] Ken Barat: *Laser Safety: Tools and Training*. Second Edition, Taylor & Francis LTD, Broken Sound Parkway, 2017.
[8] Bagyinszki Gy., Bitay E.: *Lézeres anyagmegmunkálás veszélyessége*. Műszaki Tudományos Füzetek - FMTÜ, 18. (2013) 51-56. https://doi.org/10.36243/fmtu-2013.05
[9] Kovács Z.: *A lézerek működési alapjainak és a lézersugárzás alkalmazásainak tanítása*. Doktori értekezés, József Attila Tudományegyetem, Szeged, 1995.
[10] Buza G: *Lézesugaras technológiák I.*, Edutus Főiskola. Budapest, 2012.
[11] California Institute of Technology: *Laser Safety Manual.* Caltech Environmental Health and Safety Office, California, 2023.
[12] Online tananyag: *Lézerek az Orvostudományban, Szegedi Tudományegyetem*. https://titan.physx.u-szeged.hu/tamop411c/public_html/Lézerek az orvostudományban/23_a_polulciinverzi_s_energiaszint_smk.html (2024)
[13] Seiji Katayama: *Handbook of Laser Welding Technologies*. Woodhead Publishing Limited, Cambridge, 2013.
[14] https://wtlaser-en.com/144 (2024)
[15] Buza G.: *Lézersugaras technológiák tegnap, ma, holnap*. Nagy energiasűrűségű ankét, Magyar Hegesztési Egyesület, Kecskemét, 2023. október 26., előadás-prezentáció. https://maheg.hu/wp-content/uploads/2023/11/Buza_Nagy_energiasurusegu.pdf
[16] https://www.uvex-laservision.de/ (2024)
[17] https://www.noirinsight.com/ (2024)
[18] Meszlényi Gy., Bitay E.: *The Role of Focus Position in Single Pulse Laser Drilling of Highly Reflecting Materials*. Acta Materialia Transylvanica, 2/1. (2019) 61–68. https://doi.org/10.33924/amt-2019-01-10
[19] https://www.isatechnologies.com/ (2024)
[20] https://guidegloves.com/ (2024)
[21] Tóth László: *A kézi lézeres hegesztőgépek biztonságtechnikája*. Nagy energiasűrűségű ankét, Magyar Hegesztési Egyesület, Kecskemét, 2023. október 26. előadás-prezentáció. https://maheg.hu/wp-content/uploads/2023/11/Lezervedelem_PPT_MDTL-231026-Nagy_energiasurusegu_Anket.pdf