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Hazard, risk assessment and safety management in workstations with lasers – theoretical and practical studies

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Abstract
Hazard identification and occupational risk assessment, defined as the probability of occurrence of unfavorable work-related events, is one of the areas of activity for employers in relation to current legislation and standards. Using occupational risk assessment it is possible to design and use workstations properly, respecting workers' health. This article presents an issue related to the use of workstations with laser equipment, which describes the nature of work of lasers and the specific impact of the laser beam on the material. The subject of the analysis is the workstations with a CO_2 laser for cutting polymers and a workstation with a fiber laser for marking and engraving. For the above-mentioned workstations, using a designed checklist, the features of lasers are verified, hazards are identified, and occupational risk is estimated using the risk graph method. The estimated risk at selected workplaces with lasers clearly indicated that special attention should be paid not only to the device, and the negative impact of their laser beam on the human body, but also on the treated materials. The article also draws attention to protective measures, which should be applied at laser workstations to ensure the safety of employees.

Introduction

The appearance of machines in production halls, with various types of components used to process materials, was synonymous with the appearance of an aspect of potential danger to workers. The diversity of machines and technologies has meant that the identification, assessment, and management of the risks posed by machines and equipment at workstations remains a topical issue to this day.

The machinery and equipment used today are a source of various risks. In addition, with the development of technology and the state of knowledge, new equipment is being constructed and popularized. This state of affairs makes it necessary to constantly analyze and assess the potential exposure of operators of such machines and equipment to health impairment or occupational diseases developing in the long term. The risk of health damage is most often the result of incidents directly related to work performance and may lead to occupational accidents or adverse health effects. It is the duty of the employer to ensure safe working conditions, to protect the health of workers and, therefore, to continuously assess the safety condition of the workplace (Pacana, 2019). Management of workplace safety is linked to the assessment of occupational risk, which determines whether a hazard on the job is acceptable or not (Łunarski, 2006). Once a risk assessment has been carried out, it is possible to plan and design safety activities and technical solutions. It is also assessed whether the protections already in place are appropriate and sufficient, which is why various types of alarms, sensors, guards, safeguards, and workers' protective clothing and equipment (OSHA, 2022) are installed in workplaces or on machines.

However, due to the continuous development of technology and the implementation of new, innovative manufacturing technologies, new devices are constructed and used, different from the existing ones, which may also be the source of new factors threatening humans. An example of such a dynamically developing technique is laser technology. Although lasers are not a new invention, as the first lasers appeared in the 1960s, they are constantly being modernized and find application in many fields of science and technology (Thyagatajan & Ghatak, 2010).

In the context of processing engineering materials, lasers are used for surface treatment – hardening, alloying, surfacing, marking, and engraving, as well as for welding, cutting, hollowing, and powder sintering of hard-to-machine materials (Kusiński, 2000; Sołtysiak, Sołtysiak & Wasilewski, 2019). In product design, processes lasers are used for scanning components in, e.g., revers/reconstruction engineering (Ciecińska, 2021) and in production for monitoring, e.g., automated production line, counting products, and quality control by laser measurement and identification of defects in products (Thyagatajan & Ghatak, 2010; Panasiuk & Kaczmarek, 2014; Kaczmarek, Panasiuk & Tomaszuk, 2015). In addition, lasers are utilized for research purposes in a number of measuring devices at test stands for phenomena that are later used in practical applications (IMP, 2022).

Of course, the above description does not limit the fields of application of laser devices. This fact may indicate that the characteristics of lasers are so interesting that even in recent years, in connection with the Industry 4.0 revolution, an intensive change in manufacturing technology is visible in favor of replacing conventional techniques with laser techniques (Industry 4.0, 2017; Ciecińska, Więcek & Gągała, 2018). The increasing ubiquity of the use of laser equipment leads us to analyze the risks and pay attention to important aspects of safety management in the context of workstations with lasers (Nakamura & Carroll, 2011).

Laser activity and phenomena in contact with matter

Laser radiation does not occur naturally in nature. It is generated by a device called a laser (light amplification by stimulated emission of radiation) and can have a wavelength in the range of 180 nm (or shorter) to 1 mm (PN-EN 60825-1). Laser radiation is monochromatic and highly coherent in time and space. The laser beam propagates directionally, can cover very long distances, and can be focused in an applied optical system, which enables the creation of a considerable power density, as stated in (CIOP, 2011), even up to 10^{10} W/cm^2. Laser operation consists of the excitation of the active medium by optical pumping (i.e., via arc lamps, flashes, or other lasers, e.g., semiconductors), electrical pumping (gas discharges or laser diode power supply), chemical pumping, or electron collisions. The excited active medium emits energy in the form of a coherent radiation quantum (Ziętek, 2008). By directing a laser beam, it is possible to induce various phenomena on the surface of the matter on which it falls. The nature of the impact of the beam on matter can be continuous or pulsed.

Impact on construction materials

The "laser-matter" interaction in solids initiates a number of different phenomena, not yet fully understood: ejection of atoms, ions, molecules, and fragments of matter, generation of shock and sound waves, initiation and expansion of plasma, as well as a combination of these processes (Marczak, 2004). In general, the interaction of a laser beam with a solid body is divided into three phases, as shown in Table 1.

The laser cutting analyzed in the following section may proceed with the initiation of reactions (Kołodziejczak, 2015):

Table 1. Phenomena in the three phases of laser action (Marczak, 2004)

Phase	Phenomenon
Absorption	Reflection, penetration, absorption waves, surface shaping effects
Desorption/ Ablation	Evaporation, removal of evaporated particles, boiling, shock, and sound waves
Relaxation	Surface tension, chemical and metallurgical effects (e.g., hardening)

- combustion of the material – the laser beam falls on the surface, heats it in the cutting gap area to ignition temperature, and then oxygen is supplied to intensify the combustion process;
- melting and blowing of material – the laser radiation delivers enough energy to melt the material located on the cutting line, the liquid material is then removed using a technical gas such as nitrogen or argon;
- vaporization of material – occurring at a high temperature, the material at the cutting place is rapidly heated to boiling point and brought to a gaseous state.

In laser marking and engraving, on the other hand, color effects or engraving are achieved by (TROTEC, 2022):

- annealing – the heat effect of the laser beam causes an oxidation process underneath the material surface, resulting in a color change on the metal surface;
- staining – the heat effect generated by the laser beam causes a chemical reaction in the material, which depends on the material composition, resulting in different color shades;
- engraving – the workpiece surface is melted and evaporated with the laser. Consequently, the laser beam removes the material;
- removing – the laser beam removes the topcoats applied to the substrate. Contrast is produced as a result of the different colors of topcoat and substrate;
- foaming – the laser beam melts a material. During this process, gas bubbles are produced in the material, which reflect the light diffusely. The markings will, thus, become lighter than the areas that have not been etched;
- carbonizing – the laser heats up the surface of the material (at a minimum of 100°C) and oxygen, hydrogen, or a combination of both gases is emitted. A darkened area with higher carbon concentration appears.

Impact on the human body

The energy released in the laser beam also affects human tissues. The delivery of energy causes it to be absorbed by the tissues, increasing the kinetic energy of the particles, manifested by vibrations. As a result, the temperature of the tissues increases and, above 45°C, the cell membranes are ruptured and the tissues are sintered. Above 60°C, they are partially vaporized, resulting in tissue necrosis. If the temperature continues to rise to approximately 100°C, the water in the tissues begins to boil; above 150°C, proteins become charred. Effects can be observed not only in the exposed area but also around it, the extent of necrotic changes depends on the duration of exposure. The impact described above is defined as the thermal impact (CIOP, 2011).

In addition, photochemical interactions, for radiation with characteristic wavelengths below 600 nm, cause damage to tissues as a result of molecular absorption of radiation. Chemical reactions take place in the tissues resulting in tissue damage. These reactions occur with short-term exposure but with significant radiation absorption by the tissue. In the human body, tissues with high absorption are the lens and the retina. They can undergo irreversible changes. For the retina, radiation in the range of 400 nm to 1400 nm poses the greatest threat as it enters the eye and is focused on the retina. The pathological changes to the eye can be varied, and they are wavelength-dependent (Table 2).

Table 2. Laser wavelength and pathological changes of the eye (Directive, 2006)

Laser wavelength	Type of eye disease
180 nm – 315 nm	Inflammatory corneal damage
315 nm – 400 nm	Cataract
400 nm – 780 nm	Photochemical and thermal damage to the retina
780 nm – 1400 nm	Cataract, retinal burn
1,4 μm – 3 μm	Corneal haze, cataract, corneal burn
3 μm – 1 mm	Corneal burn

Typical situations where damage to the eye occurs include:

- direct viewing of a beam (also reflected from a smooth surface) or prolonged viewing of a diffuse beam. The retina may become red, irritated, or edematous and visual acuity may deteriorate;
- the reflected beam – e.g., from smooth, mirrored surfaces (i.e., a rolled sheet metal or polished metals), or short exposure to low-power radiation causes tissue damage. In the case of reflection of a beam partially absorbed by the material from which it is reflected, the damage occurs at higher laser power.

Due to the structure of the human eye, and its ability to focus radiation falling on the cornea to a small spot on the retina, it is particularly dangerous for lasers with wavelengths of 400–1400 nm. Calculations (CIOP, 2011) show that a laser beam with a power density of 10 W/m^2 in the pupil plane will be converted to a density of 5 MW/m^2 in the retinal plane (power density may even be increased by about 500,000 times). Radiation outside the specified range should also not be underestimated.

Human skin is exposed to damage to a similar degree as the eye. Also in the case of the skin, a reflected and scattered beam causes the penetration of radiation to a depth depending on the wavelength. Radiation is absorbed and dispersed in skin tissues and can penetrate the epidermis, dermis, and subcutaneous tissue. Tissue heating may occur, giving rise to various pathological effects from hyperpigmentation to redness and swelling to the local coagulation. The wavelengths of radiation from 400 to approximately 1400 nm penetrate deepest into the hypodermis. Sometimes changes are not visible on the surface of the skin, but deeper tissues can be damaged, which take longer to heal and complications may occur during treatment (CIOP, 2011).

Paradoxically, the undesirable consequences of exposure to laser radiation in the processing of construction materials can be used during medical procedures, when changes in tissues are induced in an intentional way. The use of laser scalpels, coagulators, and biostimulation lasers is also very popular (Owczarek & Wolska, 2008; Łabędzka, Jędrusiak & Wasilewska-Michalak, 2011; Chen et al., 2013). In each case, however, the limits of this impact must be defined.

Other risk factors for laser devices

The health safety issues mentioned earlier do not represent the whole subject of exposure to harmful factors in working with lasers. The occupational risk assessment should also study other risks that arise from the use of such technology. These are mainly (Owczarek & Strawiński, 2012):

- hazards caused by the operation of laser equipment: not only laser radiation, but also associated radiation, e.g., high-frequency radiation and X-rays, and electrical hazards;
- risks due to the use of additional substances necessary for processing or those that arise during processing, as well as fire or explosion hazards – use of working gases such as air/oxygen, argon, nitrogen e.g., when cutting polymers (Sims, Ellwood & Taylor, 1993; Kołodziejczak, 2015), formation of vapors, gases in reaction with the processed material (sometimes very harmful, as shown in Table 3; for this reason, cutting, e.g., PVC is not practiced), and sparking and ignition of materials;
- hazards due to the type of room and the workplace environment – unsuitable floor covering materials, desktops, windows that let radiation outside, too low lighting with an unshielded beam (causing excessive dilation of the pupils of the eyes), and shiny rather than matt walls;
- awareness of persons temporarily or long-term connected with the workplace – disregard of the danger, especially in the case of an invisible laser beam, switching off sensors, shielding locks due to apparent convenience of operation, and lack of markings in the workplace.

Due to the different degrees of severity of the effects of the laser beam on the human body, lasers

Table 3. Examples of compounds emitted during laser cutting of selected polymers (Sims, Ellwood & Taylor, 1993)

Material cut	Cut-assist gas			
	Argon		Air	
Polycarbonate	Benzene Toluene Styrene Phenol	Naphtalene Alkanes Benzofuran derivative	Benzene Toluene Styrene Phenol	p-Cresol m-Cresol Benzofuran derivative
PVC	Benzene Toluene Alkanes Styrene	Benzaldehyde Naphtalene Methylmethacrylate Methylcyclohexane Chlorobenzen	Benzene Toluene Styrene Alkanes	1-Propynylbenzene 1,3-Butadienylbenzene Naphtalene
PMMA	Toluene Xylene Alkanes	Methylmethacrylate Trimethylbenzene	Toluene Xylene Alkanes	Methylmethacrylate Trimethylbenzene
PET	Benzene Toluene Xylene Styrene	Alkanes Phenylacetylene Benzaldehyde Methyl phenyl ketone	Phenol Benzene Toluene Styrene	Alkanes Phenylacetylene Benzaldehyde Methyl phenyl ketone
Epoxide-glass	Toluene Xylenes	Z-2-Heptenal Tridecanol Trimethybenzene	Xylenes Alkanes	Tridecanols Trimethylbenzene

have been divided into classes and assigned mandatory safety requirements within the classes. These requirements are specified in a number of documents, including the directive (Directive, 2006) and the standards (PN-EN ISO 11553-1, PN-EN ISO 11553-2, PN-EN 60825-1).

Identification of laser hazard and risk assessment – case studies

Two laser workplaces were selected for hazard identification and assessment: a CO_2 laser cutting station, which is used sporadically but is considered ready for use, and a fiber laser marking and engraving station, which is under construction (Furtak, 2020). Analyzing the work (Czerwińska & Pacana, 2018) in terms of selection of a method for estimating occupational risk, a risk graph (Figure 1) was selected, which estimates the expected extent of damage (S), time of exposure (E), probability of an accidental event (P), and evaluates the effectiveness of protection against the hazard (B). The method of parameter selection and interpretation is given in Table 4.

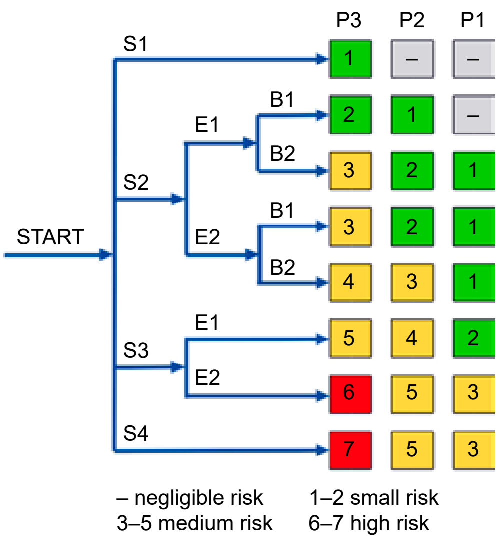

Figure 1. Procedure diagram – risk graph (Pacana, 2019)

Table 4. Parameters and evaluation criteria (Łunarski, 2006)

Evaluation parameters	Criteria
S – foreseeable extent of damage	S1 – slight injury or discomfort S2 – severe or irreversible injuries to one person or more S3 – death of not more than one person S4 – death of more than one person
E – duration of exposure of the worker to the hazard	E1 – rare or frequent occurrence of the hazard E2 – frequent to constant occurrence of the hazard
B – protection against hazards	B1 – effective when assumptions are met B2 – having almost no effect
P – probability of undesired event	P1 – very low probability P2 – low probability P3 – relatively high probability

Cutting station in use – laser plotter CO_2

For cutting, marking, and engraving polymers (e.g., PMMA, PE, PP, and laminates) and natural materials such as leather and wood or wood-based materials, a CO_2 laser plotter, manufactured and distributed continuously in Poland by ATM Solutions Company, is used in the studied organization. It is located in a small room and a flexible ventilation duct is connected to the plotter, which discharges exhaust fumes to a ventilation grid. The operator is equipped with goggles when performing material-cutting operations. Due to the frequent presence of persons in the room and its vicinity, an occupational risk analysis was carried out to adapt the workplace to the existing standards. It should be mentioned that it is not possible to turn the laser on without lowering the cover (Figure 2).

A checklist, shown in Table 5, was designed to identify the device features that affect the potential hazard.

The analysis of the use of the plotter and its technological capabilities, activities, and working conditions, allowed us to identify the risks listed in Table 6.

Figure 2. CO_2 laser plotter: a) general view with closed cover, b) inside after lifting the cover, c) laser head with nozzle on slides, and d) laser tube with propylene glycol

Table 5. Checklist for the workplace – CO_2 laser plotter

Hazard identification list	
Type of laser device	Laser plotter CO_2 ATMS PRO 1390
Device	
Manufacturer	ATM Solutions, Poland
Laser type	Molecular CO_2
Laser class	4
Wavelength	10.6 mm
Power supply	Electricity, 230 V/50 Hz
Additional laser	YES (red point)
Additional laser class	2
Labeling	YES (warning labels complying with requirements)
Beam interaction	
Nature of operation	Continuous
Pulse duration (if pulsed)	–
Laser power	150 W
Desktop height	80 mm
Direction and angle of beam	The laser beam falls in a perpendicular direction on the object in the direction from top to bottom
Working area, mm^2	1300 × 900
Workspace	Lockable, leak-proof (cover allows outside air to be drawn in)
Beam speed/frequency/nature of movement	Max speed of head – approximately 1400 mm/s Continuous travel on two axes on slideways above the worktable
Control	1. from the desktop on the device 2. software (PC + USB connection)
Variable parameters	Power, % Laser head movement speed, mm/s
Additional equipment	
Nozzle correlated with the processing head for blowing material out of the processing zone (air), compressor, liquid cooler, electric cables, and ventilation pipe	
Available personal protective equipment (PPE)	
Protective goggles	
Room	
Size	Small
Walls (color and feature)	Light beige, matt
Flooring	PVC covered with carpet
Windows (type and number)	4, double, 2 non-opening, all without beam ‘exit’ protection
Ventilation	Chimney, gravitational, ventilation riser shared with another room
Operator’s activities	
The operator places the prepared material, in the form of small pieces or sheets smaller than the dimensions of the work area, on the worktable. Turns on the device according to the manufacturer’s instructions. Activates the PC + software, defines the laser operating parameters, closes the cover, and starts the laser. When finished, opens the cover, and removes the manufactured parts.	
Materials to be processed	
Plastics: polypropylene (PP), polystyrene (PS), acrylic (PMMA)	
Substances to be processed	
The device is equipped with a glass tube filled with propylene glycol for cooling the generator	
Substances after treatment	
Solids	Waste from cut material
Liquids	–
Gases	Substances generated by the thermal action of the beam on the material (chemical compounds identified in polymer combustion)

Table 6. Risk assessment card for CO_2 laser cutting

No.	Source of danger	Hazard	Scope of damage (S)	Probability of occurrence (P)	Exposure to risk (E)	Effectiveness of protection (B)	Risk
1.	Reflected laser beam	Effects on eyes and skin	Eye, skin disease (S1)	Very low (P1)	Rare (E1)	Effective when assumptions are met (B1)	Negligible risk
2.	Electrical connections and cables	Electric shock	Burns, disability, death (S3)	Small (P2)	Rare (E1)	Effective when assumptions are met (B1)	Medium risk
3.	Hot object	Skin contact	Hand burns (S1)	Relatively high (P3)	Frequent (E2)	Effective when assumptions are met (B1)	Small risk
		Falling on the floor	Carpet melting or ignition, vapor emissions (S1)	Small (P2)	Rare (E1)	Effective when assumptions are met (B1)	Negligible risk
4.	Processing by-products	Resulting fumes	Poisoning, chronic illness or death (S3)	Relatively large (P3)	Frequent/ permanent (E2)	Not effective in current state (B2)	High risk

Assumptions for B: 1 – the worker has and uses glasses; 2 – the factory connections are installed in the room by a qualified electrician; 3 – the worker (according to the instructions) after turning off the device waits for a while, the material, if it was heated, will cool down; 4 – the device is equipped with the extraction of gas products and discharge to external ventilation, but due to the leakage of the cabin and low efficiency, these gases cause an immediate danger to human health by accumulating in the processing room; in addition, the data shows that the room is relatively small, which increases the concentration of toxic substances in the workplace.

Designed fiber laser marking station

The other subject of the analysis was a stand intended for marking and engraving metals and their alloys, as well as polymers (especially in planned experimental research with stainless steels, aluminum alloys (1xxx, 2xxx, 5xxx, 7xxx), and aluminum alloys with coverings). At the initial, not completed version stage, the radiation source was manufactured in the United Kingdom by SPI Lasers, Trumpf Group, for which the tripod, power supply, software controlling the device operation, and the galvo head were designed and manufactured in Poland by DK Lasertechnik Company (Figure 3). The laser radiation originates from a solid-state source (ytterbium) and is excited in an optical fiber. The laser is cooled by air. A hazard analysis was carried out to identify the hazardous factors and to design a complete machining station.

a) b)

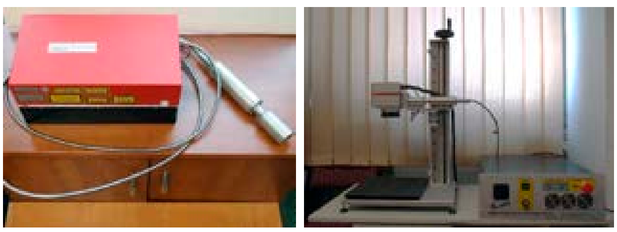

Figure 3. Fiber laser for marking and engraving: a) radiation source: generator, optical fiber, and head, and b) incomplete workplace

A designed checklist, shown in Table 7, was used to identify equipment features and planned operating conditions affecting potential hazards.

The identified hazards, when the fiber marker is operated, are given in Table 8.

Discussion of the results

In the case of CO_2 lasers, process gases emit a suffocating and unpleasant odor that causes headaches and nausea. In the context of each material to be processed, it is essential to know the type of substance emitted under heat and its effect on humans. As shown in Table 3, when cutting popular polymers on the market, polycyclic aromatic hydrocarbons, polychlorinated benzodioxins, and polychlorinated benzofurans are formed. These are very toxic compounds, causing cancer, mutagenicity, reproductive disorders, allergenicity, etc., even in very small doses. Exposure of a worker to inhalation of such substances should be treated as impermissible negligence on the part of the employer and cause for immediate preventive action. The identified possibility of ignition of the material is rather less frequent, due to the fact that the plotter is equipped with an additional nozzle with air blown into the processing zone, which is usually sufficient to extinguish the flame. The other identified hazards are not so drastic in their effects, under conditions that appropriate training is provided, the room is properly organized, supervision is implemented to create a proper work culture, and the plotter manufacturer's guidelines are followed. Legal regulations contained in directives, standards, and many publications on the safety of work with this type of equipment may prove helpful in this matter.

Table 7. Checklist for the workstation – fiber laser marking machine

Hazard identification list

Type of laser device	Fiber laser marking machine
Device	
Manufacturer	SPI Laser, Trumpf Group, the United Kingdom
Laser type	Fiber, ytterbium
Laser class	4
Wavelength	1060 nm
Power supply	Electricity, 230 V/50 Hz
Additional laser	YES (red point)
Additional laser class	2
Labeling	YES (warning labels complying with requirements)
Beam interaction	
Nature of operation	Pulsed
Pulse duration (if pulsed)	10 ns
Laser power	20 W, single pulse energy < 2 mJ
Desktop height	Variable – mobile device
Direction and angle of beam	The laser beam falls in a perpendicular direction on the object in the top-down direction
Working area, mm^2	170 × 170
Workspace	Opened
Beam speed/frequency/nature of movement	Speed Pulse frequency kHz/scanning with hatch
Control	Software (PC + USB connection)
Variable parameters	Power, % Laser head movement speed, mm/s Pulse frequency, kHz
Additional equipment	
(lack of equipment)	
Available personal protective equipment (PPE)	
Protective goggles	
Room	
Size	Not defined – in the design phase
Walls (color and feature)	
Flooring	
Windows (type and number)	
Ventilation	In considered rooms chimney, gravitational, ventilation riser shared with another room
Operator's activities	
The operator places the prepared material, in the form of small pieces or sheets smaller than the dimensions of the work area, on the worktable. Starts the device according to the manufacturer's instructions. Starts PC + software, defines laser work parameters and starts the laser. When finished, he removes the elements from the table.	
Materials to be processed	
Stainless steels, aluminum alloys (1xxx, 2xxx, 5xxx, 7xxx), aluminum alloys with covering	
Substances to be processed	
None – ambient air cooling	
Substances after treatment	
Solids	Metal, metal alloy, and metal oxide dust
Liquids	–
Gases	Substances generated by the thermal action of the beam on the material (e.g., vapors from burnt coatings)

Table 8. Occupational risk assessment card for fiber laser marking before commissioning

No.	Source of danger	Hazard	Scope of damage (S)	Probability of occurrence (P)	Exposure to risk (E)	Effectiveness of protection (B)	Risk
1.	Reflected laser beam	Effects on eyes and skin	Eye and skin diseases (S1)	Relatively high (P3)	Frequent (E2)	In its current state, the ineffective (B2)	Small risk
2.	Electrical connections and cables	Electric shock	Burn, disability, death (S3)	Small (P2)	Rare (E1)	Effective when assumptions are met (B1)	Medium risk
3.	Hot object	Skin contact	Hand burn (S1)	Relatively high (P3)	Frequent (E2)	Effective when assumptions are met (B1)	Small risk
		Falling on the floor	Carpet melting or ignition, vapor emissions (S1)	Small (P2)	Rare (E1)	Effective when assumptions are met (B1)	Negligible risk
4.	Processing by-products	Resulting fumes	Poisoning, chronic illness or death (S3)	Relatively high (P3)	Frequent/ Permanent (E2)	In its current state, the ineffective (B2)	High risk

Assumptions for B: 1 – the worker has and uses glasses; 2 – the factory connections are installed in the room by a qualified electrician.

On the other hand, when designing and commissioning a marking and engraving workplace, special consideration must be given to the emission of metal dust, alloys, and metal oxides into the air. It is necessary to purchase a filter, according to the requirements, which eliminates this factor from the environment. By inhalation, metals can cause damage to the lungs and heart, weakening of the body, problems with the digestive tract, and increases the risk of lung and liver cancer. In its present condition, the device is also not equipped with a shielding, which is the main obstacle for using the workstation. It would be advisable in this situation to determine the MDE – maximum permissible exposure – in accordance with (Directive, 2006). The shielding will not only protect the person from the radiation reflected from the surface of the workpiece, but will also create an enclosed workspace in which a filter can be positioned for safety and complete removal of dust. If it is not possible to purchase a shield, then in addition to the use of goggles, particular thought must be given to the location of the workstation in terms of the number of people in the vicinity, building elements, signage, etc., in accordance with the guidelines.

Conclusions

The availability on the market and the decreasing price, as well as the increasing quality of laser devices, make lasers increasingly more likely to be used in many industries. Although the laser as a light source is no longer a new device, laser devices, drivers, and optical components are changing with the technical progress and are adapted to the processing of new materials. For this reason, theoretically known safe working guidelines should be reviewed and analyzed in a continuous improvement mode. The problem may be the avoidance of responsibility for toxic substances released during processing or, worse, the lack of knowledge about them and underestimation of the health problem.

The analyzed cases show that apparently trivial actions are important to eliminate unnecessary risks. Such activities include the execution of appropriate extraction ventilation with filters appropriate for the treatment, and the analysis of the instructions of the manufacturer of the equipment, which clearly state that the ventilation duct must not be connected to the ventilation grid in the room. The floor in the workplace must not be made of flammable lining, as falling hot material particles may stick to it and cause emission of toxic fumes or fire.

In rooms with lasers, which are used for research and laboratory purposes and to which members of the public, such as students, have access, there should be rules and regulations posted and applied for the use of such laboratories. This will, on the one hand, make outsiders aware of the problems of safe work, as laser radiation may be invisible, and, on the other hand, it will order the performed activities and eliminate non-compliant or dangerous activities. Due to the possibility of lack of technical documentation of the laboratory equipment, or its initial incompleteness, it is necessary to develop a stationary safe work instruction. It is also crucial to make the required markings and purchase and use eye protection equipment according to the provisions and guidelines of standards, as well as shields, sensors, signaling devices, and other safety elements, if required by the manufacturer's instructions or indicated by the conclusions of the assessment of the hazard and the situation in which the work is performed.

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