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HAZARD ANALYSIS AND RISK ASSESSMENT ON LASER CLEANING WORKSTATIONS

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Purpose: The purpose of this article is to present the type of hazards, to study their impact on human safety, to carry out an occupational risk assessment at the laser metal cleaning station, and to establish corrective activities for the safety condition.

Design/methodology/approach: an analysis of the problem of the occurrence of nuisance and hazardous factors during the use of lasers in the technology of machine parts is presented, in the case-study part, the identification and analysis of factors affecting the health risk is carried out, a risk assessment is carried out at the laser cleaning station using the five-step method according to PN-N-18002, the results obtained are discussed, technical and organizational solutions necessary to achieve an acceptable risk condition are presented.

Findings: the developed list of hazards and the risk assessment sheet indicate the need to take measures to minimize the risk. The collected information on working with lasers can be used in the future for job training, creating a safety culture at the plant and reducing the negative impact on the health of employees.

Research limitations/implifications: the analysis carried out has made it possible to develop recommendations in the context of safe work at a workstation designed for laser cleaning of metal surfaces. In the future it is possible, following the example shown, to develop risk cards for laser processing of other types performed on different materials.

Practical implications: The results of the analysis and the developed recommendations for improving the organization of the machining station can be used in other companies in the context of the correct equipment of workstations, selection of individual and collective protective equipment, workstation training, risk management, etc.

Social implications: the article will enable the dissemination of information about the specifics of metalworking with lasers and the promotion of a culture of work safety and good practices at workstations with lasers.

Originality/value: The content presented in the article complements the research on the implementation and use of laser techniques in modern companies with knowledge and practical guidelines in the area of occupational health and safety management. The added value of the article is the reference to laser workstations, which have become increasingly common in recent years and are replacing previous, sometimes obsolete technologies, as well as the possibility of applying methods of analysis and assessment of occupational risk in work with lasers in practice.

Keywords: laser cleaning, hazard, occupational risk, five-step method.

Category of the paper: research paper, case study.

1. Introduction

Occupational risk is the possibility that an employee may lose his or her life or suffer an injury while performing tasks on the job (Kowalczyk, 2010). Health damage or loss of life can occur at the workplace during the performance of work tasks, as a result of work-related processes or adverse events (Klaus-Rosińska, 2023).

Risk can be defined in various ways, such as (Dębiec, 2008) defines it as the chance of loss, the possibility of loss, uncertainty or danger.

Risk is inherent in human life and activity, in its various forms of activity. The characteristics of risk include uncertainty, probability, variability, variation of consequences or undesirable effects (Laska, 2015). According to the standard (ISO 45001:2018), risk is the impact of uncertainty, which is a state of lack of information as to understanding or knowledge of an event, its consequences or probability. Risk is often characterized by reference to potential events and their consequences. In the context of occupational safety, the standard specifies health risk as the combination of the probability of a hazardous work-related event or exposure and the severity of injury and ill-health that may be caused by the event or exposure (prolonged exposure to harmful or hazardous factors) (Pacana, 2019).

An occupational risk assessment is understood as a detailed examination and evaluation of what in the workplace can harm or cause harm to employees. Then, thanks to such an assessment, the employer can check whether the measures used to reduce or eliminate risks are sufficient, and determine whether there is still something that can be done to make the risk as small as possible. An additional reason for conducting an assessment is to eliminate financial losses, organizational problems in the event of an accident at work or as a result of occupational disease, and possible downtime and the need to establish replacements (Kowalczyk, 2010; Dul, 2023).

Risk assessment can be carried out in different ways. Two groups of methods for estimating the level of risk are commonly known:

- quantitative methods - for which data on the number of accidents, occupational diseases, hazardous incidents, employed workers and other statistical data are required to enable reliable analysis;
- qualitative methods - used when there is a lack of data or the use of numbers is not justified; however, detailed identification of hazards is required, due to the fact that risk assessment is performed for each hazard separately. This is a subjective assessment, so the amount of information collected about the position, the activities performed, the materials used and the environment of the position is crucial to the reliability of such an assessment (Pacana, 2019);

- risk assessment methods can be divided into inductive (based on premises in specific cases; from the particular to the general) and deductive (based on logical reasoning over consequences; from the general to the particular) (Rzepecki, 2002).

In turn, from the point of view of evaluation methodology, methods can be distinguished:

- matrix, table-based, e.g. PHA, JSA, risk matrix according to PN-ISO 45001:2018-06,
- indicator-based, e.g. Risk Score, Five Steps,
- graphs,
- others, such as FMEA (Pacana, 2019; Ulewicz et al., 2015).

A number of popular methods for risk assessment are listed in works (Pacana, 2019; Laska, 2015; Romanowska-Słomka, 2008). These include:

- risk matrices, e.g. according to (PN-N-18002) for non-measurable and for measurable work environment factors,
- Preliminary Hazard Analysis (PHA),
- Fault Tree Analysis (FTA),
- Job Safety Analysis (JSA),
- WHAT-IF Analysis,
- Checklist Analysis,
- Hazard and Operability Study (HAZOP),
- Failure Modes and Effects Analysis (FMEA),
- Event Tree Analysis (ETA),
- Risk Score,
- Five Steps to Risk Assessment (5 Steps),
- Safety Review (SR),
- graphs and risk calculators,
- others.

Safety at work is influenced by various primary factors:

- technical factors - the type of means of work, the size and shape of work objects, the technical efficiency of the workplace and equipment at the workplace,
- organizational factors - technologicality of construction, methods and methods of execution, space at the workstation, time standards, interconnection of workstations with each other, transportation, work breaks,
- material environmental factors - microclimate, lighting, noise, vibration, air pollution, radiation, harmful substances

and secondary factors:

- physical load - static, dynamic and monotypic muscles,
- mental load - monotony, intensive thinking, decision-making, information stream,
- occupational safety - general health and safety conditions, protection from hazards, safeguards used (Kawecka-Endler, 1998).

Providing safe working conditions and minimizing risks is a fundamental task of the employer regulated by law. This aspect according to the Labor Code (Code, 2022) is formulated specifically that the employer on duty to protect the health and life of employees by ensuring safe and hygienic working conditions with appropriate use of the achievements of science and technology (Hess, 2023). Those who direct the work of other employees under Article 212 have the duty to (Muszalski, 2007):

- organize workplaces in accordance with the regulations and principles of occupational safety and health,
- take care of the efficiency of personal protective equipment and its use as intended,
- organize, prepare and conduct work, taking into account the protection of employees against accidents at work, occupational diseases and other diseases related to the conditions of the working environment,
- take care of the safe and hygienic condition of work premises and technical equipment, as well as the efficiency of collective protection measures and their use as intended,
- enforce compliance by employees with the rules and principles of work safety.

These provisions are consistent with the Constitution of the Republic of Poland, international agreements of the European Union (Directive), recommendations of the International Labor Organization.

2. Methods

A newly created workstation for fiber laser cleaning of the surfaces of products made of various metal alloys was analyzed. Consideration was given to the requirements of the material working environment - the room, the materials used, the tools, the organization and course of the technological process and the way of organizing work. Hazards were identified according to the recommendations described in (Kowalczyk, 2010; Romanowska-Słomka, 2008; Wieczorek, 2009), among others. When characterizing the position, the following were taken into account:

- planned location of the site,
- the initial phase of use of the stand,
- tasks implemented at the stand resulting from the technological process,
- activities, methods of execution, time of execution of production tasks,
- description of planned tools and equipment,
- qualification requirements (training and authorizations),
- the expected number of people at the position and the presence of people in the vicinity of the position,

- legal requirements and standards in relation to the position,
- probable hazards and their sources,
- possible effects of hazards,
- probable accidents or occupational diseases,
- selected work clothing, personal protective equipment or other means of protection against hazards.

In order to gather information, technical data of the laser device (Laser, 2023), regulations and guidelines of standards, (PN-EN ISO 12100:2012; PN-EN 60825-1:2014), safety data sheets of substances used during the process (Acethone, 2017), scientific and technical literature (Barat, 2008; Chryssolouris, 2013; Sliney, 2013; Weber, 2018) and also interviews and discussions with specialists during external training (Owczarek, 2023) were used. A job description was drawn up for the position, in which the presence of hazards was verified:

- mechanical hazards - related to the impact of physical factors on the worker, the possible consequences of the occurrence of mechanical hazards can be crushing, pulling, hitting, cutting,
- electrical hazards - associated with live parts of the equipment, the possible consequences of the occurrence of electrical hazards are electrocution due to contact or proximity to live parts,
- thermal hazards - associated with parts or tools heated to high temperatures, the possible consequences of the occurrence of thermal hazards are burns, burning of fragments of the human body due to contact with hot surfaces and initiation of fire,
- noise hazards - caused by harmful sound, as a result of which auditory fatigue, headaches, irritability, decreased attention and concentration during work, difficulty in communicating by voice and lack of response to voice signals may occur,
- radiation hazards - related to the specifics of the work of the device: laser radiation and electromagnetic radiation, possible due to, for example, the lack of a procedure for starting the station,
- hazards of materials and substances used at the workplace, touched or inhaled, liquids, dust, gases; as a result of exposure to this type of hazard, it is possible to develop occupational diseases, such as pneumoconiosis, allergies, as well as other diseases,
- hazards associated with the lack of rational organization of the workplace and ergonomics, causing physiological, psychophysical effects, such as strain on the skeletal system, muscles, stress, work under time pressure, etc.,
- hazards caused by the improper condition of surfaces, resulting in slips, falls, injuries.

The classical method on a five-grade scale (PN-N-18002) was used to assess risks. According to the five-grade scale method, risk valuation is carried out according to the degrees given in Table 1.

Table 1.
Risk valuation according to PN-N-18002 on a five-grade scale

Probability of event	Severity of consequences		
	Small	**Medium**	**Large**
Unlikely	Very low risk 1	Low risk 2	Medium risk 3
Likely	Low risk 2	Medium risk 3	High risk 4
Highly likely	Medium risk 3	High risk 4	Very high risk 5

Source: PN-N-18002.

Low severity of sequelae refers to injuries and illnesses that do not cause long-term discomfort and absenteeism from work. It is a temporary deterioration of health, such as: minor bruises and injuries, eye irritation, symptoms of minor poisoning, headaches.

Medium severity of sequelae refers to injuries and illnesses that cause minor but prolonged or recurring periodic discomfort and are associated with periods of absenteeism. These include, for example: injuries, second-degree burns on a small area of the body, skin allergies, uncomplicated fractures, musculoskeletal overload syndromes.

High severity of sequelae refers to injuries and diseases that cause severe and permanent discomfort and/or death. These include, for example, second-degree burns of a large area of the body, amputations, complicated fractures with limb dysfunction, cancer, toxic damage to internal organs and the nervous system as a result of exposure to chemical agents, vibration syndrome, occupational hearing damage, asthma, cataracts.

Events, on the other hand, are characterized as, respectively:

- unlikely - the consequences of hazards should not occur during the entire period of a worker's professional activity,
- probable - consequences of hazards that may occur no more than several times during the period of the employee's professional activity,
- highly probable - consequences of hazards that may occur repeatedly during the employee's professional activity.

Recommendations in the context of the activities are given in Table 2.

Table 2.
Measures for risks identified on a five-grade scale

Level of risk	Type of risk	Recommendations
Very high – 5	Unacceptable	Work should not be started or continued until the occupational risk is reduced to an acceptable level.
High – 4		If the occupational risk is related to work, which is already performed, action to reduce it should be taken immediately. Planned work should not begin until the occupational risk is reduced to an acceptable level.
Medium – 3	Acceptable	It is recommended to plan and take activities aimed at reducing occupational risks.
Small – 2		It is recommended that consideration be given to further reducing the level of occupational risk or ensuring that occupational risk remains at least at the same level.
Very small – 1		No action is necessary.

Source: PN-N-18002.

The severity of the harmful consequences of the hazard and the probability of their occurrence were determined using the following guidelines (Laska, 2015):

- low-harm consequences include those injuries and diseases that do not cause long-term discomfort,
- medium-harm sequelae include those injuries and illnesses that cause minor but long-lasting or periodically recurring discomfort and are associated with short periods of absenteeism,
- consequences of high harm include those injuries and illnesses that cause severe and permanent ailments and/or death,
- unlikely include those consequences of hazards that are not expected to occur during the employee's entire working life,
- probable include those consequences of hazards that are likely to occur no more than several times during an employee's working life,
- highly probable include those consequences of hazards that may occur repeatedly during the period of an employee's professional activity.

There is a requirement to define the boundaries of the workstation and list the identified risks, this information was collected at the initial stage of risk estimation.

The analysis was conducted during the start-up phase in a situation where the existing workstation was replaced by a laser.

3. Results

The cleaning operation of materials made of steel has so far used a sandblaster and mechanized equipment with embankment tools (hand grinders, sandpaper). The significant inconvenience and labor intensity of the process led to the decision to change the technology and use a laser device. As a result of the analysis of the new situation, a job guideline was developed along with an occupational risk assessment.

1. Workstation characteristics and location

The laser cleaning station consists of a workbench with a laser device placed on it. The device consists of a workbench on which the parts to be cleaned are placed, a galvo head connected to a resonator, a guide along which the head and resonator move, and a separately standing power supply unit with a generator. The power supply and resonator are connected by a flexible fiber optic cable. Next to the laser device is a desktop for a computer with software controlling the device. On either side of the table there are elements of the workstation equipment - a desktop for depositing finished products and a tool cabinet. The worker uses his hands to move the products into the machining zone himself, and after finishing the machining, he puts them back on the pallet.

The position is planned to be located in place of the previous locksmith position under an outside window, within the production hall adjacent to other positions (Figure 1), on the first floor, in one of the plant buildings. Both operators of other machine tools and customers can enter the production hall to consult orders.

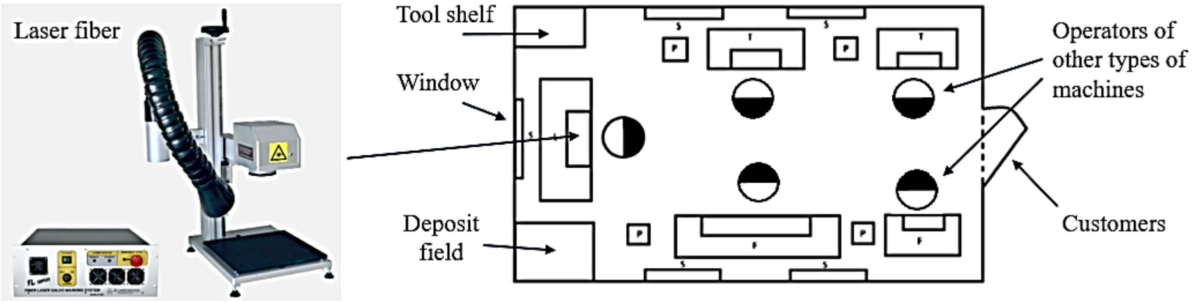

Figure 1. Scheme of the location of the laser station.

Source: own.

2. Characteristics of a laser device

The fiber laser used for cleaning metal surfaces from layers of corrosion, old paint, varnish, glue residues and other layers is a class 4 laser. The device is equipped with a second, additional 2 class laser.

The machining laser is characterized by the following parameters: wavelength of 1064 nm (Ytterbium), power of 20W, pulse frequency in the range of 1÷4000 kHz, maximum pulse energy up to 5 mJ, pulse duration of 2 ms, air cooling, power consumption of maximum 350W, power supply 230V-50Hz, operation at a temperature of 10÷35°C (Laser, 2023).

3. Materials and work resources

The operator performs work operations using a laser and a computer with a screen monitor; work is performed standing or sitting at a work table. Parts to be cleaned are brought in by forklift on a pallet and stored near the operator's seat. The operator uses acetone to pre-clean the surface of the product.

4. Qualification requirements

Expected to have at least secondary technical education, no medical contraindications to work in a laser workstation.

Initial health and safety training on admission to work, periodic training, workstation training.

5. List of hazards and their analysis

Class 4 lasers are defined as dangerous to the eyes and skin, including when interacting with scattered radiation. The radiation from this laser is invisible. Class 4 lasers are those with a power of more than 0.5 watts and are also a fire hazard (PN-EN 60825-1:2014). An additional, so-called guiding laser, is a class 2 laser. A laser of this class is defined as safe during momentary exposure, looking into the beam is a danger to the eye. It is a low-power laser (up to 1 mW) (Owczarek, 2023).

Based on the analysis of the class of lasers and the specifics of the workstation according to the above description, risks were identified:

- eye palsy and possible eye disease of the operator, as a result of exposure to laser radiation directly and as a result of reflection from smooth and shiny surfaces (walls, desktops, floors) and as a result of the passage of the beam through unprotected windows,
- paralysis of the eyes of bystanders in the vicinity or directly on the job stand,
- photochemical aging of the skin and/or burns as a result of direct exposure of the beam, e.g., to the hands of the operator, and to a lesser extent, to the body of other people in the vicinity of the working device,
- chemical agents - inhalation of acetone fumes during preparatory work,
- inhalation of fumes and dust during laser processing,
- fire hazard due to thermal effects of the laser beam,
- electric shock,
- work under stress due to the position of the body - the employee remains with his back to other people in the hall,
- work under time pressure in a situation of accumulated orders,
- microclimate - work in the vicinity of other jobs - dustiness, high temperature, lack of ventilation,
- biological factors - contact with people from inside and outside the plant,
- possibility of burns in contact with hot objects.

6. Occupational risk assessment

An occupational risk assessment card was developed for the analyzed position using the five-step method shown in Table 3.

Table 3.
Risk assessment sheet for the designed laser station

No.	Type of hazard	Source of danger	Possible consequences (severity of consequences)	Probability	Risk
1.	Direct laser radiation	Device on the workstation	Eye burns, retinal damage, corneal charring (*medium*)	Small	Small (2)
			Skin burn, skin breakage (due to shock wave) (*medium*)	High probable	Large (4)
2.	Reflected laser radiation	Device on the workstation	Eye damage, glare effect (*medium*)	High probable	Large (4)
			Skin photoaging (*small*)	Probable	Small (2)

Cont. table 3.

3.	Chemicals - acetone	Preparatory work on the station	Eye irritation (fumes, blurring), pain, tearing, redness (*medium*)	Probable	Medium (3)
			Skin irritation, allergic rash, dryness, cracking (*small*)	Probable	Small (2)
			Due to inhalation of vapors: nausea, vomiting, drowsiness, fatigue, dizziness, loss of consciousness (*large*)	High probable	Very large (5)
			Due to ingestion: irritation of mouth, throat, stomach (*medium*)	Low probable	Small (2)
			Fire and explosion hazard (*large*)	Low probable	Medium (3)
4.	Metallic dust and fumes during laser processing	The process of metal laser cleaning	Respiratory problems, throat irritation, asthma (*large*)	High probable	Very large (5)
			Chronic problems due to particles entering the bloodstream, possible carcinogenic effects, internal organ disorders (*large*)	High probable	Very large (5)
5.	Electric shock	Working with the device under voltage	Tissue burn, pain, muscle spasm, disturbance of vision, hearing, sense of balance, loss of consciousness, cardiac arrest (*large*)	Low probable	Medium (3)
6.	Fire, explosion	Beam interaction with the material	Burn (*large*)	Low probable	Medium (3)
7.	Working with a screen monitor	Computer on the stand	Eye strain (*small*)	Probable	Small (2)
8.	Stress	Work organization and workplace location	Headache, fatigue, irritability, distractibility (*small*)	Probable	Small (2)
9.	Unfavorabl e microclima te (mainly dustiness)	Neighboring stands	Fatigue, irritation of the respiratory system, coughing (*small*)	High probable	Medium (3)
10.	Hot surfaces of the product	Holding the product after processing	Redness, burning of the skin (*small*)	Probable	Small (2)
11.	Static load	Long-term work in a sitting position	Fatigue, muscle pain, back pain (*small*)	Low probable	Very small (1)
12.	Dynamic load	Long-term work in a standing position	Fatigue, muscle pain, back pain (*small*)	Low probable	Very small (1)
13.	Biological factors	People in the close vicinity of the stand	Seasonal infectious diseases (*small*)	Probable	Small (2)

Source: own.

4. Discussion

Special care should be taken when working with a laser. The laser, as a source of light, differs from typical surrounding sources. The radiation beam is coherent, monochromatic, characterized by significant energy per pulse and power density (in the context of the fiber laser under review). The hazards are not only related to the radiation of the beam, but there are other hazards, such as electrical or from the interaction of energy with materials (such as vapors and gases).

As a result of the analysis, it was concluded that the stand in its current state could not be used. Of the twelve types of hazards for which twenty possible effects were identified, high and very high risk levels (2 and 3, respectively) were established for five situations. Work on the post must not be undertaken, and corrective action must be initiated immediately if the post is to be used in the near future. Work can be started after the risk is reduced to an acceptable level. Five risk situations are rated at medium risk level, it is admittedly acceptable, but measures are recommended to reduce the negative impact on health. It should be noted additionally that the problems of high and very high risk concerned the newly implemented laser cleaning technology and the use of a chemical substance.

From the analysis of hazards, there are specific tasks directed to the employer, who is responsible for safe working conditions. The protection of the worker directly on the job, but also of other people who may be exposed to the impact of various factors associated with the switched-on laser, requires consideration of a number of aspects. The first aspect relates to the device, which in principle should be safe. The metal cleaning zone should be shielded by an enclosure and equipped with a filtration system. The benefits will be manifold: the shielding will prevent the beam from affecting the operator's body, the risk of eye and skin problems will be reduced. Filters and exhausts will prevent harmful particles from being emitted into the environment, from entering the human body or settling on workplace equipment. The risk of chronic and dangerous diseases and environmental pollution will be eliminated. The use of chemicals in connection with activities performed in the technological process poses an additional risk. The combination of two hazard factors, that is, the laser beam and a readily flammable substance, can cause an escalating event, such as a fire or explosion. It is not uncommon for sparks to occur in the laser cleaning process, hot metal particles can adhere to and thermally affect other objects. It can additionally be concluded that both the health risk to the operator and bystanders is associated with the need to start organizational work.

The aforementioned chemicals, which cause health and fire exposure, require the use of proper packaging, the implementation of storage rules within the workplace, as well as explosion-proof ventilation and emergency equipment. Mention should be made of properly selected fire extinguishing agents, face and eye washers located in the immediate vicinity of the station. Organizational issues also apply to elements of the device's surroundings: to minimize the risk of the beam bouncing or exiting through windows, remove shiny surfaces, paint the walls with light matte paint, cover the windows, use impermeable screens or partitions, and use high-intensity lighting. Then the risk of the beam penetrating the eyes of the operator and bystanders will be minimized. The rules for working with lasers indicated in PN-EN 60825-1:2000 standard, among others, additionally talk about marking the entrance to the place where the laser is working, so in the case under study it will be recommended to separate the laser cleaning station from the other stations, and to make the recommended installations and markings.

The final element in improving working conditions (after the protected equipment and collective protection devices) is personal protective equipment. It should be recommended to use protective goggles adapted to the wavelength of the laser beam, gloves, protective clothing and a respirator when working with chemicals prior to cleaning. Then you can expect to minimize the risk of harm to the health of all people in the vicinity of the site.

In the case of the investigated position, musculoskeletal loads, working under time pressure and possible transmission of pathogenic germs are of lesser importance, one can consider rationalization of the activities performed, division of activities into work for several employees or variation and variety over time.

5. Summary

The results of performed analysis can be used in various ways. In the first place, paying attention to issues of risk minimization can be used to gain knowledge about the specifics of working with lasers, develop sensitivity to new processing technologies and the ability to identify various hazardous factors. It should also be noted that in the case of the use of class 4 lasers, there is an obligation to appoint a laser safety inspector at the plant. So, issues of safe working conditions go beyond the position and also involve personnel matters. This aspect can also be enriched by the results of the analysis, you can use the described issue for job instruction and training. Choosing to deal with unacceptable risks, the decision to improve working conditions, supports proactive management and helps prevent losses. In the long run, not only will working conditions improve, but also employee awareness will increase, a proper work culture will be created, and the number of accidents or near misses may decrease.

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