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The use of quality management tools to ensure safe working conditions at CO_2 laser workstations

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Abstract

Dynamic development of various technologies replacing existing, difficult or in various ways arduous, is the reason for replacing equipment with modern ones. New equipment may be associated with a different power supply, a different way that the construction materials are processed or the tools used, than the previous one. Then arises a need to re-examine whether the working conditions at a workplace are safe, what onerous and hazardous factors are associated with the work. An example of such a technological change could be a laser processing, when equipment using a concentrated energy stream, properly controlled, produces a specific effect on materials. However, along with the benefits of the new technology, come also many risks, such as the effects of radiation on matter and the human body, electricity, fire hazards, the problem of toxic emissions and others. This paper presents the problem of ensuring work safety at a newly commissioned CO_2 laser station. Technique of brainstorming was used to identify and analyze the working conditions and types of hazards. These may be different from what was previously known, partially known, or even unconscious. Ishikawa diagram was developed and shown to be an effective tool for detailing and structuring problems in relation to safety. In the case of a technical problem, a poka-yoke solution to eliminate the hazard was proposed. Problems occurring at the workstation during machining and related to its operation were assigned, using the affinity diagram, to specific departments of the company, according to its work organization, which can significantly facilitate the management of the work and employees of the different departments in the future, in order to ensure safe and hygienic working conditions.

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1. Introduction

According to the current legislation, the employer is obliged to provide employees with premises that meet the requirements for safe and hygienic working conditions, as well as workstations that are properly prepared for the work to be performed (Badri, 2018; Salguero-Caparrós, 2022). Workplaces and entire facilities should be equipped with equipment preventing pollution or contamination to a degree, which would not be harmful to health, air, land and water, caused by chemical, radioactive or biologically infectious agents in connection with the production carried out (da Silva, 2019; Seňová, 2023). CO_2 laser under analysis, belongs to Class 4 lasers, which are defined as dangerous to the eyes and skin, also while interacting with diffuse radiation. Laser radiation can be visible or invisible. Class 4 lasers are those with a power of more than 0.5 watts and are also a fire hazard (EN 60825-1:2014).

Additional one, the so-called guiding laser, is a Class 2 laser. 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 1mW) (Henderson, 2004). Analysis of the class of lasers instruct the employer to provide guards, safety devices for bystanders in the vicinity of the laser workstation, to install signaling that informs of the laser's operation, as well as to equip the employee with safety glasses and to ensure that the workstation and its surroundings are safe due to the laser in operation. These specific requirements, in conjunction with the fire risk, are additionally related to the need to demonstrate care for the materials that are in the immediate vicinity of the device, such as carpets, window coverings, and desktops. Additional aspect of safety is the analysis of windows so that they are not permeable and analysis of lighting, which should be as bright as possible for maximum constriction of the lens of the human eye (protective reflex against radiation), as well as the provision of firefighting equipment and appropriate clothing (gloves, blouses) (Barat, 2006). All of the aforementioned aspects of safety are the focus of health and safety services and sometimes laser safety officers that represent the employer in health and safety matters (Barat, 2009; Çalış, 2019).

Analysis of the risk of injury or other accidental event is most often referred to the equipment used in production (Małysa, 2023). Indeed, in case of lasers, the direct cause of accidents or occupational diseases is the laser beam. This beam is coherent, monochromatic, and operates on a pulsed or continuous mode. It is characterized by a certain wavelength of radiation and energy. Looking into the laser beam, the impact of the beam reflected from reflective surfaces (countertops, walls, sheet metal, etc.) can contribute to thermal hazards (for the eye - burns, the formation of furrows on the retina, coagulation of the retina or cornea, charring of the cornea; for the skin - tissue burns, charring, coagulation or the occurrence of an electromechanical effect, i.e., tissue disruption due to the shock wave). Second type of hazards are photochemical hazards (redness and swelling of eyes and skin, cataracts, eye and skin tumours, retinal damage, keratitis or retinitis, photoaging, burns) (Edwards, 2002; Regulation, 2010; EN, 2017).

Somewhat neglected area when performing production work with lasers is the occurrence of other factors, called secondary or indirect factors, resulting from the effects of the concentrated energy beam on matter. This problem, especially with regard to polymer processing and the occurrence of intensive toxic emissions, was discussed in (Ciecińska, 2022). Obtaining structured results from the analysis of the causes of hazards occurring at the workplace requires the use of tools to collect the available data and assign them in an appropriate manner (Luca, 2017). Various tools and methods are used in companies to manage quality, safety and other problems (Ilie, 2010; Priede, 2012, Haddouch, 2022). Article's goal is to indicate that various solutions of the problems are possible and needed, even if they are not directly related with occupational safety and health. They can be a way to identify causes of other, nonobvious and not easy problems. Presented work proposes the Ishikawa diagram and affinity diagram as effective tools for designing and managing safe laser workstations. Ishikawa Diagram is a simple graphical instrument to understand the causes of different defects is used to analyse the relation between a problem and all possible causes (Chądzyńska, 2017; Luca, 2016; Stefanovic, 2014; Ghatorga, 2020). Affinity diagram, on the other hand, is a way to actively work as a team and enables the logical ordering of the many different reasons why one situation occurs and not another. Thanks to the affinity diagram, it is possible to systematically improve the state of safety, to show the necessary work to be done, to use the individual qualities of the people in the team, such as creative thinking, foresight, planning skills, and to delegate work to the right departments of the company, etc. (Mizuno, 2020; Woźny, 2017).

2. Identification and analysis of hazards in working with CO_2 lasers

2.1. Characteristics of the workstation and performed activities

Problem was considered under simulated production conditions in a company when a new station for CO_2 laser processing of plastic parts was commissioned. People in the vicinity of the laser began to complain of headaches or dizziness, sometimes indicating malaise, nausea and a tendency to vomit. Some said they found the odor wafting through the room "irritating", "difficult to tolerate" or "suffocating". Initially, the problem was downplayed and no action was taken, as the stand had not been used much before, operating as a test (pilot) stand. Room was ventilated intensively. It was only after an incident during the making of a component that more attention was drawn to the problem. At that time, while cutting out polycarbonate parts, a sheet lying on the table of the laser machine caught fire, and the employee, wanting to save the machine from destruction, threw the burning sheet onto the floor, which in turn caused the carpet to catch fire. Fortunately, there was no fire at the time. Additional stimulus to analyse the working conditions at this station was the urgent need to increase the technological capacity with a production line of not one, but five such stations. It was then considered that tools known from quality management would be helpful.

Basic information about the laser station and the activities:

- the equipment - a Class 4 CO_2 laser, 10600 nm, 30W power, with an additional Class 2 laser remote control, with galvo head, equipped with a work desk; the laser is controlled using a computer and intuitive software (SPI, 2014); laser is built from a radiation source manufactured by SPI - Trumpf, and a galvo head, a support, a working table ordered or manufactured and assembled in-house from separate commercially available components (galvo head, profiles, fasteners, controllers, electronic components, etc.). Control software is developed by the company's own IT programmers. Device has no enclosure separating the environment from the working area and protecting it from the effects of radiation.
- type of processing - currently cutting, planned engraving and marking;
- materials - polymers, leather, wood and glass;
- location - at the test bench stage, the machine is in a small room, possible placement in a larger hall, as well as increasing the number of workstations;
- work method - the employee picks up the material, places it with both hands on the small desktop of the device, then starts the laser, checks the focus of the beam, starts the program and supervises cutting, marking or engraving. If necessary, the material is supported by the hands. Worker should wear safety goggles and gloves while working.

2.2. Identifying factors affecting quality of work and sense of safety

There are two types of hazards in the literature: beam hazards and non-beam hazards. The first group includes accidents resulting from the direct impact of the beam on the skin or eyes. In the Fig. 1 the diagram of these problems and risk is shown.

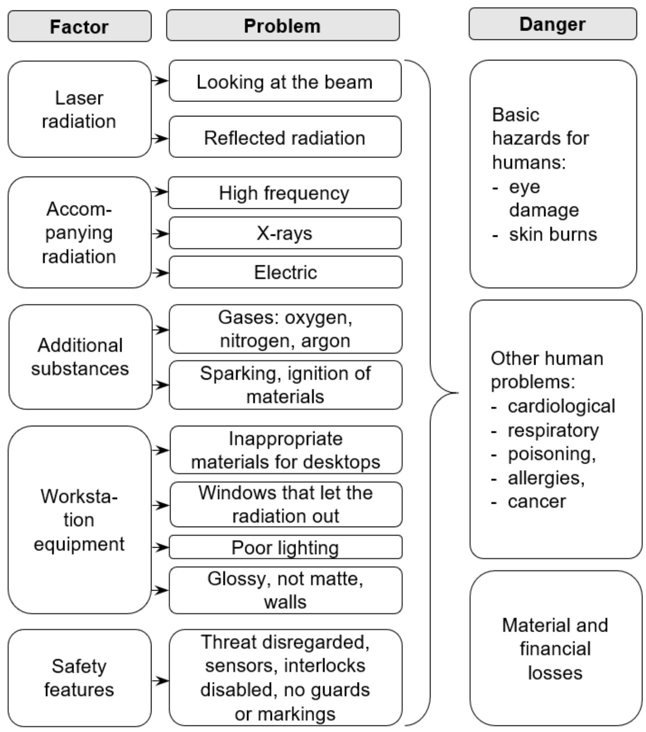

Fig. 1. Risk and impact diagram

In the case of CO_2 lasers, the beam is invisible, but the emitted infrared radiation can lead to damage to the retina, cornea of the eye, cause glaucoma, cataracts and lead to blindness. Exposure to radiation can also be harmful to the skin, causing burns and hard-to-heal wounds. Energy beam can also be glanced off smooth and shiny metal surfaces, glass or mirrors. These reflections, which are also invisible, can be a danger not only to the laser operator, but also to bystanders. For this reason, care must be taken to ensure that employees are equipped with adequate glasses and clothing. Non-beam hazards include hazards resulting from the laser operations. Electrical hazard should be distinguished here, as a CO_2 laser requires a high-voltage electrical system to generate the laser beam. Hazard is related to the possibility of an electric shock and short circuit in the installation. It can lead to a fire hazard as a consequence. Fire at a CO_2 laser station can also occur due to thermal phenomena during processing. The heat can ignite workpieces, other flammable items of equipment, or nearby items on desktops or floors. CO_2 laser cutting, engraving or marking produces fumes and particles. Vapours may contain harmful chemicals and should not be inhaled by workers. Particles accumulating in the working area can be a fire hazard. The interaction of the laser beam with the material being processed can vary depending on the type of material. Some materials may release toxic vapours, cause unexpected chemical reactions or produce contaminants that cause both health problems and damage to equipment (e.g. release gases that cause lens tarnishing, corrosion). It follows that the workplace should be adequately and intensively ventilated, as inadequate ventilation leads to health damage, equipment damage and fire hazards. In addition, attention must be paid to keeping the workstation in working order. Maintenance, set-up, service work can expose to laser radiation, electrical hazards, fire hazards. It is essential that such work is carried out by trained people who are aware of the dangers. Service technicians sometimes take the temporary option of disabling interlocks and safety features. When handing over the laser to operators, care should be taken to ensure that all technical safety measures are operational and active (no missing markings, stops). The laser workstation in the described production conditions is not isolated. The CO_2 laser can generate electromagnetic radiation (so-called associated radiation), which can disrupt electronic equipment or communication systems in the vicinity of the station. These must therefore be adequately shielded. Finally, the human factor stands out as a non-beam hazard. Routine, haste, lack of knowledge, mess, leaving flammable substances in the vicinity of the laser, lack of screens, glasses, clothing, masks, filters resulting from human negligence can cause damage to health, accidents or destruction of property.

Brainstorming technique was used to discuss the issues and identify the risks. Question posed was "Why did the fire emergency occur and was it unique (in terms of the type of hazard) to the CO_2 laser station?". Team was composed of a plant president, laser operators and IT specialists, an electronics engineer and a provider and a quality controller (10 people in total), the leader of the group was the laser operator with the longest experience. Team members formulated a number of observations, doubts and potential or observed causes of the hazard, all were listed in the order of report on the board:

- worker's little experience in the job,
- lack of skill on the part of the worker in the selection of machining parameters,
- lack of skill when starting the machine,
- worker does not know which parts of the machine to switch on and in what order, especially - whether to switch on the fan/exhaustor,
- some forget to switch on the exhaustor,
- parts were cut without knowing the effect of concentrated energy on plastics - maybe the process was too intensive?
- if there had been no carpet on the floor, there would not have been a fire,
- processing of some plastics causes extreme discomfort, but the workers do not know which ones (plastics),
- if the plastic started to burn while lying on the machine table and the worker did not throw it on the floor, the laser head would have been damaged and biting and poisonous black smoke would have escaped from the burning plastic in quantities exceeding the efficiency of the fume hood,
- cutting in a hurry, e.g. in the presence of a customer, could take place without the fume hood being switched on,

- some people work the night shift and think that no one can smell~~s~~ bad scents at night,
- some are convinced that by working fast they are working better and nothing will happen anyway,
- it's not clear, whether fire hazards are the only danger when working with lasers~~,~~
- perhaps too little space at the workstation causes various materials to be deposited on the desktop and these too can catch fire?
- does anyone check that employees always wear glasses?
- what else could happen?
- why has workplace training not been very effective?
- what would happen if there were more workstations like this on the shop floor?

Leader then suggested a discussion on the reported problems to group them and try to find the root cause of the situation. The diagram in Fig. 1 was used as a visual aid. As areas for improvement started to recur, the quality controller suggested an Ishikawa diagram to sort out the facts (Fig. 2).

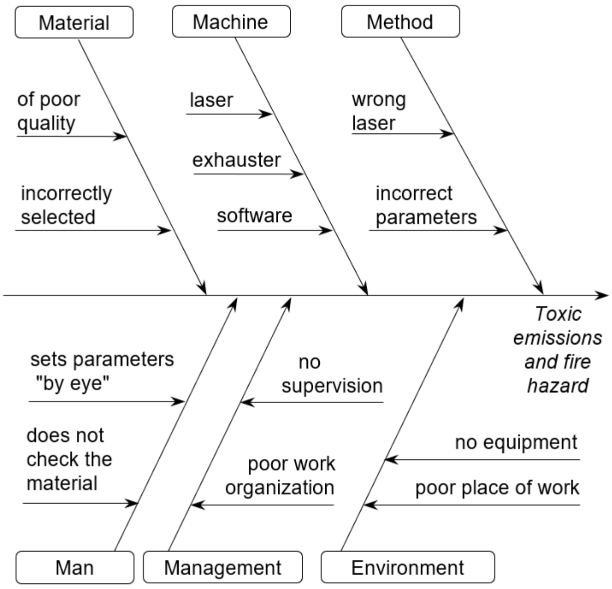

Fig. 2. Global Ishikawa diagram for the problem under analysis

Main areas were typical: Material, Machine, Method, Man, Management, Environment (Fig. 2). However, the individual 'bones' of the diagram were analyzed in detail and it was shown that the hazard problem appeared to be multifaceted.

3. Results and discussion

In the context of 'Material' – for materials accepted for processing, the pre-qualification of the customer order is essential. It is possible to have a situation where the order contains material that is not suitable for laser processing and it can generate toxic fumes or cause ignition. In such case, it is possible to propose replacing it with another grade of material. However, this requires an employee to be aware of the effects of the laser on the construction materials and any possible dangers (Fig. 3). Training the employee in this area and developing a procedure for the future is essential. When an order is accepted with materials approved for laser processing, the quality of the semi-finished products becomes important. It is then necessary to verify the suppliers and, if necessary, change them if the deliveries are damaged, materials uneven or heterogeneous in structure. This aspect should be dealt with by the procurement department. Separate issue is the use of plastics with different additives, such as talc. These can affect the process, which the technologist should be aware of and alter the machining parameters accordingly (Cienka A.E., 2021). The issue of material heterogeneity or additives will be relevant if they amplify the risk of emissions and fire.

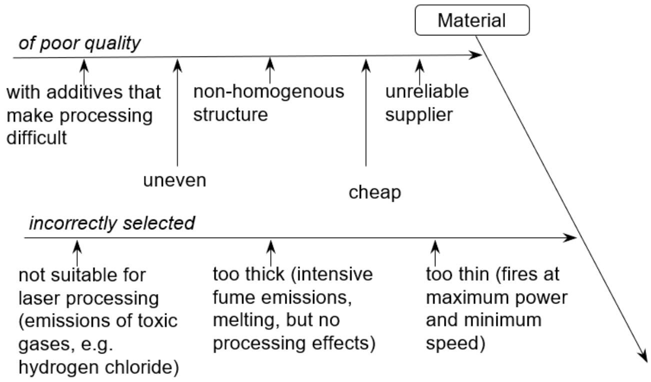

Fig. 3. Material 'bone'

Machine's components are placed on the Machine 'bone' (Fig. 4, Appendix). The most important component is the laser, i.e. the set-up consisting of the radiation source, galvo head and lens, and the controller. Basic feature, which determines safe operation with properly selected parameters, is the efficiency of the equipment and its specific quality (e.g. lens, power supply, beam power control stability, etc.). Therefore, the requirement for correct handling, correct installation, work culture and knowledge of the device is repeated in the diagram. These aspects apply to various people in the company, from the personnel receiving the components for assembly, to the worker-assembler, and the bench attendant. Furthermore, in the context of potential defects, the workstation environment must also be taken into account, whether defects can occur due to, for example, insufficient space to work freely, lack of transport routes and human traffic, storage of excess objects in the vicinity of the workstation, etc. In such a situation, more people should be involved in solving the problem, their task would be to segregate, organize and store the items in the right place. In addition, an extra team should be responsible for keeping the equipment in a working order, especially if the plant is planning to expand production and purchase new equipment. The area described as 'Machine' is important in the situation under investigation (emission of toxins), when faults in the components of the unit cause, for example, ineffective ventilation or an electrical short and fire. However, the efficiency of the appliance is an overriding requirement and the performance of the components should be respected.

'Method' bone indicates the crucial importance of the correct choice of laser for the material to be machined, as well as the knowledge and professional competence of the laser operator

(Fig. 5). In addition, poor time management and working under stress or in a hurry can result in a deliberate change to shorter processing parameters over time. However, as the intensity of the laser processing increases, the risk of vapor emission rises. If it is found that such practices are taking place at the plant, managers should rethink their existing management strategy. It will probably be necessary to change behavior and rationalize production planning using other organizational methods (e.g. scheduling, chronometric).

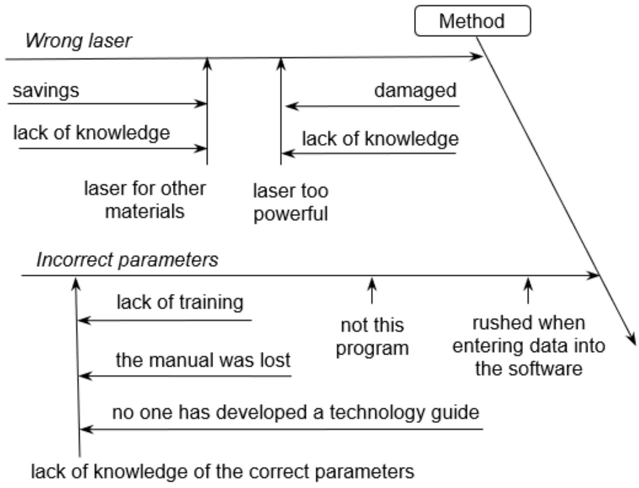

Fig. 5. Method 'bone'

Human beings play an important role in the entire production process. Two key issues are highlighted on the bone of 'Man' as a result of the personal characteristics of the operator (Fig. 6). Employee may be knowledgeable, competent, but may show reluctance, negligence, lack of responsibility for the work being done, may be distracted, tired, stressed. Work may be monotonous, tiring e.g. by standing for long periods of time, one may lack motivation to work.

Improvement in this area depends on management and the right approach to the employee's problems: job rotation, ensuring task variety, limiting non-strenuous tasks in accordance with work ergonomics. Additional incentives should include bonuses, rewards or other forms of recognition of the employee's contribution to product quality and occupational safety.

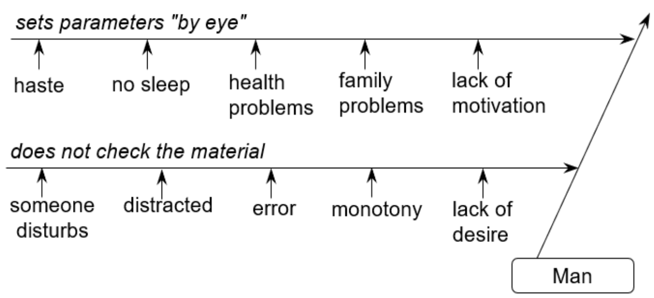

Fig. 6. Man 'bone'

In the area of 'Management', the problems already synthesised are basically shown, especially concerning the organisation of work, the work culture, the exertion of pressure on employees, the management style and the lack of possible supervision. This bone should be an incentive to review manager behavior, especially in the future when more activity is planned and there may be more orders and stressful situations. The behaviors indicated in the diagram should be treated as a warning not to do so (Fig. 7).

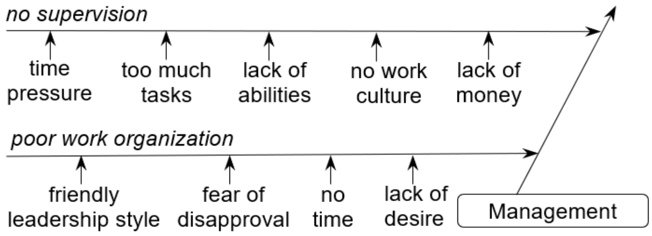

Fig. 7. Management 'bone'

Attention was also drawn to the impact of the 'Environment' of the job (Fig. 8). Deterioration of the quality of the work performed is significantly affected by the lack of equipment or its excess. Also negligence in the provision of protective clothing, forgetfulness, negligence on the part of support staff should be assessed negatively. In addition, attention was drawn to the principles of safe work and the associated risks, shiny walls, unsecured windows, flammable carpeting. These aspects should be brought to the attention of the management, due to the legal responsibility for workplace safety in the establishment.

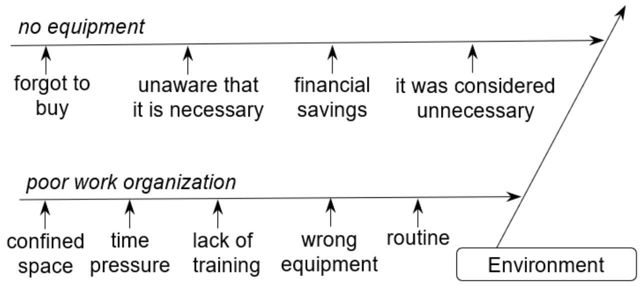

Fig. 8. Environment 'bone'

Due to the problem of toxin emission defined in the Ishikawa diagram, filtering devices should be purchased and launched as a matter of urgency, and employees should be trained in the rules of their use and obliged to properly operate the device. Due to the significant fire risk, the station should be immediately moved to a room free of flammable carpets and equipped with screens, locks and laser signaling. If there is no such room, the plant should stop production at this station, renovate the target site and ensure that health and safety requirements, including protective clothing, are met.

4. Improvement activities and conclusions

Brainstorming discussion revealed that the obvious requirement for treatment fume filtration was not met. It has been found possible for the laser to operate while the filter device is turned off. Simple 'poka-yoke' solution was developed to eliminate the risk of toxic substances accumulating in the air.

In the case in question, changes were proposed to the unit's software so that the laser could not be operated without the fan and fume extractor running. Programmer, together with the electrician, physically and functionally connected the computer with the software and the fan with the fume hood. Sequence of switching the station on and off was recorded in the sequences shown in the Fig. 9.

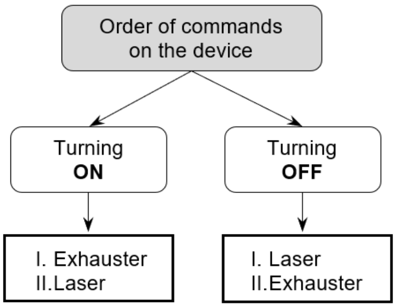

Fig. 9. Order of commands in the controller

Order in which the commands are executed is dependent on each other (Fig. 10).

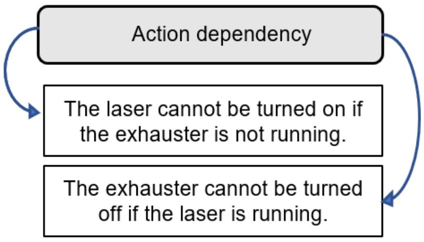

Fig. 10. Switching on/off relationship

Additionally, in order to ensure the removal of exhaust fumes after processing was completed, it was programmed to be possible to switch off the fan 5 minutes after the laser was switched off (it is not possible to switch off the ventilation before this time). In this way, risky practices were eliminated when workers unknowingly or deliberately worked on the bench without air filtration. Situations where vapours accumulated in the room putting workers at risk of health damage were avoided.

Finally, using the areas defined in the Ishikawa diagram, these were transformed into specific tasks to improve working conditions at the workplace. At the current stage of the analysis, it was considered that the risk of inhalation of hazardous substances should be removed first. Tasks in this context are scheduled as immediate. Tasks requiring the preparation and implementation of certain practices, such as training, software update, are scheduled for the next 1-2 weeks. Then, works that should be improved and a more favourable solution should be maintained in the long term were called "ongoing". These activities, such as supervision, hiring, testing, planning, should be permanent. However, in line with continuous improvement, they should also be reviewed, verified and, if necessary, corrected or updated over time.

Tasks were presented using an affinity diagram, supplemented by the assignment of responsibility for topic completion and deadlines (Table 1). In this approach, it also became a schedule for improvement work.

Table 1. Affinity diagram and schedule for improvement work

Affinity diagram and schedule		
Task	**Person Department**	**Implementation deadline**
Area: **Technology**		
1. Development of machining instruction sheets or process guides for the materials to be cut.	Technologist	Next month
2. Installation of new software (with poka-yoke).	IT specialist	Next 1 week
3. Implement the practice of testing the machining of new materials (on a prototype basis) under the supervision of an experienced worker.	Production manager	Ongoing
Area: **Training**		
1. Training on polymeric materials and their laser processing possibilities.	Technologist	Next 2 weeks
2. Training on the principles of safe operation of the machine.	Health and safety department	Immediately
3. Training on customer service - selection of accepted orders made of safe materials.	Technologist	Next 2 weeks
4. Training on assembly and maintenance of the machine.	Production manager	Next 2 weeks
Area: **Work organisation**		
1. Implementation of a procedure for handling equipment on the workplace.	Production manager	Next 2 weeks
2. Development of a workplace manual and health and safety rules.	Health and safety department	Immediately
3. Planning of working time (elimination of time pressure).	Production manager	Ongoing
4. Refurbishment of the room and removal of inappropriate items of equipment. Installation of guards, ventilation, control buttons, etc. Designation of storage and transport areas.	Employed repair company	Next month
5. Purchase of face masks for polymer cutting.	Health and safety department	Immediately
6. Implementation of job supervision.	Production manager	Ongoing
7. Employing competent staff.	Human resources department	Ongoing
8. verification of deliveries.	Purchase order department	Ongoing

Area: **Customer relationship**		
1. Organisation of the customer service room (elimination of the presence of customers in the processing area).	Customer service department	Immediately
2. Development of commercial information on the treatment of selected materials.	Customer service department	Next 2 weeks
3. Updating the website.	IT specialist	Next 2 weeks

5. Summary

Obligation to ensure safe working conditions is regulated by the relevant legal acts and standards. In the analyzed plant, the overriding issue is respecting these requirements. However, a number of difficulties were encountered during the preparation and testing of the workstation. Known qualitative tools have been proposed to solve them. In this case, "quality" meant "quality of work", without the need for both employees and customers to inhale toxic laser processing products. Proposed tools were assessed as effective. Employees admitted that some issues were unknowingly omitted or underestimated. Brainstorming was carried out in a small group, but people with different qualifications were selected, so that it was possible to analyze the issue from different points of view. This is the first time, when this method of problem solving has been used at the plant. Team was new, but the atmosphere of understanding the common good unleashed creativity and willingness to cooperate. As the company grew, it was declared that the team would be enlarged.

Using teamwork methods, a number of goals were developed and many effects were achieved in a short time, and in particular the health risk was reduced to an acceptable state. These were e.g. training to reduce ignorance in the field of laser operation, technology and materials used, indication of correct work procedures, education on risks related to the used technology. In the context of the technology, processing instructions have been implemented to facilitate the selection of materials, verification of the correctness of the type of material and the decision process in the case of the wrong material. These goals were achieved as a result of the commitment and decisions of the management, the assignment of improvement tasks to various employees, thanks to which no one was burdened with work beyond their strength, and at the same time everyone had a sense of mission, that their contribution is important for the entire crew. Involvement of non-production staff translated into the acceleration and timeliness of deliveries, both of materials for customers and additional equipment. Personnel policy has been changed: now employees do not deal with everything, but everyone deals with specific tasks. Multifaceted nature of the analysis also allowed us to take a critical look at the production hall, the rooms were renovated, equipped with appropriate protections: ventilation, filters, markings, screens, lighting, wall and floor surface finish, windows were secured, appropriate glasses and clothing were verified, changed and purchased.

Management of the plant is aware of the imperfections of the changes, as it started with a qualitative analysis. In the near future, it is planned to implement quantitative methods, especially for determining the concentration of toxic substances in the air, identifying the size and quantity of solid particles, types of gases, etc. depending on current needs. In the context of workers' exposure to laser radiation, it will also be necessary to determine exposure indicators, as well as exposure to reflected radiation.

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Reference

Badri A., Boudreau-Trudel B., Souissi A. S., 2018. Occupational health and safety in the industry 4.0 era: A cause for major concern? Safety Science 109, pp. 403-411.

Barat K., 2006. Laser Safety Management. CRC Press, Taylor&Francis Group, Boca Raton.

Barat K., 2009. Laser Safety. Tools and Training. CRC Press, Taylor&Francis Group, Boca Raton.

Chądzyńska M., Klimecka-Tatar D., 2017. Use the quality management tool, which is the Ishikawa Diagram on the example of small leather business. Archives of Engineering Knowledge, 2(1), 20-22.

Ciecińska B., Oleksiak B., Furtak J., 2022. Hazard, risk assessment and safety management in workstations with lasers – theoretical and practical studies. Scientific Journal of the Maritime University of Szczecin, 72 (144).

Cienka A.E., Ciecińska B., 2021. Optimization of laser cutting conditions of polypropylene and polypropylene with talc. Physics for Economy, 4(1), 5-15.

Çalış S., Büyükakıncı B. Y., 2019. Occupational Health and Safety Management Systems Applications and A System Planning Model. Procedia Computer Science 158, 1058-1066.

Edwards B., Barnes L., Gibbs, B., Nguyen G., 2002. Development of a Laser Safety Hazard Evaluation Procedure for the Research University Setting. The Radiation Safety Journal. Health Physics, 82, S37-S46.

EN 207:2017-07 Personal eye-protection equipment – Filters and eye-protectors against laser radiation.

EN 60825-1:2014 Safety of lasers products – Part 1: Equipment classification and requirements.

Ghatorga K. S., Sharma R., Singh G., 2020. Application of root cause analysis to increase material removal rate for productivity improvement: A case study of the press manufacturing industry. Materials Today: Proceedings. 26(2), 1780-1783.

Haddouch H., Khadija F., El Oumami M., Beidouri Z., 2022. Exploratory Qualitative study of the supply chain management practices in the Moroccan companies. Management Systems in Production Engineering, 1(30), 1-8.

Henderson R., Schulmeister K., 2004. Laser Safety. CRC Press, Taylor&Francis Group, New York.

Ilie G., Ciocoiu C. N., 2010. Application of Fishbone Diagram to Determine the Risk of an Event with Multiple Causes. Management Research and Practice, 2(1), 1-20.

Luca L., 2016. A new model of Ishikawa diagram for quality assessment. IOP Conf. Ser.: Mater. Sci. Eng. 161 012099.

Luca L., Pasare M., Stancioiu A., 2017. Study to Determine a New Model of the Ishikawa Diagram for Quality Improvement. Fiability&Durability, 1.

Małysa T., Furman J., 2023. Visual solutions as a way to improve work safety when using machines – selected aspects of VM. Management Systems in Production Engineering, 1(31), 53-58.

Mizuno S., 2020. Management for Quality Improvement: the 7 New QC Tools. CRC Press.

Priede J., 2012. Implementation of Quality Management System ISO 9001 in the World and its Strategic Necessity. Procedia Social and Behavioral Sciences, 58, 1466-1475.

Regulation, 2010. [Rozporządzenie MPiPS z dn. 27 maja 2010 r. w sprawie bhp przy pracach związanych z ekspozycją na promieniowanie optyczne], Dz. U. z dn 27 maja 2010 r., poz. 643.

da Silva S. L. C., Amaral F. G., 2019. Critical factors of success and barriers to the implementation of occupational health and safety management systems: A systematic review of literature. Safety Science, 117, 123-132.

Salguero-Caparrós, F., Rubio-Romero, J. C., 2022. Evaluation and comparison of selected methodologies to investigate occupational accidents. *Work*, (Preprint), 1-13.

Seňová A., Pavolová H., Škvareková E., 2023. Assessment of the impact of working risks in the exploitation of raw materials. Management Systems in Production Engineering, 1(31), 86-94.

SPI, 2014. Laser Applications Handbook, SPI Lasers, UK.

Stefanovic S., Kiss I., Stanojevic D., Janjic N., 2014. Analysis of technological process of cutting logs using Ishikawa diagram. Acta Technica Corviniensis, 7(4), 93-98.

Woźny A., Saja P., Dobosz M. Kucęba R., 2017. Occupational health and safety management with the use of brainstorming method. Production Engineering Archives, 17, 18-23.

Appendix

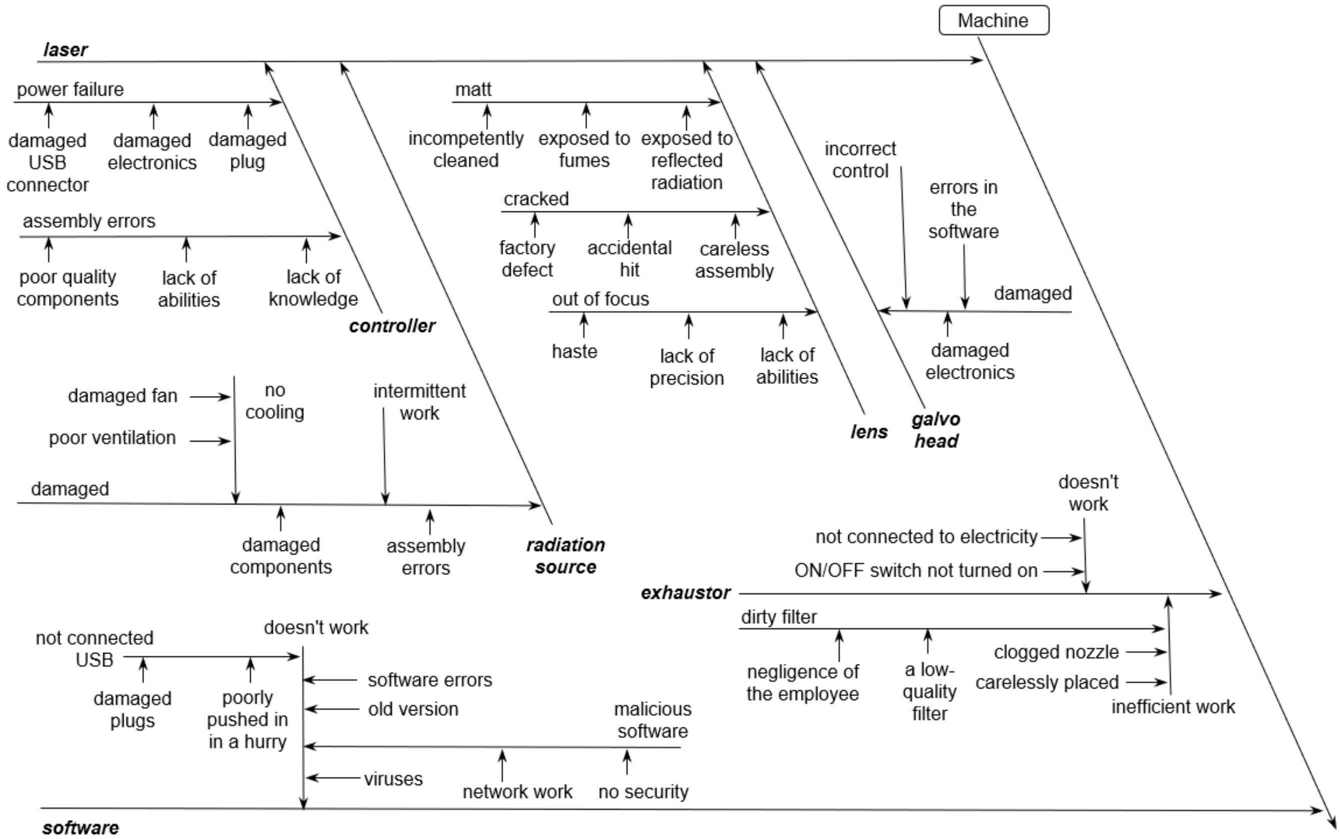

Fig. 4. Machine 'bone'

使用质量管理工具确保 CO_2 激光工作站的安全工作条件

關鍵詞
二氧化碳激光
石川图
头脑风暴
亲和图
防错

摘要
各种技术的动态发展取代了现有的、困难的或以各种方式艰难的技术，是用现代设备替换设备的原因。 与以前的设备相比，新设备可能与不同的电源、不同的建筑材料加工方式或使用的工具相关联。 那么就需要重新检查工作场所的工作条件是否安全，工作中存在哪些繁重和危险因素。 这种技术变革的一个例子是激光加工，当设备使用集中能量流并适当控制时，会对材料产生特定的影响。 然而，在新技术带来好处的同时，也带来了许多风险，例如辐射对物质和人体的影响、电力、火灾隐患、有毒排放问题等。 本文提出了新投产的CO2激光站的工作安全保障问题。 采用头脑风暴技术来识别和分析工作条件和危险类型。 这些可能与之前已知的、部分已知的、甚至是无意识的不同。 石川图的开发并被证明是一种用于详细说明和构建与安全相关的问题的有效工具。 在出现技术问题的情况下，提出了消除危险的防错解决方案。 将加工过程中工作站出现的与操作相关的问题按照工作组织结构，通过亲和图分配到公司的具体部门，可以极大地方便对工作和员工的管理。 未来各部门，以确保安全卫生的工作条件。