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SAFETY IN A MANUFACTURING COMPANY

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Abstract: The safety systems include the functioning of the institutions of a state, central, and local government, businesses, and social organizations. Research in this discipline should contribute to the development of the theoretical foundations and systems of national and international security and operating systems in the area of technical safety. Technical safety engineering should deal with a design, build, operation, and decommissioning of technical measures in order to minimize the opportunities and the size of their negative impact on the environment, people, and the good of civilization. With this in mind, the main purpose of the research was to evaluate the safety of technical manufacturing company that uses a wide machine park. A plant manufacturing parts and components for automobiles was the audited company.

Keywords*:* manufacturing company, safety measures, risk analysis, safety precautions.

1 Introduction

The research subject of the security studies is the modern security systems in the military and non-military dimension. Additionally, their functioning at different organizational levels is examined as well. These systems include activities of state entities, state and local government institutions, entrepreneurs, and social organizations. The research within this discipline should contribute to the creation of theoretical foundations and development of national and international security systems and operating systems that function in the area of security.

Taking into consideration the above-mentioned scope of studies, it can be said that their component, based on the quantitative sciences, is the technical safety. It constitutes a discipline whose aim is to develop, enhance, and popularize methods that rationally maximize protection effectiveness of people, environment, and fruits of civilization by counteraction and prevention of security hazards (natural, civilizational, and public). Additional goals of the technical safety are as follows: preparation of public bodies and security systems in the event of prospective hazards, as well as reaction to the negative effects of emerging security risks for human beings and the environment in which man functions. Technical safety engineering should deal with designing, building, using, and decommissioning of technical objects in a commonsense way that allows to rationally minimize the possibilities and extent of their negative impact on surroundings, people, the environment, and the fruits of civilization.

With this in mind, the purpose of the study is to evaluate the technical safety in a manufacturing company that possesses a substantial machinery fleet. The surveyed company is a manufacturing business that produces spare parts and components for automobiles. In the examining corporation, the production department includes three sections: Processing, Clean Assembly, and Final Assembly.

2 Analysis of issues - legal conditions

The study is based on the EU security concept relating to the use of machines. It consists of implementation of two principles: first, for the machines that are introduced to the market for the very first time, and second, for the machines that have already been in use (they are called "old machines") (Łabanowski, 2013). The latter have already been accepted by the European Union. The above-mentioned security concept is implemented through a series of activities. The most relevant of them is obeying the minimum requirements concerning use and maintenance of machines in accordance with the manufacturer's safety guidelines. Furthermore, pursuant to social directives, there are controls of machines implemented into new workstations. Moreover, machine owners take additional technical and organizational safety measures; they inform machine manufacturers about malfunctions of machinery. Besides, machine operators take part in risk reduction trainings. All the above-enumerated activities significantly increase the level of security (Żółtowski, et al., 2012).

The manufacturers apply the so-called HSE (Health, Safety and Environment) Triad (Fig. 1) in order to shape qualified machine safety. It is based on the approach to machine design in three steps (Łabanowski, 2013).

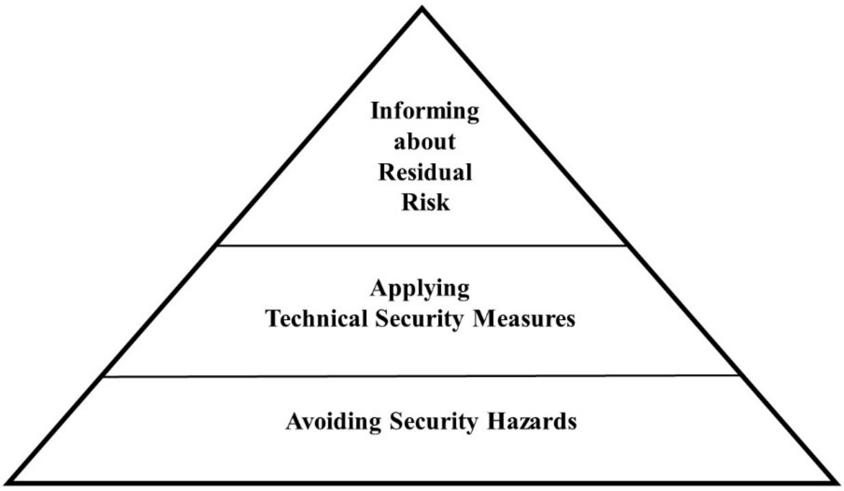

Figure 1. Health, safety, and environment triad while using a machine (*source:* own work based on Żółtowski, et al., 2012)

1) Constructing an internally safe machine. Thanks to proven design solutions, some significant risks can be eliminated or reduced. Examples of such solutions include:
   - elimination of sharp edges and protruding parts,
   - placement of the elements that pose a threat out of reach for machine operators,
   - reduction of the force or speed of rotating parts and so on.
2) Using appropriate technical protective measures. If the design does not eliminate all hazards, or the risk does not decrease enough, additional safety measures must be taken. Among other things, the technical safety measures include:
   - fixed and movable guards,
   - devices that detect intrusion, or presence of human in a danger zone,
   - emergency stop systems.
3) Informing a user about remaining residual risks. The user of the machine should know everything when it comes to intended use of the machine and its safe handling. The knowledge about the hazards that have not been eliminated by the design and additional protective measures should be conveyed to the users as well; they have to be warned of machine misuse consequences. To encapsulate, machine instruction manuals should be delivered with the machinery. Moreover, additional measures to inform about the hazard (safety signs, pictograms, warning notices) are to be applied.

3 Technical safety measures in a manufacturing company

Taking into account the EU guidelines, every single employer is directly accountable for occupational safety and health (OSH) in their factories (Ustawa, 1974). In the surveyed company, the advisory and control body within the scope of safety is the Occupational Safety and Health Department.

While using machines, the employee's safety is provided through a number of activities, such as:

1) Proper organization and management of work, which aims to guarantee safety while using a machine. Such measures include:
   - preparation of suitable working procedures that limit access to dangerous zones,
   - preparation of OSH instructions, occupational risk assessment forms on workstations, and information sheets of chemicals (if available) to which an employee is acquainted during OSH initial training and has unlimited access to them because they are at every workstation,
   - management of permit system for hazardous work,
   - planning by the technical department: inspections, routine maintenance, and overhauls of machines,
   - supervision under adherence to OSH regulations,
   - trainings aimed at improving employees' knowledge concerning hazards while using machines,
   - shaping the sense of responsibility not only for yourself but also for coworkers by motivating, encouraging, and rewarding appropriate behaviors to improve safe working conditions.
2) Attention to proper selection and application of additional technical protective measures on machines, that is, the technical solutions that have not been applied by the machine manufacturer, particularly, if specific working conditions require their use. Such conditions include a place of the machine installation, its placement in relation to other machines, or power supply. The most frequently used additional protective measures are distance guards that prevent access to the dangerous zones (moving parts) or guards that secure cables – electrical, hydraulic, and pneumatic – from mechanical damage.
3) Selection of Personal Protective Equipment (PPE) – it protects workers against hazards in their workstations. The surveyed company applies the following PPE: goggles, helmets (in a high-bay warehouse), hearing protection (ear plugs), boots, gloves, and working clothing. PPE is used in situations where there is no possibility to reduce hazards by technical means of collective protection or by appropriate organization of work.
4) Training of machine operators, which in the field of Occupational Safety and Health, is divided into preliminary (general and focused on a workstation), periodic, and specialized. During the training, an employee receives information on the procedures and regulations of Occupational Safety and Health, hazards in a workstation, occupational risks associated with using of machinery, and the principles related to the protection against hazards.

Table 1 depicts the description of possible hazards and PPE that protects against them.

Table 1. PPE that protects against hazards
(*source:* own work)

No.	**PPE**	**Hazards**
1	Safety goggles	Oil, lubricant, dust
2	Helmet	Falling objects
3	Ear plugs	Noise
4	Boots	Falling objects and materials, sharp protruding elements
5	Gloves	Sharp protruding elements, roughness, oil, lubricant
6	Working clothing	Protective clothing against mechanical and chemical hazards

Most of the risks related to mechanical hazards can be reduced to acceptable forces or energy levels by applying a risk reduction strategy (Fig. 2). If this is impossible, the hazards must be isolated from people by guards that maintain a safety distance between the danger zone and the people, with the main result being to reduce the access to the danger zone (Laurent, 2009).

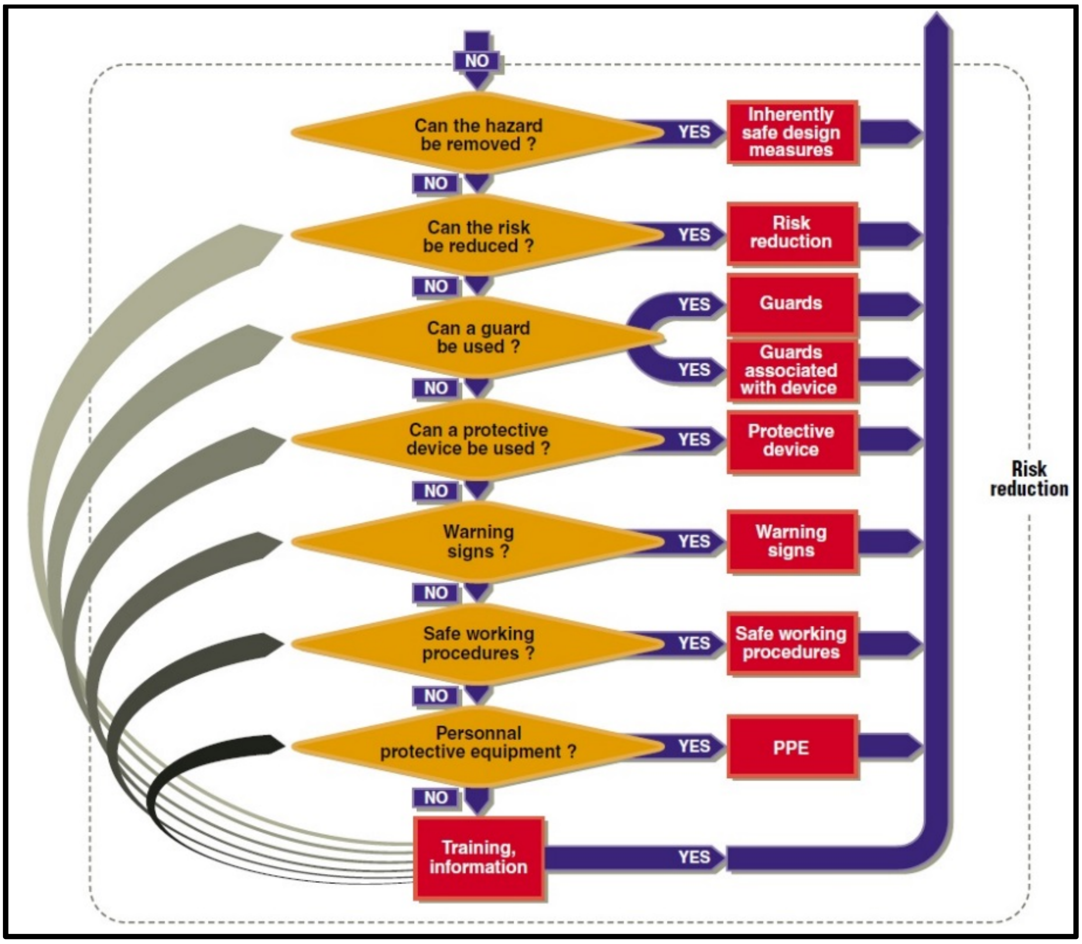

Figure 2. Risk reduction hierarchy
(*source:* based on Laurent, 2009)

3.1 Technical protective measures against mechanical hazards

Technical protective measures are divided into physical barriers (guards) and protective devices. When selecting protective measures, a risk assessment in relation to a particular machine is taken into account. Therefore, the criterion of the location and the need for access to the danger zone should be taken into consideration as well. Mechanical hazards occur in two areas: in the power transmission zone and working zone (Łabanowski, 2013).

A guard is a part of a machine that constitutes a physical barrier between a worker and a mechanical device – it is intended to protect an operator. Terminology of guards depends on their design. Hence, it can be a casing, a screen, a door, a cover, a barrier, a compartment, and so on. While designing and selecting guards (Fig. 3), first of all, mechanical hazards must be taken into account. Nevertheless, other risks associated with a working process cannot be skipped.

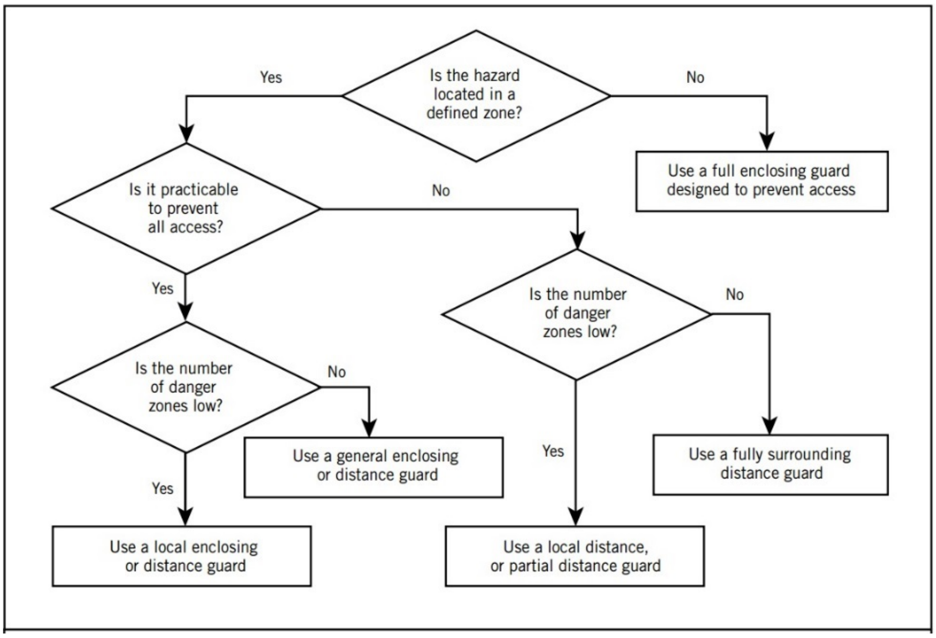

Figure 3. Chart for the selection of guards according to the number and location of hazards (*source:* Annex B of: ISO 14120:2002)

Thus, guards and other protective devices should:

- have solid design,
- be difficult to be removed or stopped,
- be placed in a safe distance from a danger zone,
- not obstruct a working process,
- not cause any hazards,
- be designed so that operations such as adjustments, lubrications, or maintenance are feasible without removing or opening them.

A fixed guard (permanent protector) is a guard that is connected to the machine, for instance, by being welded or attached by fixing elements; it can only be removed with the assistance of a tool. In the surveyed factory, fixed guards are installed on each machine in the production department.

A movable guard is connected by movable mechanical components (e.g., hinges, runners) with a machine frame or other fixed parts. This type of a guard can be opened without using tools. Movable guards, among other things, include (Łabanowski, 2013)

- interlocking guards,
- interlocking guards with guard locking.

Movable guards should be effective in all positions. Thus, they ought to be equipped with a locking device (a guard position sensor). The following are the requirements to be met by interlocking guards:

- the machine's hazardous functions that are protected by the guard cannot operate until the guard is closed,
- a stop command is given if the guard is opened while the machine's hazardous functions are operating,
- the machine's hazardous functions that are protected by the guard can operate when the guard is closed, but closing the guard does not by itself initiate their operation.

Interlocking guards with guard locking are used if the machine stopping time is not short enough for the hazard to stop before the worker can reach it. In addition to performing the functions of the interlocking guard, the guard locking locks the interlocking guard in the closed position until the hazard has completely passed. This type of guards has a higher degree of additional safety requirements – it must meet all functions of the interlocking guards. In addition, it has to be equipped with a guard locking.

In addition to the guards, the next category of protective measures is protective devices – devices (other than guards) that reduce the risk, either alone or in conjunction with a guard. They do not constitute a physical barrier. They prevent a worker from accessing active mechanical hazards during normal machine operation and prevent a machine from violating its normal function. Thus, they forbid exposure of a worker to mechanical hazards that occur during normal use of a machine. Additionally, they block generating of new factors by preventing abnormal situations.

Protective devices, similar to guards, should be installed at a safe distance from the danger zone. The safe distance (S) between the danger zone and the protective device is described by a general formula (1):

$$S = (K \times T) + C \tag{1}$$

where:

S – is the safe distance [mm],

K – is the intrusion speed (2000 or 1600) [mm/s],

T – is the time for reaction of a protective device + machine stopping time [s],

C – is the safety coefficient [mm].

Protective devices are divided into two types: contact and non-contact (electro-sensitive protective equipment (ESPE), e.g., light curtains). The most commonly used ESPE is curtains and light barriers (active optoelectronic protective device (AOPD)). When there is a possibility that the operator often reaches the machine dangerous zone, instead of guards or contact protective devices, applying of AOPD is suggested. In case of violation of the danger zone, the light beam is broken (Fig. 4). Consequently, a signal "stop" is sent to the machine; it stops the hazardous machine functions. The light curtains reduce access time, increase productivity, and improve ergonomics in the workstation. In addition, the operator and third parties are protected equally. The function of the light curtain (Fig. 5) is to produce a protective field between an emitter and a receiver with resolution of 14–49 mm (spacing beams) (Łabanowski, 2013).

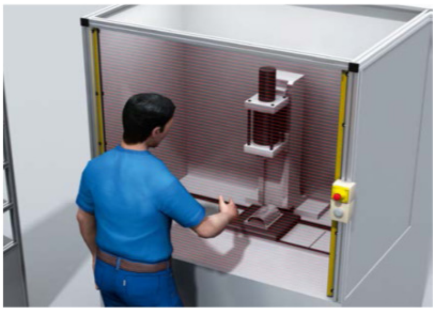

Figure 4. Hazardous point protection using a safety light curtain

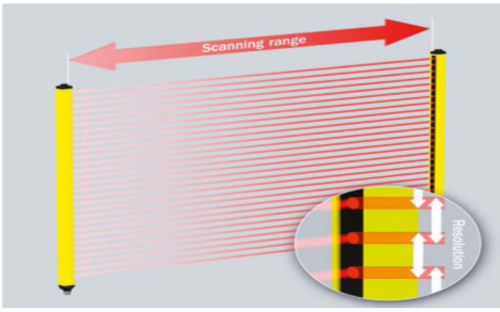

Figure 5. Typical structure of a safety light curtain

(*source:* Goernemann and Stubenrauch, 2013)

In the case of the surveyed company, the required safety distance of the light curtain has been examined in one of the assembly workplaces:

- use of an optical curtain placed vertically controls the access to the working area – Sick FGSS 1050-11 with a resolution of 14 mm,
- the localization of the main actuator lock release point is 150 mm from the top position,
- an actual curtain detection distance from the nearest dangerous place (a device socket) is L = 305 mm,
- the approach speed to the working area is K = 2000 mm,
- the maximum response (stop) time of the main actuator is equal to 0.104 s,
- C is 0 (as the curtain resolution is 14 mm).

Therefore:

$$S = (K \times Tmax) + C = 2000 \text{ mm/s} \times 0.104 \text{ s} + 0 \text{ mm} = 208 \text{ mm}$$

The actual curtain detection distance from the nearest dangerous place (a device socket) is L = 305 mm. It is larger than the required minimum safety distance, S = 208 mm. Intrusion of the light curtain while the machine is operating results in sending a signal to the buzzer. The signal activates an audio and light sensor that informs about the intrusion into the working area of a machine.

After examining the causes of the interruption of the curtain, deactivation of the device is performed by using a key. On the control panel, there is a key module that has an ON/OFF option. When selecting the OFF option, the audio and light signal is turned off. The key that allows to turn the buzzer off is kept by a quality control inspector.

An emergency stop button (emergency stop) is one of the additional safety measures (Żółtowski, et al., 2012). The emergency stop function prevents or reduces hazards. It is used when the normal stop function is insufficient. Emergency stop systems are considered to be complementary safety measures. Emergency stop is designed so that the operator, deciding on its use, does not have to consider the dangerous consequences related, for example, to the working area or the response time. The system that controls emergency stop function should be superior to all other control signals (Kowalewski, Kusiak, 2005). In the surveyed company, the emergency stop buttons are distinguished from the other elements by shape (mushroom) and color (red). Around the red emergency stop button there is a yellow background.

3.2 Method of risk and properties of protective devices assessment

There are numerous methods of risk estimation. In this research, the method presented in the standards for control systems related to security has been used. The graph risk method has been applied to estimate the risk level (RL) and determine the properties of protective devices that guarantee the effectiveness of monitoring the identified hazards (Łabanowski, 2013). This method has been implemented from PN-EN 954-1 norm (Norma PN-EN 954 1:2001) and PN-EN ISO 13849-1 norm (Norma PN-EN ISO 13849 1:2008). When carrying out the risk assessment process, requirements and guidelines of the following norm and standards have been taken into account in a particular way:

- PN-EN ISO 12100: "Safety of Machinery. General Principles for Design. Risk Assessment & Risk Reduction" (Norma PN-EN ISO 12100, in Polish).
- PN-N-18002:2011: "Occupational Safety and Health – Management Systems. General Guidelines for Occupational Risk Assessment" (Norma PN-N-18002:2011, in Polish).

The RL coefficient estimated for the identified hazard is a combination of the expected parameters: severity of injury (S), frequency of exposure to injury (F), and possibility of avoiding the hazard (P).

The Severity of Injury (S). To evaluate the risk that arises when defects occur, the following injuries are taken into account: slight injuries (normally reversible, e.g., bruises) and severe injuries (normally irreversible, such as amputation or death).

To decide about it, while determining S1 and S2, the most common consequences of accidents and the treatment process should be considered. For instance, bruising and/or incised wounds without further complications are classified as S1, whereas injuries including amputation or death are classified as S2:

- S1 – slight, usually reversible injuries,
- S2 – severe, usually irreversible injuries or death.

Frequency of Exposure to Injury (F). Essentially, the duration of exposure to the hazard should be set at the average level, which is assessed based on the total time in which the device is used:

- F1 – seldom to quite frequent and/or short period of exposure,
- F2 – frequent to continuous and/or long period of exposure.

Possibility of Avoiding the Hazard (P). When the hazard appears, it is vital to know whether the hazard is known and if it is feasible to avoid it before an accident happens. For instance, it is relevant whether the encountered hazard may be defined on the basis of its physical characteristics or only by using technical means, for example, measuring equipment indications. Further important factors while selecting the parameter P include:

- intentional and unintentional work,
- service by qualified personnel or by amateurs,
- pace of hazard appearance (fast or slow),
- possibility of avoiding the hazard, for example, by escape or integration of third parties,
- practical experience with security related to the process.

When there is a risk of a hazardous event, the parameter P1 should be selected only if there is a real possibility of avoiding an accident or if there is a real possibility of significant reduction in its impact. The parameter P2 should be selected if it is not possible to avoid a hazard:

- P1 – possible under specific conditions (low speed, high visibility, awareness of operators),
- P2 – almost impossible and impossible.

3.3 Acceptance criteria of risk level

To assess the calculated coefficient of RL, and particularly its acceptance or not, the use of the criteria from Table 2 should be taken into account.

As a result of the injury risk analysis concerning a hydraulic press, the following parameters have been defined:

S = S2, F = F2, P = P2.

Thus, the RL = 5. In accordance with Table 2, RL = 5 is very high and unacceptable.

Table 2. Risk Acceptance
(*source:* own work based on Łabanowski, 2013)

Level of Safety Assurance	Risk Level	Risk Level Assessment	Risk Acceptance
a	**RL 1**	Very low	Acceptable
b	**RL 2**	Low	Acceptable
c	**RL 3**	Medium	Conditionally acceptable
d	**RL 4**	High	Unacceptable
e	**RL 5**	Very high	Unacceptable

Hazard identification for the mentioned machine is presented in Table 3. It has been prepared based on the interviews with employees of the surveyed object.

Table 3. Hazards connected with using a hydraulic press
(*source:* own work)

1	Name of the machine	Hydraulic press
2	Activities of an operator	Everyday usage, regulations, maintenance
3	Exposure to hazards	Frequent
4	Risk factors	The closing movement of a slider with an upper tool, material being processed, auxiliary tools
5	Hazards	Capturing of hands, fingers, head, strike, ejection of material or an instrumentation component
6	Effects of hazards	Crush injuries, amputations, fractures, squashing, bruises, cuts, hand lacerations

In order to reduce the risk related to the above analyzed machine, the following enumerated technical safety measures have been applied:

- fixed guards from left and right side of the tool zone,
- interlocking guard controlled by a limit switch, lifted by a pneumatic actuator, gravitationally closed,
- emergency stop system,
- power supply main switch with the possibility of locking in the off position.

Pieces of information (safety signs, pictograms, warning notices) posted on the machine have a significant impact on its safe operation, both its everyday usage and maintenance. After examining the object, it was found that the user manual is in line with the Regulation of the Minister of Economy of 30 October 2002 on minimum requirements for Occupational Safety and Health while using machinery by workers at work (Journal of Laws 2002 No. 191, item. 1596) – implementation of Directive 2009/104/WE (Rozporządzenie Ministra Gospodarki, 2002, in Polish).

4 Conclusions

The research material presented in this paper allows to formulate the following conclusions:

1) Work safety, in particular technical safety of the machine operation, is an indispensable issue in the management process of the company, because it has direct impact on all other aspects of this process.
2) The conducted research clearly proves that some organizations are serious about the Occupational Safety and Health and employers fully meet their obligations in this field. An example of this approach is the surveyed company that implements "safety first" principle. The enterprise reliably aims to meet the requirements for ensuring the safety of people working there and takes care of their continuous training in this field.
3) In the examined company, the applied technical safety measures on machines fully meet their role. It is evidenced by the small number of accidents related to use of machines.
4) The analyzes carried out on individual machines with regard to the safety issues are fairly studied, and conclusions and recommendations are met.
5) Detailed analysis of the hydraulic press safety shows that despite a high risk level in its use, such safety measures that should protect workers from potential injuries or accidents have been applied on the machine.
6) The conducted studies and the obtained results can be used in practice during planning and organization of machine operation processes, design, and installation of production lines in this type of companies.
7) In this article, the presented issues do not fully cover the topic, that is, technical safety in manufacturing companies. Complexity of the issues related to technical safety of machines leads to continuous exploration of knowledge on this subject. It seems to be necessary especially in relation to persons involved in business activity with the use of machines, particularly those who are responsible for safety in manufacturing companies.

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