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THE REQUIREMENTS ON MACHINERY SAFETY AND THEIR INFLUENCE ON OHS EFFECTIVENESS

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Abstract:
A legislative requirement that specifies the scope for occupational health and safety (OHS) and machinery safety has been implemented in the EU for 30 years. Basic condition for maintaining OHS is safely constructed and operated machinery / equipment. The obligation of constructors (producer, representative) is to launch only such machinery equipment which does not threaten health and safety of persons, domestic animals or property. The criterion for meeting these regulations is risk assessment. For maintenance activities, there are, in the EU directive on machinery safety (2006/42/ES), set requirements for the isolation of hazardous energy, which may threaten life or health of maintenance workers when performing the required activity. Identification process of this energy must be a part of risk assessment, the result of which is such a construction solution that enables disconnecting from all energy sources in a safe and convenient way together with its lockout. The management methodology of this approach, applied in practice, is called LOTO.
The objective of this paper is to describe the process of hazardous energy identification and methods how to assess those risks. Using research there were checked the LOTO system implementation approaches in different organisations. The findings were evaluated through 9 critical characteristics.

Key words:
safety, risk assessment, hazardous energy, maintenance, accident

INTRODUCTION

The history of machinery safety unfolds from a simple construction solution with a characteristic mechanical risk related to its robust and simple construction to complicated automatic systems [1, 2]. Even though for a customer, reliable is such a machine which is able to perform required tasks in the given time and environment, safety is perceived rather as a certain inevitable aspect ("black box"). Some authors emphasise the issue of safety as a fundament already when the machine is designed (safety-in-design), where they accentuate realistic risk assessment [2, 3, 4], while risk assessment in the design phase is understood as a step into the unknown – with a high uncertainty rate [3]. Others, however, emphasise the importance of the whole risk assessment process related to the entire life cycle of a machine, mainly its use in practice during the changes of machine conception in a certain phase of its operating life [5, 6]. Current digitalisation and automation trends (Industry 4.0) are, on the one hand, a way of work simplification, on the other hand, during the development of new technology, e.g. robotic systems, collaborative robots, assumptions for emerging risk are generated. These risks, as they are a source of high uncertainty rate, require implementation of new and modified risk assessment methods [5, 7, 8].

Simplification of work environment, digitalisation, information processing and the ability of dynamic management in time can be a significant objective of OHS improvement in work environment, however, wear and tear, technology aging, errors in processes will require a replacement, repair, cleaning, setting, i.e. a lot of maintenance activities during which the safety elements are usually disabled or their functionality is limited [9, 10, 11].

A European agency in Bilbao declares, as a result of work accident, 2.78 mil. deaths in 2018 and more than 30 serious industrial accidents annually [12]. The American institution Deloitte and Manufacturing Institute [13] informs on their websites that: ´In 2018, more than 115 500 production operators and 17 000 warehouse workers were absent from their work due to work accidents, which caused additional direct and indirect costs for the companies, with indirect costs being 20 times higher´. The statistics imply that the most serious situation is a direct contact of a person with a machine during common maintenance performance. The most threatened professions by a work accident in industry are: mechanics, electricians, engineers (technicians) and supervisors.

Maintenance as a set of technical organisational and mainly management activities [14] has its task, i.e. maintain and renew the required condition of an object in accordance with set goals (company management, maintenance management). Yet it is difficult to meet this requirement without thorough planning of activities (preventive, corrective) so that they are performed in the required time, quality, but mainly in a safe way for maintenance workers as well as for employees in the proximity. During the construction of machines, mainly with a historical development of the ´Directive on machines´ No.: 2006/42/ES (in the past the Directives 89/381/EHS and 89/37/ES), for the purposes of accordance determination, the field of requirements for safety in maintenance has expanded from the requirement for their diagnosing (Annex I, 1.6.1) to the requirement for hazardous energy isolation by its lockout, if it is identifiable and present throughout the performance of the required maintenance activity (Annex I, 1.6.2).

Even though the directive in machines moves the safety borders by setting rules for constructors, producers or representatives so that their operation and maintenance are safe, the reality of practice is different. The machinery park nowadays requires renewal or automatization by introducing new components – functions into existing, older equipment. This ´old-new´ machinery equipment must meet the requirements for safety in accordance with directive requirements. Similarly, if new equipment, which is in accordance with the directive requirements and is equipped with *energy isolating device* (e.g.: valves, switches, etc.) to disable hazardous energy sources, these devices are not always properly marked and, what is important, the process and way of their lockout is not described in their user instructions. This often leads to risks with fatal consequences, mainly during maintenance activities [15, 16, 17].

1 LITERATURE REVIEW

LOTO methodology (or concept): Log-out and Tag-out comes from the USA. In 1989, American agency for Occupational safety and health (OSHA) [12, 13] published a regulation 29 CFR 1910.147, dealing with conditions of hazardous energy management in industry, i.e. the energy (mechanic, electric, pneumatic, heat and etc.), which has the ability to cause a serious work injury. Mainly activities related to repair or preventive maintenance of technical equipment are concerned, and their residual risks throughout performance of such activities cause life hazard to the maintenance workers. The requirements for hazardous energy sources identification, creation of specific work procedures, training of respective persons on safety procedures during the maintenance performance and technical solutions of safe disconnection of these energies became a systematic tool used not only in the USA but also in industrial companies worldwide. Some authors highlight the importance of LOTO during the isolation of electric energy mainly [15, 19], while the others describe their experience with its implementation by selection of LOTO devices in industrial companies [17, 18, 20].

In the USA, ANSI standard ANSI/ASSE Z244.1 [19, 21]: *The Control of Hazardous Energy Lockout, Tagout and Alternative Methods*, was issued to support LOTO implementation, and its actual version was issued in 2016. Its origination is dated since 1973, and since then, it has gone through changes and it became a basis for the creation of legal regulation.

Although this methodology firstly appears to be simple, as its basic principle is to secure, block, lock, tag the source (equipment, knot, element) of hazardous energy by means of sufficiently reliable and effective device, implementation of the methodology requires systematic approach, certain time and costs. However, the truth is that its application is interrelated with business activities of the LOTO devices´ suppliers [22].

Production of new machines and equipment within the EU, based upon risk assessment, must take into consideration a requirement of the directive on machinery, i.e. to create such construction solution so that the part / element or specific equipment, which is a part of the machine (e.g. engine, hydraulic system etc.), was lockable (Figure 1).

***Fig. 1** Example of hazardous electric energy isolation*
Source: [*author*]

The fact that the directive does not specify the obligation of machine producers to supply the respective equipment with appropriate lockout – isolation devices, and neither does it require in user instructions to elaborate a manual of how to use the devices, it is a sensitive element of successfulness of LOTO concept implementation [23, 24]. The process of ´setting´

of the hazardous energy isolation concept/ system, which may threaten the lives and health of maintenance staff during performance of both preventive and also corrective maintenance activities, may take into consideration operators´ activities in connection with the performance of certain preventive activity, during which the entry into hazardous area is required – e.g. autonomous maintenance. However, the issue is that implementation and maintaining of the LOTO concept (or sometimes also programme) is left on users (owners of the machinery equipment) [25].

Comparison of maintenance requirements´ development in a historically changing directive on machines with requirements CFR 1910.147 points at the fact that in the EU, an emphasis is put on the safety already in the construction design phase. However, in the USA, the safety maintenance workers´ programme during their activities is elaborated in detail and the responsibility is transferred on the equipment operator, see Table 1.

Tab. 1 Comparison of selected requirements of *Machinery directive and regulation CFR 1910.147*

The control of hazardous energy (LOTO)		**Machinery safety (Annex I.)**	
Section	**CFR 1910.147**	section	**2006/42/ES**
1910.147(a)(1)(i)	Servicing and/or maintenance which takes place during normal production operations is covered by this standard only (normal production operations are not covered by this standard)	**1.6** 1.6.1	**Maintenance** ***Machinery maintenance:*** Adjustment and maintenance points must be located outside danger zones. It must be possible to carry out adjustment, maintenance, repair, cleaning and servicing operations while machinery is at a standstill.
1910.147(a)(3)(i)	This section requires employers to establish a program and utilize procedures for affixing appropriate lockout devices or tagout devices to energy isolating devices, and to otherwise disable machines or equipment to prevent unexpected energization, start up or release of stored energy in order to prevent injury to employees	1.6.2	***Access to operating positions and servicing points:*** Machinery must be designed and constructed in such a way as to allow access in safety to all areas where intervention is necessary during operation, adjustment and maintenance of the machinery.
1910.147(c)(1)	***Energy control program:*** The employer shall establish a program consisting of energy control procedures, employee training and periodic inspections to ensure that before any employee performs any servicing or maintenance on a machine or equipment where the unexpected energizing, start-up or release of stored	1.6.3	***Isolation of energy sources:*** Machinery must be fitted with means to isolate it from all energy sources. Such isolators must be clearly identified. They must be capable of being locked if reconnection could endanger persons. After the energy is cut off, it must be possible to dissipate

	energy could occur and cause injury, the machine or equipment shall be isolated from the energy source and rendered inoperative.	normally any energy remaining or stored in the circuits of the machinery without risk to persons.

Source: [12]

It is necessary to understand the LOTO concept as a process, or a system of management of hazardous energy influence, which is targeted on specific activities and hazards arising from maintenance activities management. Such ´system´ must coming-out from basic requirements for occupational health and safety management (OHSM) [26, 27].

The basis for implementation of the concept of hazardous energy management, the so-called ´hazardous energy management system – HEMS´, is assessment of activities risks [28] of operators, as well as maintenance workers in relation to specific equipment or a group of equipment, and a correctly elaborated preventive maintenance plan. If there are autonomous maintenance activities performed on equipment by the machine operator, and it is probable that throughout the performance of such activities, the operator may be hit by hazardous energy (he will happen to be in the zone), it is possible to apply the requirement for energy isolation also for these activities, where the condition is a correctly elaborated safety procedure.

2 METHODOLOGY AND METHODS

Safety is the opposite of feeling of danger (identification and estimate and range of hazard) in our everyday life. In the past, the no longer valid version of OHSAS18001 from 1999 [29] defined safety as *´the state when all inacceptable risks are eliminated´.* Generally, it is possible to define safety based on energy equilibrium by using the law of thermodynamics as follows:

$$\Delta S(t) = \Delta C + \Delta(I_{ESM} + I_{NSM}) \quad (1)$$

where: ΔS *- represents change of safety level in time (potential of human protection within work environment),*
ΔC *- is a change of all external and internal conditions having influence on safety at a given time (management support, legislation requirements, influence of the public, ...),*
ΔI_{ESM} *- level of implementation of measures having positive influence on safety,*
ΔI_{NSM} *- level of implementation of measures having negative influence on safety.*

By implementation of HEMS, it is inevitable to realize that there are several influences on maintenance management at the same time, e.g.:

- not the same activities are often performed, or their frequency depends on many factors (production, condition of equipment, capacity, quantity of equipment, ...),
- status equipment changes, their failure rate – *´they are always able to surprise us ´*,
- their maintenance requirements change (legislation, customer, costs),
- operation conditions change, impact of environment (operator activities, condition of buildings, production programme, ...),
- team and maintenance knowledge changes (leaving of experienced employees and coming of the new ones with insufficient experience and knowledge of the operation),
- information gets lost (chaotic control of information flow and its assessment),

- **organization management and also requirements – goals change,**
- in case of maintenance activities failure, the character of consequences is usually fatal.

Total risk evaluation of hazardous energy striking when performing maintenance activities, it is possible to define formally as follows:

$$R_{HEi} = P_{HEi} \times C_{HEi} \qquad (2)$$

where: R_{HEi} *- represents risk of injury origination as a result of influence of i-hazardous energy throughout the required maintenance activity,*
P_{HEi} *- is a probability of hazard of i-hazardous energy*
C_{HEi} *- seriousness of consequence of hitting by i-hazardous energy*

For individual risk parameters, it is necessary to define types of hazardous energy, e.g. electrical, mechanical, heat, gravitational, chemical, radiation. Sometimes a specific description of energy such as water, vapour, gas etc. is applied in practice.

With their properties, the hazardous energy types represent source of threat while performing given activity. The threat itself is characteristic depending on the process of its releasing and activity, e.g. by means of compressing, burning, reeling etc. [30, 31].

From the viewpoint of the consequence seriousness rate, it is necessary to define the range (extent) of the given hazardous energy type, as various pressure, speed, temperature have a different impact on a human in terms of range and degree of their injury. The part of assessment is also a possibility of safe storage of energy or its diversion.

Therefore, correct hazardous energy implementation is a basis for HEMS implementation, see Table 2. Without cooperation of a company management, coordination of OHS manager with maintenance manager and process engineering, there is a threat of incompleteness and inaccuracy when implementing LOTO system.

Tab. 2 *Example of hazardous energy identification form*

TYPE OF HAZARDOUS ENERGY (X)					
□E-electric	□H-hydraulic	□M-mechanical	□R-radiation	□ W-water	□VA-vapour
□G-gravitational	□Ch-chemical	□P-pneumatic	□T-thermal	□ others	□ G-gases
□S-stored	□U energy type U(X):				
Assessment of HE sources					
ASSESSMENT AND EVALUATION OF HAZARDOUS ENERGY SOURCES					
No.	Source description	HE Isolation equipment	Range of HE	Type of HE X; (U)X*	Isolation method LO/TO/other**
Z1					□ /□/□
Z2					□/□/□
Z3	...				□/□/□

Way of isolation and verification method			
No.	Isolation devices	Verification method	Brief description of HE threat
Z1			
Z2			
Z3	...		
Notes:			
Explanatory notes: HE – hazardous energy, X – tagging of HE, U(X) – stored energy of a given type			

Source: [*author*]

Risk management has its algorithm – a procedure, or series of logical steps which must be followed, if the result should be keeping a satisfactory level of risks on acceptable level. By threat identification and OHS risk assessment, regulations pursuant to standard ISO 12100 [31] are usually followed, by machinery construction but also by risk assessment in operation. OHS management system (see ISO 45001) is also a structured system stemming from the fundamental Deming cycle for management and improvement, the so-called P-D-C-A (Plan - Do - Check - Act) [32].

Hazardous energy management system represents an integrated part of the OHS management system (OHSMS). Its structure must both refer to and intersect the existing occupational health and safety management system. It must stem from the respective steps:

P – Planning
- Identification of machinery and equipment risks (user instructions – requirements for operation and maintenance).
- Identification and work activities risk assessment (labour-safety procedure for operator and preventive maintenance plan).
- Identification and analysis of sources, types and range of hazardous energy (HE) and elaboration of hazardous energy isolation procedures.
- Orientation meetings, LOTO introduction, workshops.

D – Realization
- Hazardous energy isolation procedure and hazardous energy restoration procedure (LOTO procedures - LOTOP).
- Inspection of observance of individual LOTOP steps.
- Teaching and training of authorised persons, trainings of persons in question.

C – Control
- Performance evaluation: measurement and assessment of LOTOP effectivity and efficiency.
- Audit of hazardous energy management system.
- Proposal of improvement measures.

A – Improvement
- Re-evaluation by the management and realization of the measures taken.
- Layout with the listed lock out spots.
- Raising awareness – gradual training of all the respective persons and operators.
- Instruction videos and constant approaching to employees.

By HEMS system application, its maintenance and interconnection with the existing OHS management structure is the most important part.

If in TPM (Totally productive maintenance), there is a requirement for the so-called ´early equipment management´, as one of the fundamental TPM pillars [33, 34], then it is obvious that the effectivity of the maintenance control depends on the level of its involvement already in initial intention of the new equipment acquisition. It is similarly valid that if HEMS is to be both efficient and effective, as an integrated constituent part of OHSMS, it must begin already in the early stage of the equipment life cycle, i.e. during its design

3 FINDINGS AND DISCUSION

In order to verify the level of HEMS control within industrial companies, a questionnaire was drawn up by a research team of the department – see Table 3, which was assessed by both maintenance managers and OHS managers in the companies, where the system had been implemented or, they were in the middle of its implementation planning phase.

The questionnaire was structured in 9 basic parts, whereas, the examined areas were, Q1: Industry area where the questioned person exists / works; Q2: Who is responsible for LOTO within the organization; Q3: What is the level of experience with LOTO implementation; Q4: Level of the attended LOTO training; Q5: Employees´ expectations from the implementation of HEMS; Q6: HE Identification – way and method; Q7: Level of experience with realization of LOTO procedures; Q8: Who is responsible for/ prepared LOTO procedures; Q9: Measurement and Improvement of HEMS. In the conclusion, there was a possibility to add own opinions as to LOTO implementation.

45 questionnaires were returned, out of which 10 were completed only within the area of planned activity and however, so far, they had not even taken the introductory training. These questions were not included into the total assessment.

Tab. 3 *HEMS questionnaire evaluation*

Area of interest		Answers
Q1: Industry area where the questioned person exists / works?		
Q1.1	Automobile	20
Q1.2	Chemical / petrochemical	10
Q1.3	Food industry	0
Q1.4	Metallurgical	2
Q1.5	Other (describe).......................	3
Q2: Who is responsible for LOTO within the organization?		
Q2.1	Maintenance Manager	4
Q2.2	Foreman of operation	8
Q2.3	OHS Manager	4
Q2.4	OHS and Maintenance Manager	12
Q2.5	Other (describe)........................	7
Q3: What is the level of experience with LOTO implementation?		
Q3.1	Only initial LOTO training	13
Q3.2	We have attended pilot	8
Q3.3	Fully implemented HEMS system	8
Q3.4	We are improving the already implemented system	6
Q4: Level of the attended LOTO training?		
Q4.1	Without initial training, instructions were sent by e-mail	3
Q4.2	We were only bought locks	3
Q4.3	We had an introductory course	18
Q4.4	Action plan of trainings and responsibility was established	10
Q5: Employees´ expectations from the implementation of HEMS?		
Q5.1	From HEMS, we mainly expect improvement of safety	23
Q5.2	Improvement of maintenance	6
Q5.3	Improvement of relationship with operators	2
Q5.4	Problems by keeping of maintenance performance time	4
Q5.5	Formalism without noticeable improvement	0

Q6: HE Identification – way and method?		
Q6.1	No HE was identified, only isolation devices were purchased	8
Q6.2	Database for HE identification was used	16
Q6.3	We made something up	8
Q6.4	We did not understand what HE is	3
Q7: Level of experience with realization of LOTO procedures?		
Q7.1	LOTOP are not real, others have made them up	3
Q7.2	They do not provide sufficient overview; they are too complicated	7
Q7.3	They do not provide sufficient overview; they are too simple	6
Q7.4	They are exactly as we need them	19
Q8: Who is responsible for/ prepared LOTO procedures?		
Q8.1	LOTOP were elaborated by supplier of machinery or LOTO devices supplier	1
Q8.2	Mainly maintenance	15
Q8.3	Mainly safety workers	3
Q8.4	Team: Safety and maintenance	9
Q8.5	Team: Safety, maintenance and LOTO devices supplier	7
Q9: Measurement and Improvement of HEMS?		
Q9.1	Is HEMS implementation a subject of regular meetings?	10
Q9.2	Are HEMS goals established, and their measurement and evaluation?	15
Q9.3	Are proposed improvements accepted by management?	10

Source: [*author*]

In terms of research, the following facts were found:

- Mainly the respondents from automobile industry (57 %) participated in the survey.
- 1/3 of the questioned claims that HEMS is a responsible OHS manager and maintenance manager, i. e. their cooperation is inevitable 34 %.
- Not even one third of organizations has a fully implemented system, whereas 37 % have attended only initial LOTO training.
- In some organizations, employees were not trained, they were only bought locks or sent the general regulation (usually corporations)! However, as much as 53 % of the questioned have already attended the introductory course.
- More than a half does expect significant safety improvement from HEMS, as much as 66 % of the questioned persons.
- Initial HE identification was performed in more than 46 % of the cases based on the provided database of the possible HE.
- LOTO procedures were mostly (more than 54 %) created according to real necessity and condition of the equipment, and they were mainly created by maintenance workers (43 %) – the so-called authorised employees.
- HEMS is a constituent part of regular company management meetings, its performance and improvement (43 %) is assessed.

4 CONCLUSIONS

The aim of this article was to point at the actual state of hazardous energy identification system by performance of maintenance activities on the machinery and equipment in the Slovak industrial companies. The latter identification must be a basis of complex risk management as well as integrated part of the OHS management system.

By means of analysis of legislation and valid standards of both the EU and worldwide, it was found that the non-existing standard within the EU is a serious absence, which would serve as a sufficiently good instruction on how to proceed by LOTO implementation, or HEMS. In the EU, there is a high emphasis put on the safety integration already in the construction phase, where both operator's and maintenance activities must be taken into consideration. In the USA, LOTO was implemented as obligation for equipment operators of how to improve safety while entering the hazardous area of the equipment itself (its maintenance). However, the offered services from LOTO devices suppliers in the EU stem from the USA legislation and ANSI standard only. As there is no binding methodology for HE management for employer in our country, LOTO suppliers often offer simplified procedures to maintenance workers. They are targeting on identification of energy isolation devices existing on the equipment, and not on the identification of the hazardous energy when performing the respective activity. Therefore, it is necessary to realise that LOTO implementation represents a set of system steps which must be integrated into OHSMS within the organisation. Proposal for ´renaming´ of LOTO programme, as it is usually called, to hazardous energy management system, extends the frame of its understanding and management as a constituent part of the complex OHS management within organization. A survey has revealed that only 34 % of organisations understand LOTO implementation as a system (HEMS), and it is mainly safety and maintenance management who is ´hand in hand´ responsible for its implementation and improvement. However, on the other hand, which is a positive thing, even though HEMS is not a legislative requirement of OHS, the trend of implementation is significant – 46 % of the questioned had already been informed about LOTO requirements in their practice.

Future research in this area should explicitly point at creation of standard for HEMS implementation within the EU. The effort shall be to create a structure which would be fully integrable with actual management systems (ISO, Annex SL) and to build a database of measurable performance indicators which would support to both manage and improve HEMS.

LOTO programme cannot be understood only as a methodology effective for maintenance workers, it must have a structure which shall emphasize the importance of hazardous energy management, i.e. the states which are often not realised by even the equipment constructor, because he does not have enough of information on possible failures and necessary procedures for their elimination.

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