Journal of KONBiN 2023
Volume 53, Issue 3
DOI 10.5604/01.3001.0053.9062

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THE MOST COMMON NON-CONFORMITIES IN THE AREA OF MACHINE SAFETY AND METHODS OF THEIR ELIMINATION – NON-MECHANICAL HAZARDS

Najczęściej występujące niezgodności w obszarze bezpieczeństwa maszyn oraz metody ich eliminacji – zagrożenia niemechaniczne

Abstract: *This article presents the author's experience gathered during audits in the area of machine safety in the field of repeated non-compliances and errors occurring on machines, production lines and machine assemblies. The purpose of this article is to familiarize machine designers with safety requirements that are often neglected and to indicate to users purchasing machines what requirements should be taken into account when placing an order. This article focuses on non-conformities regarding non-mechanical hazards.*
Keywords: machine safety, safety requirements, machinery directive, improvement of machine safety, hazards

Streszczenie: *W niniejszym artykule przedstawiono doświadczenia autora zebrane podczas audytów w obszarze bezpieczeństwa maszyn w zakresie powtarzających się niezgodności i występujących zagrożeń na maszynach, liniach produkcyjnych i zespołach maszyn. Celem niniejszego artykułu jest przybliżenie projektantom maszyn wymagań bezpieczeństwa, które często są zaniedbywane a użytkownikom nabywającym maszyny wskazanie na jakie wymagania należy zwrócić uwagę podczas formułowania zamówienia. W niniejszym artykule skupiono się na niezgodnościach dotyczących zagrożeń niemechanicznych.*
Słowa kluczowe: bezpieczeństwo maszyn, wymagania bezpieczeństwa, dyrektywa maszynowa, poprawa bezpieczeństwa maszyn, zagrożenia

Received: September 18, 2023 / Revised: September 26, 2023 / Accepted: September 27, 2023

1. Introduction

The EN ISO 12100 *'Safety of machinery. General principles for design. Risk assessment and risk reduction'* [1] is absolutely fundamental in the context of machine safety. According to Annex B of this standard, hazards are divided into:

1) mechanical (e.g. loss of stability, fall from a height due to incorrect permanent means of access to machinery, crushing, impact and cutting caused by moving machine actuators, gravity fall or whipping of flexible fluidic hoses),
2) electrical (direct contact with live parts, indirect contact to exposed conductive parts),
3) thermal (contact with hot or very cold surfaces),
4) caused by noise and mechanical vibrations (exceeding permissible levels),
5) caused by radiation (laser, ultraviolet, electromagnetic field),
6) caused by hazardous substances (produced in the production process or used for production and maintenance),
7) combinations of hazards, e.g. from unexpected start-up resulting in mechanical injury or exposure to electrical shocks during maintenance work,
8) caused by failure to comply with ergonomic principles, e.g. in the area of excessive effort, inadequate lighting, incorrect location and identification of controls.

Mechanical hazards are most often visible to the naked eye and manufacturers better or worse implement safety measures for operators. However, they very often forget about other hazards that do not seem worth analyzing at first glance, e.g. hazards related to the substances used, produced or processed, hazards of burns, hazards related to ultraviolet, laser radiation or emitted electromagnetic fields. Typically, the quality of machinery documentation and its consistency leaves much to be desired, because often electrical, pneumatic, hydraulic diagrams and the controller program are created by different people. Difficulties then arise in understanding such documentation, even by the manufacturer's engineers [2–4].

In this article, the focus is on hazards 2 to 7. According to EN ISO 12100, a hazard is a potential source of harm. The term hazard can be qualified in order to define its origin (e.g. mechanical hazard, electrical hazard etc.) or the nature of the potential harm (e.g. electric shock hazard, cutting hazard etc.). The hazard can be permanently present during the machine's intended use or can appear unexpectedly. In some cases, a more appropriate term may be a hazardous event (an event that may cause harm) or a hazardous situation (a circumstance in which a person is exposed to one or more hazards). Another important term is a hazard zone or a danger zone, which means any space within and/or around machinery in which a person can be exposed to a hazard.

The article provides recommended measures to address identified non-conformities and risks arising from the hazards considered.

2. Electrical hazards

In contrast to mechanical hazards, which are very diverse and occur in different - sometimes unexpected - parts of the machine, electrical hazards are quite easy to catalogue and prepare checklists. The requirements in this respect are specified in EN 60204-1 [5] for electrical equipment of machines within a supply voltage range not exceeding 1000 V AC or 1500 V DC. This standard implements IEC 60204-1:2016, but it is also essential to consider the important amendments made by the European CENELEC [6]. For higher voltages, the EN 60204-11 standard applies.

2.1. Direct contact with live parts

Direct contact with live parts occurs especially when identifying defective electrical equipment and maintenance. Contact with a single-phase or three-phase voltage of 230 V is life-threatening. The requirements of EN 60204-1 are sometimes neglected, so the condition of electrical equipment should be inspected and diagrams analysed. Among other things, the requirements for electric shock protection should be checked in the following respect:

- whether the power cable is protected against mechanical and environmental damage,
- whether the degree of protection against the ingress of dust and water is adequate; that there are no unblocked openings in the control cabinet, that unused cable glands are blanked off, and that the cable glands are not too large in relation to the wiring carried. Checking the IP degree (according to EN 60529) is particularly important when cleaning the production line (especially the motor connection boxes),
- whether the control cabinet is opened with the use of a key (so the equipment is inaccessible to unauthorised persons) OR whether there is a pre-emptive power-off when the door is opened and can be bypassed, e.g. by deactivating the disconnector locking device on the door with a screwdriver OR whether the electrical equipment inside the cabinet has a protection degree of at least IP2X,
- whether the ISO 7010-W012 pictogram with a lightning symbol (Fig. 1) on the cabinet is used (required when hazardous voltages are present and the enclosure does not clearly indicate the electrical nature of the hazard - e.g. there are no control elements on the panel),
- whether the span of supply of the main disconnector is described on the label (particularly relevant for large machines with several control panels with disconnectors),
- whether the terminals of the disconnector provide a degree of protection of at least IP2X,

- whether a plate with a lightning symbol above the external power connection strip and a terminal cover on the main disconnector is used,
- whether the special conductors staying live when the main insulator is disconnected are coloured orange and there are appropriate warnings about live circuits in the vicinity of the disconnector,
- whether ferrules are used on the ends of the conductors and thus the possibility of fraying and protruding wires from the conductor lines is excluded,
- whether wires are labelled (identifiable) to prevent mistakes when changing apparatus, i.e. contactors, relays, circuit breakers, etc.,
- whether warnings against stored energy (in capacitors of frequency converters, UPS, etc.) are used.

Fig. 1. ISO 7010-W012 pictogram [5]

2.2. Indirect contact with exposed conductive parts

Protection against indirect contact concerns not only qualified electricians but also operators and members of the public. The exposed conductive parts can come under life-threatening electrical potential when the insulation is damaged, e.g. due to moisture, harmful radiation or mechanical damage. An unaware worker may touch the body or frame of a live machine, with serious consequences.

EN 60204-1 specifies in clause 18 the tests to be carried out to obtain confirmation of correct protection against electric shock due to indirect contact. The report of the protective measurements should include at least:

- checking the conformity of electrical equipment with the wiring diagram,
- testing the continuity of the protective bonding circuit (PE),
- measurement of the fault loop impedance ZS in the case of protection by automatic disconnection of supply (comparison of the current causing the automatic operation of the disconnecting protective device applied to the short circuit current),
- and functional tests that provide an answer to the question of whether the machine behaves as expected when a particular control device (switch button, potentiometer knob, etc.) is used.

In addition, insulation resistance measurements, voltage tests of the insulation and a check of the protection against residual voltages can be carried out.

The aforementioned protective measurements are very often neglected by manufacturers, even in the mandatory part.

Other safety-relevant requirements can be checked visually, such as:

- whether the electrical cabinet (control panel) and its doors are connected to the PE protective bonding circuit,
- whether the frame and conductive covers of the machine are connected to the PE circuit,
- whether there is a separate terminal for the neutral conductor and a separate one for the PE conductor,
- whether one terminal is used for only one PE conductor (disassembly of any part of the machine must not cause a loss of continuity of the PE circuit - this is a common error in the protective bonding circuit),
- whether the PE terminals are labelled with, for example, the IEC 60417-5019 symbol (Fig. 2).

Fig. 2. IEC 60417-5019 [5]

3. Hazards caused by unexpected start-up

The need for measures to isolate the media supplying the machine is referred to in Directive 2009/104/EC on minimum safety requirements, Machinery Directive 2006/42/EC and national regulations implementing the aforementioned directives.

Also, the **LOTO** (LockOut/TagOut) system implemented in the USA by the *'OSHA Control of Hazardous Energies Standards'* - 29 CFR 1910.147 - meets European legal requirements when organising and carrying out non-productive work (maintenance, repair) that requires the machine to be stopped.

The machine should therefore be equipped with energy shut-off-isolation devices (switch-disconnector or disconnector, main valves for pneumatic, hydraulic, process water, flammable gas, welding gas, CIP/SIP cleaners and sterilisers, etc.), which should be correctly labelled and easily accessible to reduce the motivation to bypass them. The essence of reliable isolation is the ability to lock isolation equipment, e.g. with a padlock or lids (Fig. 3).

Fig. 3 Examples of LOTO devices for locking energy insulators and tags [7]

In addition, care must be taken to ensure that the absence of utilities in the isolated installation can be confirmed, e.g. by the reliable position of the electrical disconnecting handle with its marked ON (I) / OFF (O) position, the indication of flow pressure gauges or other sensors and whether there are means to dissipate accumulated energy in the isolated installation (dump valves).

It is also important to check that all the controls (buttons) are labelled to prevent their misuse which may cause unexpected activation of the machine's actuators.

4. Thermal hazards

A common mistake in machine safety is to underestimate contact with hot surfaces, e.g. in process lines. The permissible instantaneous and long-term contact temperatures for different types of surfaces, e.g. plastics, ceramic materials, uncoated and coated metal surfaces, wooden materials, etc. are described in EN ISO 13732 [8]. The first part of the standard provides charts with temperature ranges at which burns do or do not occur and burn thresholds depending on the duration of skin contact with the surface of the material in question. It is therefore important for the manufacturer to carry out a risk assessment in this respect, to draw up appropriate safety instructions and to use pictograms warning of hot surfaces (Fig. 4a), information on the cooling down time to values considered safe, pictograms prohibiting access by unauthorised persons (Fig. 4b) and prescribing the use of Personal Protective Equipment (PPE), i.e. protective clothing, gloves (Fig. 4c), sleeves, etc.

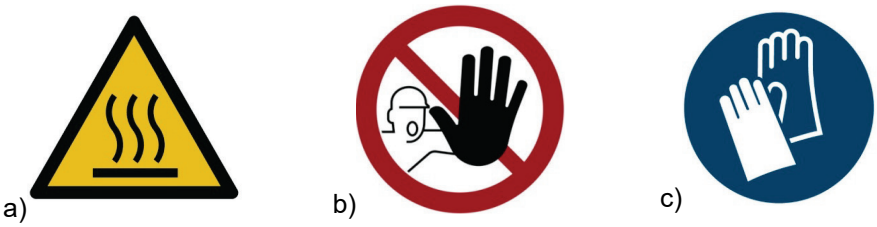

Fig. 4. Examples of pictograms [8] applicable to the hazard under consideration a) ISO 7010-W017 - hot surfaces, b) no access for unauthorised persons, c) ISO 7010-M009 - protective gloves must be worn

The same hazard applies to particularly cold surfaces. Human reactions to touching cold surfaces are given in part three of EN ISO 13732.

Another example is the manufacturers of robotic welding cells, who often focus all their attention on the implementation of appropriate safeguards for stopping dangerous robot movements, which according to EN ISO 10218 [9] requires the use of a two-channel architecture (Category 3) and the achievement of a safety level PLr=d, while neglecting to stop the welding process itself with an appropriate safety level.

5. Radiation hazard

An inherent danger with welding cells is ultraviolet radiation, as well as the electromagnetic field emitted into space. UV radiation can cause loss of vision, which is why the shutters of robotic welding cells are fitted with suitable filters and the cell itself is enclosed with solid shielding. However, there are cases of gaps in the aforementioned shielding that allow unauthorised access with the whole body or parts of the body, which can expose personnel to dangerous radiation and contact with moving parts and hot surfaces.

To complete the safety requirements, the learning mode of the robot should also be considered (usually manual mode with limited speed and raised shutter). In this case, the welding process should either be inactive so as not to expose the eyes of the setter, or individual filters should be provided and adequate screens should be provided to separate it from the rest of the shop floor.

Health and safety requirements for the exposure of workers to electromagnetic fields (EMF) hazards are regulated by Directive **2013/35/EU** [10]. Publications issued by the European Commission - two volumes of guidance on the subject [11, 12] - are a great help. In volume one, Table 3.2 is given, listing machines for different industrial sectors, stating for which machines the measurements of the EMF are expected, depending on whether workers have active medical implants, passive implants or are not particularly exposed.

Manufacturers of machinery are obliged to provide information on likely emissions of non-ionising radiation which may be harmful to humans, including those using implanted medical devices (see Directive 2006/42/EC Annex I, 1.7.4.2 v). The following series of standards EN 12198 *Safety of machinery - Assessment and reduction of risks arising from radiation emitted by machinery*, harmonised with the Machinery Directive are very helpful, as well as:

- EN 50499 *Procedure for the assessment of the exposure of workers to electromagnetic fields,*
- EN IEC 62822-1 *Electric welding equipment. Assessment of restrictions related to human exposure to electromagnetic fields (0 Hz to 300 GHz) Product family standard.*

The machines also contain laser tools for measuring, marking details or machining materials. The most sensitive part of the body to laser radiation is the human eye. According to EN 60825-1 *'Safety of laser products. Equipment classification and requirements'*, the following classes of lasers are distinguished: 1, 1M, 1C, 2, 2M, 3R, 3M and 4. In simple terms, the higher the class, the more dangerous the laser is for humans. The aforementioned standard defines minimum safety requirements as well as warning labels depending on the laser class in question.

Manufacturers of processing machines for laser cutting use sight glasses through which the operator can monitor the production process. These sight glasses usually contain appropriate filters for the wavelength emitted by the laser. However, what is forgotten is that the filter should also be effective for the ultraviolet radiation produced by the processing itself.

6. Hazards caused by hazardous substances

Hazards from hazardous substances must be analysed in the different phases of a machine's life, e.g. in the maintenance phase, in the production phase. In the maintenance phase, it will be all kinds of lubricants, oils, cleaners, emulsions, while in the production phase, it could be gases generated by welding, gases used for inerting during welding, paints, varnishes and solvents in paint booths, aluminium and magnesium filings during the grinding of castings, in the food industry: food concentrates, preservatives, flavour enhancers, etc.

It is important to analyse in detail the Material Safety Data Sheet (MSDS) of the used chemicals to select, if necessary, PPE on the basis of these and/or to apply organisational measures in the form of strictly defined residence times and warnings in the form of appropriate pictograms (see EN ISO 7010).

Another important aspect is to ensure adequate ventilation and to decide whether the ventilation should switch on automatically when the production process starts and switch off after a certain delay or whether it can be switched on manually.

In addition to the consequences of poisoning and injury to personnel, the rules for ensuring explosion-proofness must also be taken into account. The manufacturer is bound by the **ATEX Directive 2014/34/EU** [13] and the user by the **ATEX USER Directive 1999/92/EC** [14]. The manufacturer is obliged to equip the machine with equipment of an appropriate explosion protection category adapted to the substances under consideration that are present in the explosive zones of gases and/or dust. The user should, in accordance with the Explosion Protection Document, carry out a systematic review of the protective measures used.

7. Hazard caused by noise

A very common mistake appearing in machine instructions is the absence of data on noise emissions or incomplete data with no information on the corrective characteristics. However, Directive 2006/42/EC in Annex I, 1.7.4.2u) provides detailed requirements for the determination and declaration of noise level.

According to the quoted paragraph, the following information on airborne noise emissions is required:

- the A-weighted emission sound pressure level at workstations, where this exceeds 70 dB(A); where this level does not exceed 70 dB(A), this fact must be indicated,
- the peak C-weighted instantaneous sound pressure value at workstations, where this exceeds 63 Pa (130 dB in relation to 20 μPa),
- the A-weighted sound power level emitted by the machinery, where the A-weighted emission sound pressure level at workstations exceeds 80 dB(A)

These values must be either those actually measured for the machinery in question or those established on the basis of measurements taken for technically comparable machinery (…).

In the case of very large machinery, instead of the A-weighted sound power level, the A-weighted emission sound pressure levels at specified positions around the machinery may be indicated.

Whenever sound emission values are indicated the **uncertainties** surrounding these values must be specified. The operating conditions of the machinery during measurement and the measuring methods used must be described.

Where the workstations are undefined or cannot be defined, A-weighted sound pressure levels must be measured at a distance of **1 metre from the surface of the**

machinery and at a height of 1.6 metres from the floor or access platform. The position and value of the maximum sound pressure must be indicated.

It is noteworthy that, according to Directive 2003/10/EC [15], **above 80 dB (A) the employer must provide workers with hearing protectors**, while **above 85 dB (A) the employer requires hearing protectors to be worn**. In these cases, the pictogram mandating the use of hearing protectors ISO 7010-M003 should be used.

8. Nonconformities concerning the content of the machine documentation

Rarely does a manufacturer produce a complete machine instruction handbook in accordance with the essential requirements of Directive 2006/42/EC in Annex I, par. 1.7.4.2 on the content of the machine instructions.

The instructions lack descriptions regarding transport, maintenance, safety-relevant spare parts, workstations descriptions, warnings regarding unauthorised use of machinery, essential properties of tools, methods of action to be taken in the event of jamming, accident or breakdown, and, as mentioned earlier, the correct declaration of noise levels.

In addition, typically there are differences in the designation of apparatus and equipment in electrical and pneumatic or hydraulic diagrams and in the software of safety controllers. Analysis of such diagrams is then significantly hampered.

An integral part of the machine instructions is the **EC Declaration of Conformity** (or a document setting out the content of the EC Declaration of Conformity), the content of which should comply with Annex II of the Machinery Directive. When creating the declaration of conformity, manufacturers make a whole range of mistakes, starting with incorrectly titling it by calling it a "CE Certificate" or "CE Declaration".

It is very common to cite the Low Voltage Directive (LVD) in addition to the Machinery Directive. Meanwhile, in section 1.5.1 of Annex I, the Machinery Directive states that *'The safety objectives set out in Directive 73/23/EEC (former LVD) shall apply to machinery. However, the obligations concerning conformity assessment and the placing on the market and/or putting into service of machinery with regard to electrical hazards are governed solely by this Directive'*.

In most cases, it is also important to comply with the EMC Directive **2014/30/EU**, something that manufacturers repeatedly forget.

It is also important to comply with the language version requirements. The instructions should be provided to the user in the original language and in the language(s) understood by the user. The same applies to the EC Declaration of Conformity.

9. Summary

Despite the fact that the Machinery Directive was published in 2006 and this is the next edition, machinery manufacturers are still struggling to understand and implement its requirements correctly. Statistics on serious and fatal accidents in Europe show that efforts are still required to make machinery safer and to check the correct implementation of safety measures. The content of this article presents the author's selective insights from the conducted safety audits. The aim of this paper is to provide both manufacturers and users of machinery with practical advice in this area.

The manufacturer must remember not only about mechanical and electrical hazards, which are quite obvious, but also about other, often underestimated, e.g. hazardous substances, radiation, electromagnetic fields, noise and inconsistent documentation. In addition, one should pay attention to ergonomics, which is quite an extensive topic to analyse.

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