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

Najczęściej występujące niezgodności w obszarze bezpieczeństwa maszyn dotyczące zagrożeń mechanicznych oraz sposoby ich eliminacji

Abstract: *The article presents the author's experience gathered during machine safety audits in the field of repeated non-conformities and errors occurring in machines and assembly of machinery in various industry sectors. This work aims to show machine designers how to eliminate these errors when designing machines, and to indicate to users/investors what aspects to pay attention to during acceptance and when ordering machines. This article focuses on non-compliance regarding mechanical hazards.*

Keywords: machine safety, machinery directive, safety requirements, improvement of machine safety

Streszczenie: *W artykule przedstawiono doświadczenia autora zebrane podczas audytów bezpieczeństwa maszyn w zakresie powtarzających się niezgodności i błędów występujących w maszynach i zespołach maszyn w różnych sektorach przemysłu. Celem pracy jest pokazanie projektantom maszyn, w jaki sposób błędy te należy eliminować już podczas projektowania maszyn, natomiast użytkownikom/inwestorom wskazanie, na jakie aspekty zwrócić uwagę podczas odbiorów oraz na etapie zamawiania maszyn. W niniejszym artykule skupiono się na niezgodnościach dotyczących zagrożeń mechanicznych.*

Słowa kluczowe: bezpieczeństwo maszyn, dyrektywa maszynowa, wymagania bezpieczeństwa, poprawa bezpieczeństwa maszyn

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1. Introduction

In accordance with Annex B of the EN ISO 12100 standard [1] titled '*Safety of machinery. General principles for design. Risk assessment and risk reduction*', the existing hazards are divided into:

- mechanical (e.g. loss of stability due to improper anchoring and during transport, fall from a height caused by incorrect permanent means of access to machinery, crushing, impact and cutting caused by moving machine actuators, gravity fall or whipping of flexible fluidic hoses),
- electrical (direct contact with live parts, indirect contact with exposed conductive parts),
- thermal (contact with hot or very cold surfaces),
- caused by noise and mechanical vibrations (exceeding permissible levels),
- caused by radiation (laser, ultraviolet, electromagnetic field),
- caused by hazardous substances (produced in the production process or used for production and maintenance),
- caused by failure to comply with ergonomic principles, e.g. in the area of excessive effort, inappropriate lighting, incorrect location and identification of control elements,
- combinations of hazards, e.g. unexpected start-up that may result in mechanical injuries or exposure to electric shock during maintenance work.

An important part of the risk assessment of machines is their control systems with implemented safety functions that prevent accidents, see works [2] [3]. Cybersecurity is becoming an increasingly noticeable problem and has been included in the list of essential requirements in the new Machinery Regulation 2023/1230 [4]. This regulation will apply from 2027, while the challenges related to cybersecurity in the industry have been noticed for years by many experts [5] [6] [7].

It is impossible to fully assess the compliance of machines without the documentation related to a given machine, which has a significant impact on safety (content of the machine instruction handbook and EC/EU declaration of conformity, consistency and completeness of diagrams of electrical, hydraulic and pneumatic control systems).

This article focuses on mechanical hazards and recommendations for eliminating the identified hazards. Where possible, concepts are illustrated using sample photos and drawings.

2. Loss of stability

The hazard related to loss of stability is considered first to determine whether the machine poses a risk of tipping over on people in its immediate vicinity. A positive result of the check allows you to continue the audit. The check involves visually checking the state of anchoring the machine to the ground. Particular attention is paid to the dimensions of the machine and the location of its centre of gravity. This is particularly important in the case of tall and narrow machines with a high centre of gravity, which may additionally change depending on the products being transported, e.g. spiral conveyors (Fig. 1).

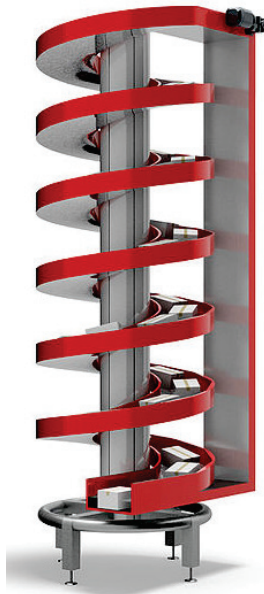


Fig. 1. A spiral conveyor placed on four feet, the height of which dominates over other dimensions[8]

A common error is the lack of anchoring of the machine despite the existing anchor holes, and at the same time, there is no information in the assembly instructions whether anchoring is required or only optional.

In this situation, the manufacturer should supplement the instructions with clearly formulated anchoring requirements (e.g. the minimum number of anchor bolts and their location to guarantee the stability of the machine), while the user or integrator should anchor the machines to a surface with appropriate strength parameters.

Loss of stability must also be taken into account when transporting the machine. In this respect, the machine instruction handbook is checked to see whether it contains appropriate guidelines regarding the required means of transport at various stages (long-distance transport,

short transport - in the hall), a division into components (boxes), information about their weight and centre of gravity. The visual assessment includes the arrangement of guides for forklift forks, the presence of eyebolts for crane or overhead crane slings, and the presence of appropriate labels and/or pictograms indicating attachment points.

3. Fall from a height

According to the multi-part standard EN ISO 14122 [9] [10] [11] [12], a fall from a height is considered **above 0.5 m**, although the risk assessment indicates it may also be necessary below this height. However, according to the Regulation on General Occupational Health and Safety in force in Poland [13], work at height is work performed on a surface **at a height of at least 1.0 m** above the floor or ground level. However, work at height does not include work on a surface, regardless of the height at which it is located, if the surface is covered on all sides to a height of at least 1.5 m by solid walls or walls with glazed windows or is equipped with other permanent structures or devices protecting the employee against falling from a height. This Regulation also states that on surfaces raised to a height of more than 1.0 m above the floor or ground level, on which employees may stay in connection with their work, or serving as passages, guard-rails should be installed consisting of protective handrails placed on at least 1.1 m high and **toe-plates at least 0.15 m high**. A knee-rail should be placed halfway between the handrail and the toe plate, or this space should be filled in a way that prevents people from falling out. The toe-plate dimension is 5 cm higher compared to the requirements of the EN ISO 14122-3 standard (Fig. 2), which is a common error when delivering machines to Poland from foreign manufacturers. As you can see, the orderer should specify in detail the requirements for the machine manufacturer to avoid this error during delivery.

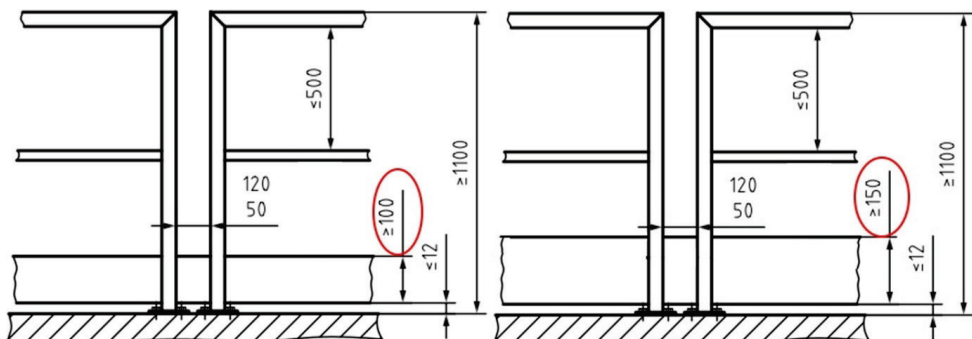


Fig. 2. Requirements for the dimensions of guard-rails according to the EN ISO 14122-3 standard with a 100 mm toe-plate and a 150 mm high toe-plate in accordance with Polish legal requirements (based on [11])

A common mistake with ladders is placing the hoops or vertical parts too sparsely in the safety cage. The correct sizes in accordance with EN ISO 14122-4 are shown in Fig. 3. Additionally, it is necessary to remember that the width of the rungs should be in the range of 400-600 mm (exceptionally 300 mm), the height between the rungs should be in the range of 225-300 mm, and the depth of the rung was at least 20 mm and that the **rungs were not round**. The descent to the ladder should be secured with a self-closing gate to prevent falling from a height, e.g. in the event of a person retreating.

A self-closing gate is not necessary when accessing stairs or ladder-stairs, however, a risk assessment may indicate such a necessity, e.g. when there is a control panel right next to the descent.

A self-closing gate is not necessary when accessing stairs or stepladders, however, a risk assessment may indicate such a necessity, e.g. when there is a control panel right next to the descent. After completing tasks related to operating this control panel, the operator may take a step back or to the side, intuitively expecting to lean on the guard-rail, and this may result in a fall from a height.

The ladder entrance at the bottom area should also be protected against unauthorized climbing, e.g. by means of a flat cover placed on the rungs to a height that makes it impossible to climb (anti-climb device) and/or a trap door hatch cover, which is usually secured with a padlock.

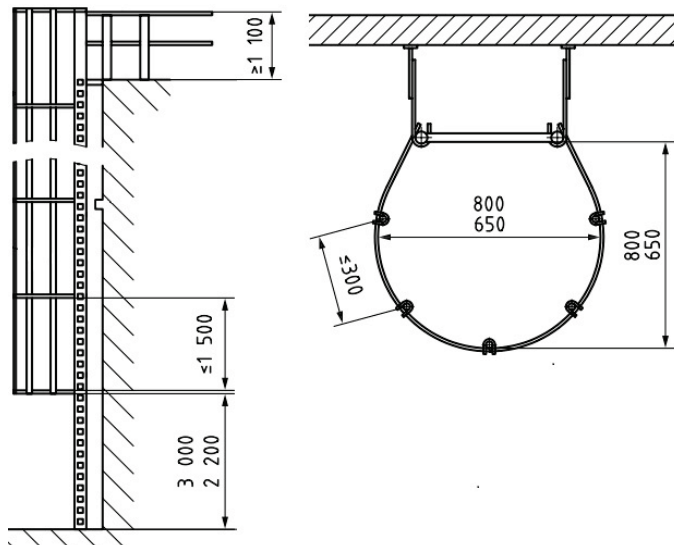


Fig. 3. Arrangement of the safety cage, hoops and uprights of the cage on a ladder according to [12]

A significant difference from the normative requirements according to EN ISO 14122-2 regarding the width of clear passages, which is a minimum width of 800 mm, and in the

case of passages intended for simultaneous use by several people - 1000 mm or occasionally used passages with a width of 600 mm or shorter passages than 2 meters with a width of 500 mm, the Polish Occupational Health and Safety Regulation [13] provides for a **minimum passage width of 750 mm**.

Securing pipeline passages through floors and gaps between working platforms and adjacent structural elements, e.g. a building wall or a machine body, poses significant problems. The EN ISO 14122-2 standard comes to the rescue in this case, providing detailed requirements for reduced heights of toe-plates and handrails.

4. Crushing and impact caused by moving machine actuators

Moving parts of the machine (cylinder piston rods or electric drives with tools) that may cause crushing or impact should be protected with **fixed guards** meeting the requirements of EN ISO 14120 [14], provided that frequent access to them is not necessary. If access is required **more frequently than once a week**, this standard recommends that the guard be **coupled with an interlock** (i.e. a sensor detecting its opening) or **coupled with an interlock with locking**. The lock keeps the door/cover closed most often until the dangerous movement of the machine stops or slows down significantly to ensure safety. The requirements of the EN ISO 14119 [15] standard dedicated to interlocking guards with guard locking are to be applied.

In the case of perforated (mesh) guards, it is important to properly distance the cover from dangerous machine elements, depending on the shape of the mesh and its dimensions. The EN ISO 13857 standard [16] is helpful in this respect and also provides tabulated dimensions regarding the distance of distance guards (perimeter fences) depending on their height and the height of the hazard zone (Fig. 4).

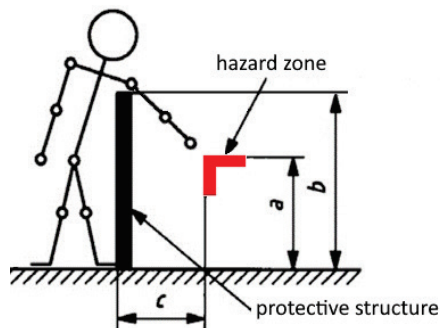


Fig. 4. Concept of safety distance between the protective structure (fence) and the hazard zone; a – height of the hazard zone, b – height of the protective structure, c – horizontal distance ensuring safety (based on [16])

In case of very frequent access to the hazard zone, e.g. when feeding and removing the processed workpiece from the press, **light curtains** are often used to prevent the movement of the press punch. The condition for using "nonmaterial" protection in the form of light beams is that there is no possibility of material or parts being thrown out of the machine during operation and the time the machine stops from the moment of entering the protective zone is short enough to ensure that movements stop before the operator is able to reach into the zone. Requirements in this respect are specified in the EN ISO 13855 standard [17]. Figure 5 shows the concept of the safety distance between the light curtain and the hazard zone.

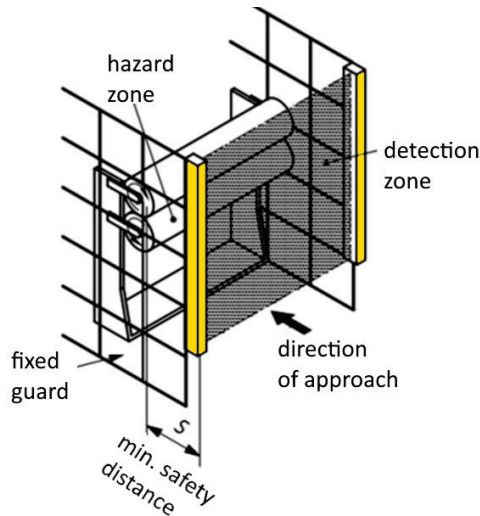


Fig. 5. The concept of the safety distance from the light curtain to the hazard zone based on [17]

In order to determine the safe distance, the EN ISO 13855 standard provides a number of requirements and formulas. For example, for a curtain with a resolution (distance between adjacent beams) of no more than 40 mm, the appropriate formula takes the form:

$$S = (K \cdot T) + 8(d - 14)$$

where:

S – minimum distance from the detection zone to the hazard zone [mm]

K – speed of approaching the human body or parts of the human body [mm/s]

$K=1600$ mm/s for distances S greater than 500 mm (e.g. whole body approaching)

$K=2000$ mm/s for distances S not greater than 500 mm (e.g. quick hand movement)

T – the overall system stopping performance (time to stop the dangerous part of the machine) [s]

d – detection capability (resolution) of the curtain [mm]. It is assumed that the minimum resolution ensuring finger detection is 14 mm, so the second part of the above equation will be zero if a curtain with such a resolution is used.

The mentioned stopping time (overall system stopping performance) after entering the zone protected by the light curtain can be determined by summing the activation times of individual elements in the safety-related control system (sensor, logical unit, actuator(s), brake/tool inertia). but the result is a longer time than the actual measurement, which forces the curtain to be moved further away. This solution is often suboptimal because there is usually no space in the production hall, and there would be a dead zone behind the curtain where an employee may be undetected. Therefore, such a dead zone should be additionally protected, e.g. with a horizontal laser scanner or a horizontal curtain, or with mechanical covers, which increases costs and worsens ergonomics. It is therefore worth measuring the overall system stopping performance in accordance with the EN ISO 13855 standard using a mobile **stop time meter** (Fig. 6), which often significantly shortens the distance between the hazard zone and the curtain. The EN IEC 62046 [19] standard recommends repeating the **stopping time measurement every 12 months** (unless local legislation requires otherwise). This is related to the wear of friction elements and deterioration of braking parameters during machine operation.

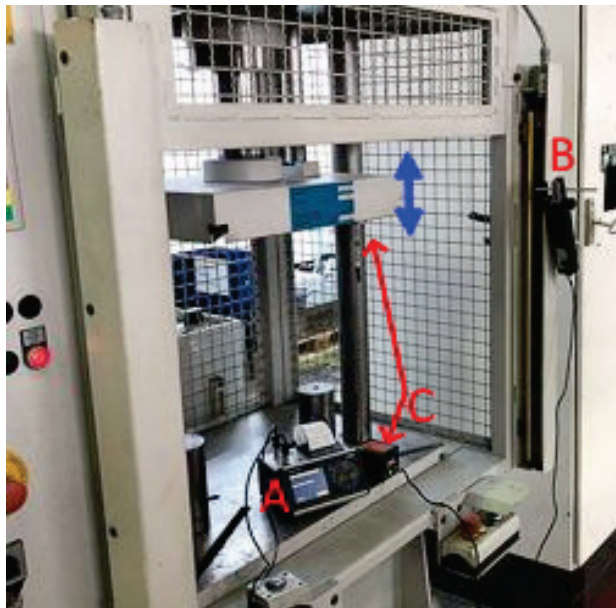


Fig. 6. Measurement of the machine's stopping time using a stop time meter (A) equipped with an electromagnet with a flag (B) and an encoder C with a thin line attached to the dangerous moving part [18]

The overall system stopping performance (stopping time) can be precisely determined using a device called a stop time meter [18]. Fig. 6 shows the principle of measuring the overall system-stopping performance. The parameterizing and printing protocol device (A) triggers an electromagnet with a moving flag (B), which covers the beam of the light curtain. The encoder (C) attached to the stationary part of the machine is driven by a thin line attached on the other side to the dangerous moving part of the machine. Time T is measured from the moment the electromagnet (B) is triggered until the movement stops or the speed is reached ensuring safety. Ten measurements are taken and the worst case is selected, and the safety distance S is determined.

If a workpiece may be thrown out of the machine, instead of a light curtain, a mechanical cover or roll-up roller shutter should be used, which is coupled with an interlocking sensor that performs a safety function with an appropriate **Performance Level** according to EN ISO 13849 [20,21,22].

The roller shutter itself also generates a risk of hitting the operator's head or shoulders during rapid lowering, so it should be equipped with a **pressure-sensitive edge** in accordance with EN ISO 13856-2 [23]. In this case, the PL level may be lower compared to the main protections regarding the movement of the press punch.

It is worth noting that power-operated guards that can generate a force of up to **150 N** and energy of up to **10 J** should automatically re-open after encountering an obstacle (protection against human impact). If no pressure-sensitive edge is used, the above-mentioned values should be limited to **75 N and 4 J** (see EN ISO 14120).

The risk reduction measures used may vary depending on the machine's operating mode. For example, different safeguards are often used to prevent unintentional gravity descent during press maintenance and repair than during production. For example, in presses, in the first case, a mechanical support device (mechanical restraint device) is used - the slide support(s). If such a device cannot independently withstand the full force of the slide pressure, it must be interlocked with the control so that the closing stroke cannot be made while the support is in the position supporting the slide. On presses with a stroke of more than 500 mm and a table depth of more than 800 mm, a supporting device should be permanently installed in the press and by (manual) setting able to support the slide.

However, when it comes to protection against falling of the slide during production (the operator manually feeds the workpiece to/from the press), this risk should be reduced either by:

- a mechanical restraint device,
- a hydraulic restraint device,
- a combination of a single valve hydraulic restraint device and a mechanical restraint device.

A frequently encountered device is a mechanical restrained device in the form of a safety catcher of the SITEMA type (Fig. 7). However, a common mistake is the incorrect

selection of safety devices, where the holding force of the safety catcher is lower than the force generated by the press slider, which may result in tragic accidents. It is therefore important to select a device with a holding force not lower than the maximum force generated by the press.

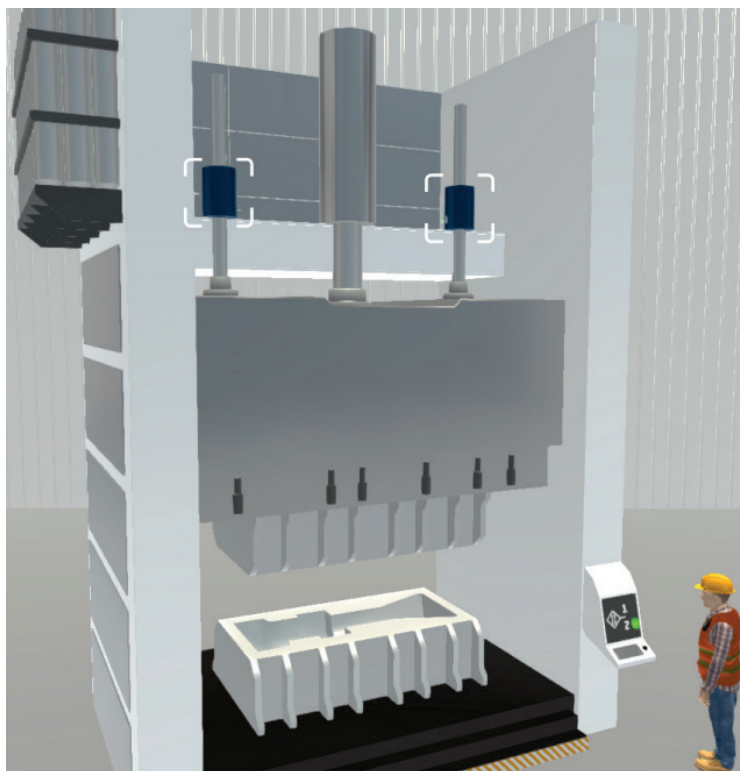


Fig. 7. Use of two SITEMA catchers in a press [24]

The withdrawn EN 693 standard for hydraulic presses did not clearly define the required safety category for both of the above-mentioned functions. Therefore, many manufacturers have tried to achieve the highest Category 4 required by the standard for other press functions/protections, but were often unable to meet such high requirements. This gap has been filled by the new EN ISO 16092-3 standard [25], which provides required Performance Levels for a number of safety functions. For the above-mentioned functions of preventing gravity descent during repairs/maintenance and during production, the standard specifies the required level $PLr=c$ with Category 1 and $PLr=d$ with Category 2, which simplifies the analysis and reduces implementation costs.

5. Fluid systems

Fluid mechanics related to hydraulic fluids and compressed air is used in many machines. To ensure safety in this area, the EN ISO 4413 [26] and EN ISO 4414 [27] standards come in handy - the first one concerns ensuring the safety of machines equipped with hydraulic systems, and the second one with pneumatic ones.

A frequently considered mechanical hazard is whipping of a disconnected hose, which may result in blows and/or injection of emulsion under the skin or loss of an eye. Both standards define this threat, but they operate at a relatively high level of generality. Thus, the EN ISO 4413 standard states that if damage to the hose assembly may constitute a whipping hazard, it should be immobilized or covered by appropriate means. Similarly, if damage to the hose assembly may constitute a fluid ejection hazard or fire hazard, it should be protected by appropriate means.

The EN 289 standard for rubber moulding presses provides excellent assistance in this respect, which states that to prevent whipping of **flexible hydraulic hoses at a pressure of more than 50 bar** or **pneumatic hoses at a pressure of more than 10 bar**, at least one of the following measures must be taken:

- tear-proof hose assembly; the hoses shall have a minimum of two steel-cord layers in order to achieve the tear-proof connection mentioned; in addition, the ratio of the burst pressure of the hose and fitting to the maximum pressure in the circuit shall not be less than 3,5,
- fixed enclosing guards according to EN ISO 14120,
- attachment of the hoses by additional means e.g. by a chain (Fig. 8).

Additionally, to prevent inadvertent disconnection from connection points, ring connectors should not be used. Suitable connections are, for example, flange, flared or conical connections.



Fig. 8. Example of preventing whipping of a hydraulic hose with a rope [28]

The above requirements can be applied to many machines, bearing in mind that risk assessment is a higher priority than the requirements of the type C standard.

A common mistake made by manufacturers is the discrepancy in marking valves and their coils on pneumatic/hydraulic and electrical diagrams. Then there is a problem in their correct identification. Meanwhile, the EN ISO 4413/4414 and EN 60204-1 standards for electrical equipment of machines require consistency in the marking of control elements in diagrams.

While it is not necessary to convince manufacturers to mark electrical cables in control cabinets, marking flexible fluid hoses is often neglected. However, the EN ISO 4413/4414 standards require marking of both hoses and valves and their ports unless the design solutions prevent mistakes during assembly or replacement of the element, e.g. each hose in the bundle has a different diameter or different lengths, which means that they are not able to reach inappropriate ports.

6. Summary

The content of this article presents the author's observations and conclusions resulting from experience gained during machine safety assessments, including: based on the work [29]. The article cannot be treated as a complete set of applicable requirements, as it is intended to present the most common non-conformities and hazards, the risk of which has not been sufficiently reduced. The aim of the work is to familiarize both producers and users with the experience of encountered non-conformances and methods of preventing them in accordance with legal and normative requirements.

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