BASICS OF MACHINE OPERATION

Laboratory · Exercise 4

Designing safeguards for the human work zone

Guards · light curtains · safety distances



Akademia Techniczno-Artystyczna Nauk Stosowanych w Warszawie

Prepared by: dr inż. Radosław Gościniak

Akademia Techniczno-Artystyczna Nauk Stosowanych w Warszawie

Academic year 2026/2027

1. Goal and assumptions

Goal. Design the safeguarding of the workstation analysed in Exercise 3: fixed guards and doors, optoelectronic protective devices with calculated safety distances, emergency stops and two-hand controls, PPE and safe-work procedures.

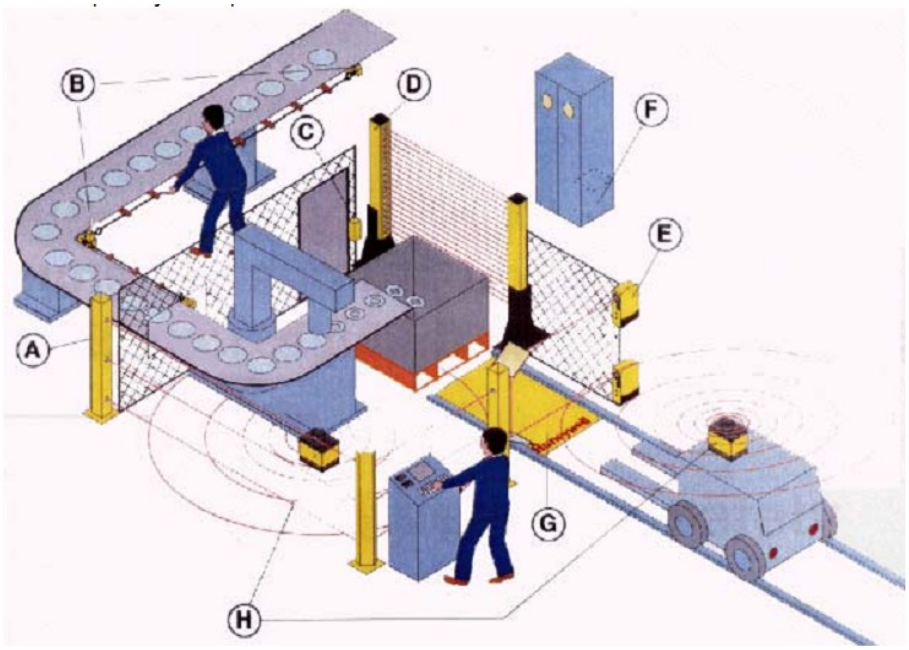
Input. The completed worksheet from Exercise 3 (same topic t1–t7) and catalogues of safety equipment (e.g. SICK, Pilz, Schmersal, Bosch Rexroth, Item, Axelent, Troax).

Organisation.

- Same team and workstation as in Exercise 3.
- In class (about 80 min): layout with the three volumes, route of guards, selection and positioning of optoelectronic devices with calculations.
- At home: safe-work procedures, re-evaluation of risk and the report.
- Report as PDF, file name: BMO_Ex4_<team number>.pdf.

2. Protective devices

The type of device depends mainly on the size of the protected zone, how often people must enter it, and the cost. Often it is easier to change the design and add a fixed fence than to use other devices. The best solution: a machine fenced so that the operator neither can nor needs to be near the danger zone.



Complete safeguarding of the operator work zone in an automated cell.

Mark	Device	Function
A	light barrier (multi-beam)	detects entering the danger zone
B	rope-pull emergency stop	stops the machine from any point along a conveyor
C	interlock with key, bolt and guard locking	detects and blocks opening of the door

Mark	Device	Function
D	light curtain	detects reaching into the danger zone
E	single light beam	detects a vehicle entering the zone
F	safety controllers	evaluate the signals of all protective devices
G	pressure-sensitive mat	detects presence in the danger zone
H	safety laser scanner	detects presence in a programmable area

Light curtains and scanners are **optoelectronic protective devices**. Their **resolution** – the smallest detected object – must fit the task: 14–16 mm for fingers and hands, about 30–35 mm for arms and legs, larger for the whole body. Three functions: **point protection**, **access control** and **area protection**.

Function	Advantages	Disadvantages
Point protection – not even a finger passes (e.g. operator feeds parts)	short distance, high productivity, ergonomic	high cost
Access control – the whole body cannot pass unnoticed	low cost	long distance, lower productivity, no presence detection
Area protection – continuous control of the area where people may be	presence detection	high cost

A laser scanner can have a **warning field** (slow down the robot, flashing light) and a **protective field** (stop all motion – treated by the PLC like an emergency stop, with a siren). The **restart button** must be outside the protected zone, where the operator sees the whole zone and can be sure nobody is inside.

3. Safety distances – EN ISO 13855

The minimum distance of an optoelectronic device from the danger zone depends on the approach speed and the total stopping time (EN ISO 13855 replaced EN 999):

$$S = K \cdot T + C$$

S – minimum distance [mm]; K – approach speed [mm/s]; T – response time of the device + stopping time of the machine [s]; C – intrusion distance [mm]; d – resolution [mm]; H – height of the detection plane [mm].

Application	Resolution d	Formula
Point / hand protection (vertical curtain)	d ≤ 40 mm (14 mm finger, 30 mm hand)	S = 2 000·T + 8·(d − 14); min. 100 mm; if S > 500 mm, recalculate with K = 1 600 (min. 500 mm)
Access control (multi-beam, whole body)	2–4 beams	S = 1 600·T + 850 (beam heights e.g. 400/900 or 300/700/1 100 mm)
Area protection (horizontal: mat, scanner)	–	S = 1 600·T + (1 200 − 0.4·H); C ≥ 850 mm, 0 ≤ H ≤ 1 000 mm

Example: light curtain d = 14 mm, response time 20 ms, press stopping time 180 ms → T = 0.2 s → S = 2 000 × 0.2 + 0 = 400 mm.

4. Guards and fences

Guards separating the energy sources from people are used first. The cheapest are fixed guards: steel or aluminium posts with mesh, transparent plastic (acrylic, polycarbonate), opaque plastic or sheet metal. A guard protects people and should still allow visual control of the machine.

Infill	Use
Mesh (3.5–80 mm, wire 2–8 mm)	medium and high mechanical loads, e.g. parts dropped by grippers; wire and mesh chosen for the energy
Transparent rigid (acrylic, polycarbonate)	dust, fumes, sparks, molten material; more expensive than mesh
Transparent flexible (overlapping strips)	moving elements without extra doors
Opaque rigid (sheet metal, plastic)	welding light, hydraulic fluids, coolants, high temperature
Opaque flexible (oil- or heat-resistant rubber)	moving pallets and tables, welding enclosures
Sound-absorbing	noise reduction – thickness for the frequency band

Typical mesh (mesh × mesh × wire, mm): 20 × 20 × 2.5; 20 × 20 × 4.0; 27 × 27 × 4.0; 40 × 40 × 4.0; 50 × 50 × 5.0. Posts are anchored to the floor; removal only with tools. Distances for reaching over or through guards: **EN ISO 13857** (replaced EN 294).

Service space and doors: at least 0.8 m between the guard and the machine; doors open outwards; sliding doors on the outside of the fence; hinged doors 0.8–1.0 m for a person, above 1.0 m double doors, sliding doors up to about 2 m (tool and transport trolleys); every door with a safety interlock and a lock for authorised staff only.



Example of transparent guards of an automated machine.

5. Two-hand control and service work

When the operator works in the rhythm of the machine, motion should start only on the operator's **release**. A **two-hand control** (EN ISO 13851) requires both buttons within 0.5 s and held during the hazardous motion; releasing one stops the machine. The control must be fault-tolerant (redundant) and meet the required PL (EN ISO 13849-1) or SIL (IEC 62061).

Fault finding often requires work inside the internal volume with energy on (e.g. adjusting a pneumatic cylinder). Then a **two-person procedure** applies: one person works inside, the second stays at the control panel, prevents unauthorised start, starts single motions on request and can stop the machine or help the injured.

Removing the cause of a fault always requires full shutdown and isolation of all energy sources (lockout/tagout).

6. Tasks

Task 1: Layout

Draw the workstation (scale 1:50 or on the 1 000 mm grid) with the three volumes from Exercise 3.

Task 2: Guards and doors

Design the fixed guards: route, height, infill and mesh size, doors (type, width, opening direction) and the 0.8 m service space.

Task 3: Optoelectronic devices

Select devices (type, resolution, catalogue model), mark their position and calculate the minimum safety distance S for each.

Task 4: Control devices

Place emergency stops, the restart button and any two-hand control; justify each position.

Task 5: PPE and procedures

List the PPE from Exercise 3 and write the safe-work procedures: normal operation, clearing a jam, setting and changeover, maintenance with lockout/tagout, two-person procedure.

Task 6: Re-evaluation

Re-evaluate the highest risks from Exercise 3 after your design (R after).

Deliverable: report (max. 6 pages) with layout, guards and doors, device table with S calculations, control devices, procedures and re-evaluated risks.

Standards: EN ISO 12100, EN ISO 13855, EN ISO 13857, EN ISO 13854, EN ISO 13850, EN ISO 13851, EN ISO 14119, EN ISO 14120, EN ISO 13849-1, EN ISO 10218-1/-2.

7. Assessment

Exercises 3 and 4 are graded together (max. 5 points): Exercise 3 – max. 3 points, Exercise 4 – max. 2 points. Exercise 4: guards and devices, safety distance calculations, completeness of procedures, quality of the layout.