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## THE ROLE AND IMPORTANCE OF RISK ASSESSMENT IN MACHINERY DESIGN AND CONTROL SYSTEMS ON THE EXAMPLE OF A MODEL RESEARCH LINE DESIGNED FOR THE PRODUCTION OF LOW-EMISSION COMPOSITE FUEL

### Rola i znaczenie oceny ryzyka w konstrukcji maszyn i systemach sterowania na przykładzie modelowej linii badawczej przeznaczonej do wytwarzania niskoemisyjnego paliwa kompozytowego

**Abstract:** *The article discusses the construction and functionality of a modular line for the production of low-emission composite fuel, which was developed as part of a project co-financed by European Funds, the aim of which was to develop an ecological, composite solid fuel intended for low and medium power boilers. The designed and built innovative production line has been tested in terms of safety requirements in accordance with the Machinery Directive 2006/42/EC. Based on the harmonized standards, the risk estimation algorithm was selected. The assessment covered, inter alia, mechanical, electrical and thermal hazards, hazards related to noise and processed material, and those related to control systems that perform safety functions. In order to eliminate non-conformities, technical and organizational measures increasing the safety of service were proposed.*

**Keywords:** low-emission composite fuel production line, risk assessment, safety analysis, safety-related control systems

**Streszczenie:** *W artykule omówiono budowę i funkcjonalność modułowej linii do wytwarzania niskoemisyjnego paliwa kompozytowego, która została opracowana w ramach projektu dofinansowanego z Funduszy Europejskich, którego celem było opracowanie ekologicznego, kompozytowego paliwa stałego przeznaczonego do kotłów małej i średniej mocy. Zaprojektowana i zbudowana innowacyjna linia produkcyjna została sprawdzona pod kątem wymagań bezpieczeństwa według Dyrektywy Maszynowej 2006/42/WE. Na podstawie norm zharmonizowanych dokonano wyboru algorytmu szacowania ryzyka. Ocenie podlegały m.in. zagrożenia mechaniczne, elektryczne, termiczne, zagrożenia związane z hałasem i przetwarzanym materiałem oraz dotyczące systemów sterowania realizujących funkcje bezpieczeństwa. W celu eliminacji niezgodności zaproponowane zostały techniczne i organizacyjne środki podnoszące bezpieczeństwo obsługi.*

**Słowa kluczowe:** linia do produkcji niskoemisyjnych paliw kompozytowych, ocena ryzyka, analiza bezpieczeństwa, systemy sterowania związane z bezpieczeństwem

## 1. Introduction

Due to the high demand of highly developed societies for energy and the accompanying limitations in meeting the demand for fuels, while meeting the requirements for environmental protection, the development of new low-emission fuels, and technological lines is an extremely important task for scientists, technologists, and engineers [11, 24, 34]. This problem is thus widely discussed in scientific research works [1, 23, 27, 29]. Possibilities for the production of environmentally friendly solid fuels are provided, among others, by pelleting [26, 28]. This process was initially applied mainly to plant biomass [25]. However, nowadays, various types of waste are increasingly used [11], e.g. vegetables or fruit [2], fungi [12], or even seeds [14]. An unquestionable disadvantage of pellet production is usually the high humidity of the input raw materials forcing them to be dried [32], obtaining the proper grinding before consolidation, and also the low calorific value of the finished pellets [20]. An alternative to this process can be briquetting [33, 40]. However, due to the operating characteristics of the devices, first of all, the ratio of energy inputs to efficiency, the most advantageous is the use of roller briquetting machines [4, 7]. Therefore, the issue of producing environmentally friendly composite fuels in roller presses is currently being developed [3, 6, 8, 22]. Additionally, as shown based on the tests carried out on lump coal and briquettes made of the same type of coal, briquetting in roller presses changes the internal structure of the fuel and, thanks to the created pore network, enables easier extraction of volatile parts from the inside of the fuel. The change in structure changes the reactivity of the fuel [5]. Additionally, briquetting at the stage of material preparation enables the catalyst and/or

sorbent to be evenly distributed throughout the entire volume of the fuel, not only on its outer surface [5, 35].

In order to meet the energy and environmental challenges, a scientific and industrial consortium was established, composed of:

- Science and Industry Centre EMAG JSC,
  - Łukasiewicz Research Network - Institute of Innovative Technologies EMAG,
- designed to develop an innovative, modular line for the production of low-emission composite fuel as part of the project entitled "Development of a technology for the production of low-emission, qualified composite fuel based on hard coal and a research technological line for checking product quality".

The project developed technology for the production of environmentally friendly composite solid fuel for small and medium-sized boilers. A fine fraction of hard coal is used to prepare the fuel. Depending on the parameters of the input raw material, various binders, sorbents and water are added in specific proportions. The mixture, thus prepared and averaged, is compressed in a roller press to the form of microbriquettes of 1 to 3 g and a unit volume of 1 to 2.5 cm<sup>3</sup>. The briquettes are then dried to an air-dry moisture content, cooled and packaged. In addition to meeting the requirements for production efficiency and low electricity consumption, it is also necessary to ensure the safety of the operators of the production line. According to the legal regulations in force in the European Union in the form of the Machinery Directive 2006/42/EC [13], machines should be safe for users and bystanders. To achieve this, machines are designed to meet the technical safety requirements for safe operation (the aforementioned Machinery Directive), explosion-proofing (ATEX Directive 2014/34/EU) and electromagnetic compatibility (EMC 2014/30/EU). An example of a machine that meets all relevant requirements is the mobile mining robot described in the paper [9].

## **2. Materials and Methods**

However, before discussing the risk assessment process and risk estimation algorithm, the construction and functionality of the composite fuel production line will be presented.

### **2.1. Construction and functionality of a composite fuel production line**

The production line was designed so that it could be easily transported and set up at the final production site. The mobility of the line was ensured by the use of standardised transport containers equipped with machines and equipment implementing the technological process (Fig. 1).

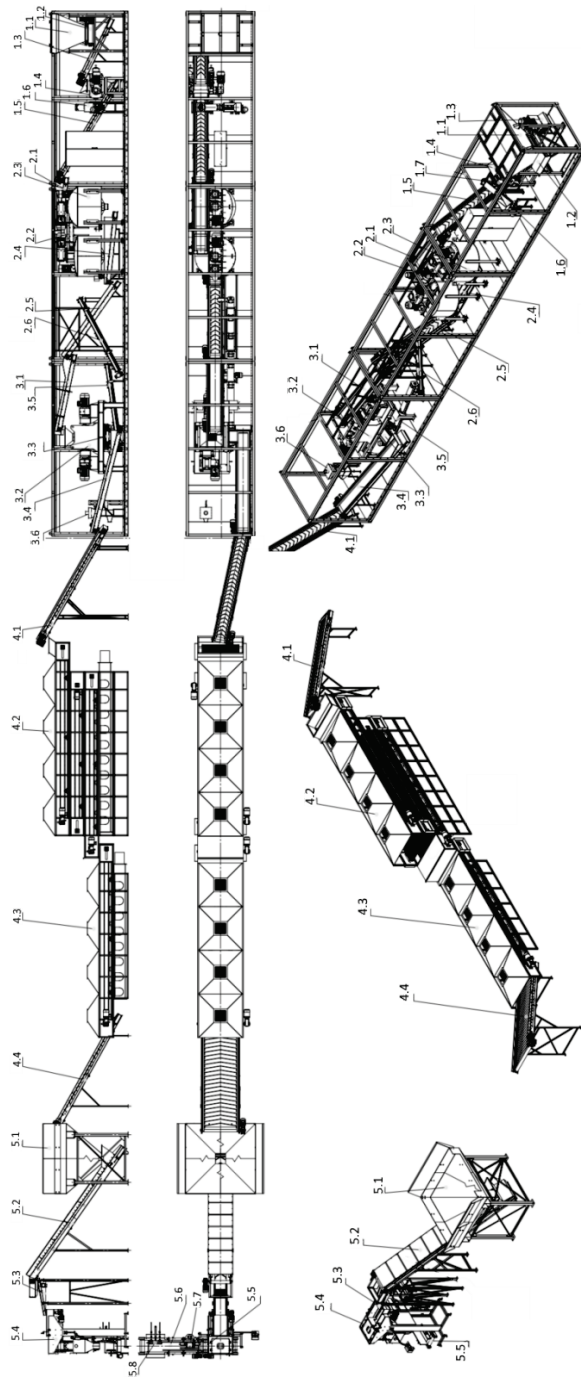


Fig. 1. Construction of the composite fuel production line

The line consists of the following assemblies listed below and highlighted in Fig. 1: coal hopper (1.1), conveyor below the hopper (1.2), feeder conveyor to crusher (1.3), crusher (1.4), conveyor below the crusher (1.5), binder charging hopper (1.6), testing scale (1.7), ascending conveyor (2.1), reversing conveyor (2.2), planetary mixers (2.3), conveyor receiving the feed from the mixers (2.4), ascending conveyor (2.5), screw conveyor 2 (2.6), belt conveyor for feeding to the press (3.1), roller press (3.2), vibrating sifter 3 (3.3), receiving conveyor belt (3.4), screw conveyor 1 (3.5), drying device (3.6), conveyor belt (4.1), dryer (4.2), cooling unit (4.3), conveyor belt (4.4), hopper (5.1), conveyor belt (5.2), vibrating sifter (5.3), weighing and bagging machine (5.4), conveyor with 1 m length (5.5), conveyor with 2 m length (5.6), bag sealer (5.7), and bag ejector (5.8).

Assemblies 1.1 to 3.6 are housed in containers. The sides of the containers are covered with covers made of tarpaulin and opened with a tool. The remaining assemblies (from 4.1 onwards) are free-standing machines.

The line is equipped with a central control cabinet that serves as the operator's panel. The machine is powered by 3-phase 400 V, compressed air and water. It is designed for use in an industrial environment and should be operated by trained operators.

Knowing the construction and functionality of the production line defining the limitations of the machine. To discuss the process of risk assessment and risk estimation, which have been adopted from international standards to ensure full objectivity.

## **2.2. Risk assessment**

The standardisation of the risk assessment process is intended to reduce the subjectivity of assessments made by different auditors with different professional backgrounds.

In order to ensure an adequate level of safety and to apply appropriate technical measures, such as mechanical guards that are unmonitored or monitored with sensors to detect their opening, light curtains and laser scanners to detect intrusion of the danger zone, etc., it is first necessary to carry out a risk assessment of the individual parts and areas of the machine. The trouble is that the assessment should not be subjective and dependent on the individual views of the auditors.

To this end, international standardisation technical committees, e.g. ISO and IEC, have developed standards harmonised with directives, which allow a systematic and algorithmic approach to the risk assessment process. The standard for risk assessment is the international standard EN ISO 12100 [17], while the technical report ISO/TR 14121-2:2012 [19] proposes specific methods for risk estimation.

According to EN ISO 12100, a risk assessment consists of a risk analysis and a risk evaluation. The risk analysis itself consists of three steps:

- identifying the limits of the machine (e.g. industrial or domestic use, technical parameters, capacity, type of material processed, etc.),
- identifying the hazards (e.g. mechanical - crushing, electrical - shock, thermal - burn, noise-related hearing loss, etc.),
- and the aforementioned risk estimation.

There are many qualitative and quantitative methods for estimating risk. Based on the technical report [19], it was decided to use a qualitative approach based on the risk graph shown in Fig. 2, which consists of four parameters: S, F, O, A.

The individual parameters of this graph can be defined as follows:

1. Severity of injury (S)
  - S1 - slight and reversible injuries, e.g. cuts, bruises, mild burns, minor fractures e.g. of a finger
  - S2 - severe and irreversible injuries, e.g. an arm or leg fractures, amputations, loss of sight or hearing, life-threatening and fatality
2. Frequency or duration of exposure (F)
  - F1 - rarely, e.g. less than 24 minutes accumulated per shift (1/20th of shift time), once a day, once a week/month/year
  - F2 - more than 24 minutes accumulated during one shift of 8 hours
3. Probability of occurrence of a hazardous event (O)
  - O1 - Low - almost impossible
  - O2 - Medium - likely to occur at some time
  - O3 - High - will occur frequently
4. Possibility of avoidance of the harm (A)
  - A1 - possible under certain conditions, e.g. hazard is foreseeable, visible to the naked eye, operator is aware of it, movement speed is limited, movement is repetitive cyclically
  - A2 - impossible, e.g. shrinkage from electric current, hazard not visible to the naked eye (accumulation of explosive gases), unpredictable and fast movements, e.g. of a robot.

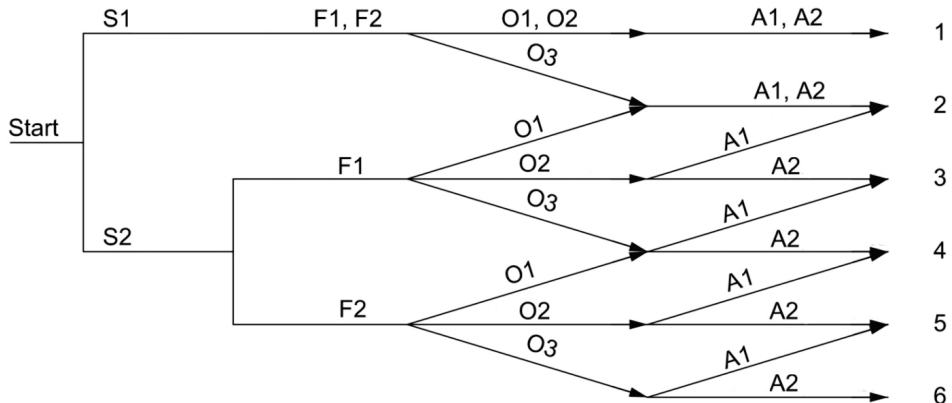


Fig. 2. Risk graph for risk estimation

This results in 6 risk levels (1,...,6). Naturally, the higher the level of estimated risk, the more demanding the preventive measures to be implemented and the faster this should

be done (see Table 1). On the other hand, at low risks, one can limit oneself to warnings presented in the form of texts and pictograms or recommend personal protective equipment or the training of workers. It is at this point that the risk evaluation is carried out, as the last step in the risk assessment.

If there are hazardous areas on the machine, they must be separated from direct human access. This can be achieved by means of mechanical guards on the machine itself or by means of fences (distance guards) fixed with anchor bolts, for example. If such a guard had to be removed frequently, e.g. once a week, it might not be reinstalled due to negligence. It should therefore be fitted with a sensor to detect its presence. Such a sensor should be connected to a logical subsystem, e.g. a controller or safety relay, and this should control an output subsystem in the form of a contactor or converter shutting off an electric motor or an electro-hydraulic or electro-pneumatic valve shutting off fluid systems.

**Table 1**

**Actions required depending on the level of risk (own elaboration)**

<b>Risk level</b>	<b>Risk name</b>	<b>Interpretation and required actions</b>
<b>1</b>	Negligible risk	The risk is negligible from a health and safety point of view; preventive measures are not required.
<b>2</b>	Very low risk	Significant preventive measures are not necessary. The use of personal protective equipment and/or training of workers should be considered, and risks should be minimised with pictograms and warnings.
<b>3</b>	Low risk	Preventive measures should be implemented if a worker has frequent access to the danger zone or a pictogram with a warning if only a qualified worker can be exposed infrequently.
<b>4</b>	Significant risk	The implementation of preventive measures is necessary at the earliest opportunity.
<b>5</b>	High risk	Implementation of preventive measures is urgent – they should be provided as soon as possible.
<b>6</b>	Very high risk	The machine should be isolated from energy sources, followed by the implementation of preventive measures.

This brings us to the realisation of the safety function implemented in the machine control system.

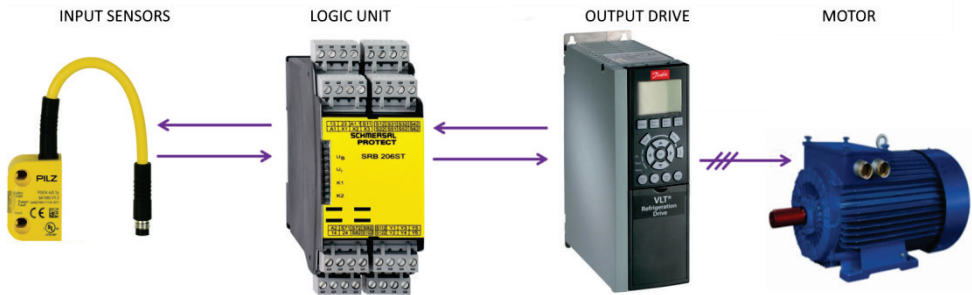
**2.3. Safety functions performed by the machine control system**

The requirement specification for a safety function consists of functional requirements and safety integrity requirements. Functional requirements are usually specified as a

natural language formulation, e.g. "Stopping the hazardous drive in zone X when safety guard Y is opened and preventing it from starting until the guard is closed".

Typically, the safety function is performed from three subsystems (Fig. 3):

- a sensor that detects the hazardous situation (electromechanical switch limit, light curtain, laser scanner),
- a logic unit analysing the signals from the sensor, and
- an actuator (e.g. a contactor that shuts down a dangerous drive or solenoid valve).



**Fig. 3.** Typical implementation of the safety function of stopping the dangerous drive after opening the guard monitored by limit switches (based on [36-39])

These subsystems form a safety-related control system. At the same time, the signal flow can be 2-way due to the diagnosis by the logic of the other subsystems. Two safety-related system standards can be used in the field of machinery safety: EN IEC 62061 [16] and EN ISO 13849-1 [18]. We use the requirements from EN ISO 13849-1.

How should the safety function be implemented? Should it be implemented in a two-channel form (with redundancy) or is a single-channel architecture sufficient? What diagnostics should be provided? The answers to these questions will depend on the amount of estimated risk, which, according to EN ISO 13849-1, must then be translated into the required Performance Level (PLr). The diagram in Fig. 4 of EN ISO 13849-1 can be used to determine the required PLr level of a given safety function of the control system.

In the graph, a path is to be selected consisting of:

- severity of injury (S),
- frequency and/or exposure times to hazard (F), and
- possibility of avoiding the hazardous event (P) and probability of occurrence.

The individual coefficients are described in the graph and coincide with the explanations in the section on the risk estimation graph (Fig. 2) with the difference that the probability of occurrence O is taken as certain and therefore has a value of 1. However, the standard ISO 13849-1 allows for a reduction of the required PLr by one level if a low probability of occurrence of the hazardous event O can be justified.



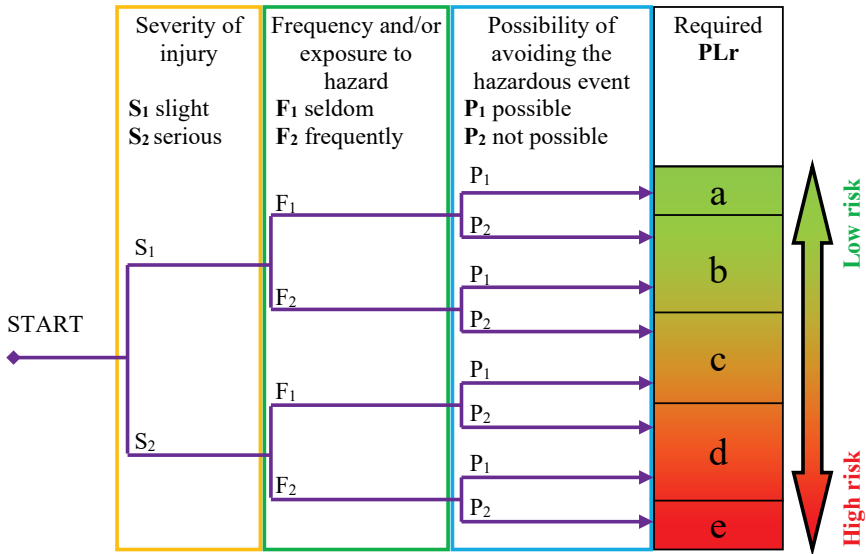


Fig. 4. Graph for determining the required PLr (own elaboration)

A given safety function is performed using hardware components and safety software. The individual subsystems are most commonly characterised by the manufacturer with safety parameters (PFH<sub>d</sub>, PL, categories) required by EN ISO 13849-1.

On the basis of appropriate formulas or simplified methods, the probability (frequency) of a dangerous failure per hour PFH<sub>d</sub> of the entire safety chain (safety function) consisting of the individual subsystems is to be determined and the achieved PL level of the safety function under consideration is derived from this (Table 2).

Table 2

**Determination of the Performance Level of a given safety function on the basis of PFH<sub>d</sub>**

PFH <sub>d</sub>	PL
$10^{-5} \div 10^{-4}$	a
$3 \cdot 10^{-6} \div 10^{-5}$	b
$10^{-6} \div 3 \cdot 10^{-6}$	c
$10^{-7} \div 10^{-6}$	d
$10^{-8} \div 10^{-7}$	e

The achieved PL must then be compared with the required PLr. The PL achieved must be equal to or greater than the required PLr; otherwise the safety function must be redesigned. In case the PL/PFH<sub>d</sub> is not known for all subsystems, the safety level of such a subsystem must first be determined independently. The determination of the PL and PFH<sub>d</sub> value for the subsystem is obtained from:

- the structure/architecture of the system (category B, 1, 2, 3, 4, describing single or dual channel systems, with different levels of diagnostic coverage),
- the mean time to dangerous failure (MTTF<sub>d</sub>, which may be low, medium, high),
- diagnostic coverage (DC, which may be low, medium or high),
- immunity to common cause failure (CCF<sub>≥65</sub>).

We will not discuss the selection or calculations of all the individual factors mentioned above here due to the limited volume of the article, and we refer the interested reader to the article [21] or directly to EN ISO 13849-1. It is also worth mentioning that there is software available on the market to assist in the determination of the required and achieved Performance Level, e.g. SISTEMA [31] or PAScal [30], to which manufacturers of safety components attach their libraries.

## **2.4. Selected non-conformities of the composite fuel production line**

For the purpose of this risk assessment, the method and the interpretation of the risk estimation parameters were selected. The research composite fuel production line was checked. The risks of the following hazards were listed, analysed and estimated:

- Mechanical
  - Instability of machinery
  - Crushing/impact during transport of machinery
  - Entanglement and crushed by moving parts in the machinery
  - Crushing by moving parts in mixers
  - Failure of the emergency stop function
  - Falling from a height
  - Possible head impact by protruding constructional elements
  - Eye contact with bulk materials
- Electrical hazard
  - Direct contact to live parts
  - Indirect contact with exposed conductive parts
- Thermal - Contact with hot surfaces and air
- caused by noise
- caused by materials and substances
- caused by failure to observe ergonomic rules
- caused by the environment in which the machine is used
- caused by unexpected start-up
- caused by incorrect labelling
- caused by incorrect documentation.

### 3. Results and Discussion

We will not be discussing all the hazards but will present the approach based on the sheet entitled Mechanical hazard - Entanglement and crushing by moving parts of machinery (Table 3).

As can be seen from the risk card shown, the hazard areas are first located, the exposed body parts are listed, the mode of operation and the handling activities during which the hazard occurs are given. Next, the current technical state is analysed, after which the level of risk is estimated based on the risk graph from Fig. 2 and the name of the risk and its interpretation is determined based on Table 1.

The above risk assessment and estimation is complete from the point of view of formal requirements, but the user may not know what to do next. Therefore, the rest of the sheet contains recommended measures in the form of technical protective measures (additional guards, additional safety sensors incorporated in the machine control system, etc.) and organisational measures (instructions, warnings, training, PPE, etc.). Details of the specific requirements can be found in the international standards quoted.

Particularly noteworthy is the fact that after the hypothetical implementation of the recommended countermeasures, a reassessment of the risk is carried out, verifying that the risk will be properly reduced to an acceptable risk level.

**Table 3**

**Description of the selected hazard, risk estimation before and after implementation of protective measures, current state and recommended protective measures**

<b>Hazard name</b>	<b>Mechanical hazard - Entanglement and crushing by moving parts of machinery</b>
<b>Location</b>	Conveyors, crusher, screw of the binder hopper, briquetting press (Figs. 5-12)
<b>Exposed body parts</b>	Upper limbs
<b>Mode of operation</b>	Normal work
<b>Handled activity</b>	Minor interventions during production
<b>Current state</b>	There are a number of upper limbs catching points along the production line (Figs. 5-12). Such points include the zones between the rollers and the conveyor belt and between the conveyor belt and the machine frame (Figs. 5, 6), between the belt and the reversing roller (Fig. 7); also access to the rollers of the crusher (Fig. 11), access to the screw of the hopper (Fig. 8), access to the rollers of the briquetting machine (Fig. 9). The crushing zones are extremely dangerous because in the event of jamming (suspension of the bulk material), an attempt to push the material by hand may occur, which may result in the hand being caught and crushed. There is also access to the entanglement and crushing zone in the screw conveyor (Fig. 10)

		There are no written procedures on how to unblock machine jams and/or material flow.	
<b>Risk estimation in current state</b>			
Severity of injury:	S2	Probability of occurrence of a hazardous event:	O3
Frequency or duration of exposure:	F1	Possibility of avoidance of the harm:	A2
Risk level:	<b>4</b>	Risk name:	<b>Significant risk</b>
<b>Recommended countermeasures</b>			
<p>A distance guard (fence) in accordance with EN ISO 14120 must be used around the control cabinet. If the fence is not monolithic but mesh, the safety distances (through the mesh eye, under the mesh and over the mesh) resulting from EN ISO 13857 must be ensured (Figs. 12 and 13). Access to the binder hopper should be prevented by a cover with a hinged sensor that blocks the movement of the auger when the cover is open (Figs. 8, 14). The sensor should be connected to a safety relay and this should cut off the auger motor drive. The safety function should meet PLr = c (S2, F1, P1) according to EN ISO 13849-1. If the flap is raised at one end and there will be hinges at the other end (including the interlocking sensor), care must be taken to ensure that the flap does not fall by gravity - a folding support should be provided, for example.</p> <p>To exclude access from the sides of the line, fixed guards complying with EN ISO 14120 should be used on the sides of all containers. These should be able to be opened with a tool or key (Figs. 12, 15 - green).</p> <p>Of separate note is the cover that excludes access to the mixers (Fig. 15 - blue colour). The mixer flaps have locking sensors. According to the designers, there may be a need to access the mixers once a week. In this case, the container cover must first be opened (blue colour in Fig. 15). According to EN ISO 14120, it is recommended to use movable guards when the foreseeable frequency of access is high (e.g. more than once a week) or when the removal or re-attachment of the fixed guard would be cumbersome. Movable guards should be interlocked or interlocked and locked according to EN ISO 14119.</p> <p>It must not be possible to insert a finger between the conveyor belt and the reversible roller. A solution may be the use of hood covers for the corners of the conveyors. The available gaps between the conveyor belt and fixed parts, such as the frame, should not exceed 5 mm in accordance with EN 620. This can be achieved by matching the assemblies with each other or using an additional filling flat bar.</p> <p>Prepare written instructions according to EN ISO 20607 on how to unblock machine jams and / or material flow (necessary tools, PPE, energy isolation measures).</p>			
<b>Risk estimation after implementing the recommended countermeasures</b>			
Severity of injury:	S2	Probability of occurrence of a hazardous event:	O1
Frequency or duration of exposure:	F1	Possibility of avoidance of the harm:	A2
Risk level:	<b>2</b>	Risk name:	<b>Very low risk</b>



**Fig. 5.** The places of catching under the conveyor (between the belt and rollers and between the belt and the frame)



**Fig. 6.** Access to the catching area between the support roller and the belt and between the belt and the conveyor frame



**Fig. 7.** Access to the catching area between support roller and belt and between the belt and reversable roller



**Fig. 8.** Access to the entanglement and crushing zone in the binder charging hopper



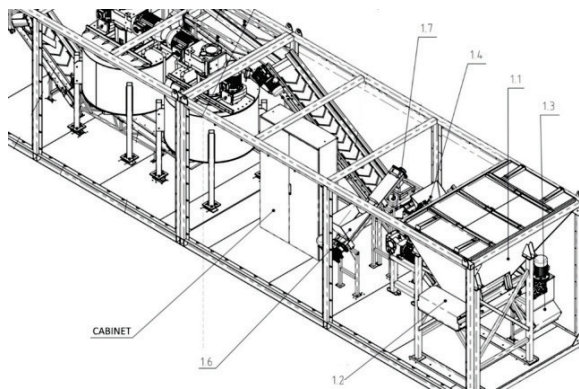
**Fig. 9.** Access to the catching and crushing zone of the briquetting press



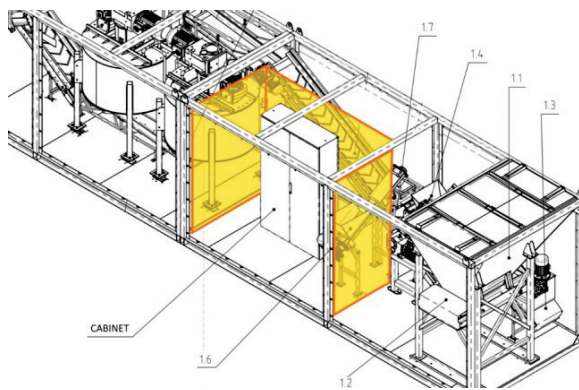
**Fig. 10.** Access to the entanglement and crushing zone in the screw conveyor



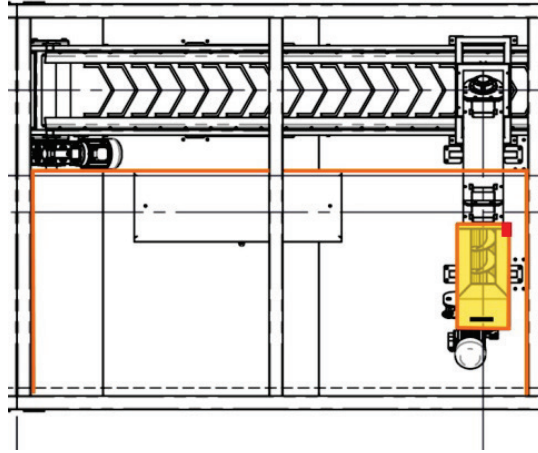
**Fig. 11.** Access to the rollers of the crusher



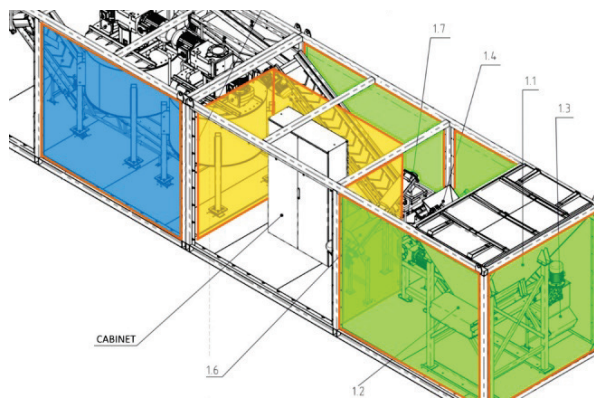
**Fig. 12.** Access to hazardous areas from the control cabinet



**Fig. 13.** Exclusion of access to hazardous areas by fencing around the cabinet



**Fig. 14.** Exclusion of access to the crushing zone in the charging hopper for the binder by means of an interlocking cover (flap)



**Fig. 15.** Exclusion of access to dangerous zones by means of guards around containers (fixed guards - green; fixed or interlocking guards - blue)

The sheet for just one hazard was presented above. However, as indicated above, more than a dozen hazards of different origin (electrical, thermal, noise, etc.) have been identified. Therefore, each of these must be considered separately, as they result in different injuries, different frequency of exposure due, for example, to different types of mode of operation (normal operation or repair).

For example, Electrical Hazard - Direct contact to live parts will primarily affect qualified electricians carrying out repair work on the control cabinet. The frequency of this type of work will be infrequent, e.g. once a year, but the severity of injury will be very serious (including fatality). In this case, the requirements of EN 60204-1 [15] for protection against direct contact are checked, as follows:



- the cabinet's IP degree of protection is not less than 20 (no holes, unused glands blanked off)
- the cabinet can be opened with a tool or has a pre-opening disconnection mechanism or that its apparatuses provides at least IP20 protection
- the cabinet door bears the ISO 7010-W012 symbol (lightning)
- the main disconnector is labelled with the power supply area (span of supply)
- the terminals of the main disconnector provide IP at least 20
- the conductors remaining live after switch disconnection are coloured orange and that appropriate warnings are provided
- all wires are marked according to the diagram to prevent connection errors and consequent electrocution
- the supply cable is protected against mechanical damage
- there are warnings against stored energy (on drives, UPS).

In the case of protection against indirect contact, the requirements of the EN 60204-1 standard related to the grounding of exposed conductive parts, their correct marking and the performance of protective measurements have been verified. The protocol of protective measurements should include the results concerning:

- compliance of electrical equipment with the electrical drawings,
- measurements of the continuity of the PE conductor(s),
- fault loop impedance measurements and proper selection of overcurrent protection, and
- functional tests.

Contrary to the hazard of direct contact, which is rare, such as once a year when repairing an electrical cabinet, exposure to hazard from indirect contact with exposed conductive parts occurs all the time while the machine is being operated.

An important and at the same time very specialised part of the risk assessment process is the functional safety analysis. For this purpose, safety functions are distinguished, most often related to stopping or slowing down the machine drives to a reduced speed (specified in standards) after opening the interlocking guards (monitored with a sensor) or intrusion of the light curtain or the field supervised by a laser scanner.

Validation of the required PLr levels on the basis of the graph from Fig. 4 or the levels given directly in the specific standard is subject to detailed analysis, and then the determination of the achieved PL levels of the considered safety functions.

Determination of the achieved PL level is based, in the first instance, on analysis of the electrical, pneumatic and hydraulic diagrams.

It is essential to use components designed to work in safety systems with the reliability and safety parameters specified by the manufacturer. Otherwise, such calculations have to be made independently, which is often not easy and sometimes not feasible (especially for electronic devices).

Once all the subsystems of a safety function have been identified, a calculation is made of the PL achieved for the whole chain starting from the input subsystem through the logic subsystem and ending with the output subsystem, which most often cuts power to the

actuator. The safety function is considered to be properly designed if the PL achieved is at least equal to the PLr required.

A complementary safety function is the emergency stop function, which does not itself monitor the machine's danger zones, but allows the production line to be stopped in case of an emergency. It is subject to the same analysis and validation as the safety functions described above.

## **4. Conclusions**

The search for new, efficient and environmentally friendly energy sources implies the construction of complex and innovative production lines. In addition to guaranteeing adequate production efficiency and economic viability, it is also important to ensure safety, which is a legal requirement in the European Union and in other countries.

A common cause of serious accidents is the intervention of operators during machine jamming caused by a disruption in the flow of workpieces, raw materials or products. The operator, unaware of the danger, may attempt to unblock the machine manually, which can result in parts of the body being caught. This is why it is so important to use the right technical protective measures to separate the dangerous zones from the operators, to properly train the operators and to provide instructions, tools and personal protective equipment for each foreseeable development scenario.

The risk assessment carried out identified existing hazards on the production line. Based on the risk estimation, risk levels were determined and prioritised for the implementation of countermeasures. Equipping machines with protective measures will allow the risks to be reduced as required by legislation. More importantly, both the operator and the manufacturer can feel more secure in the area of safety.

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