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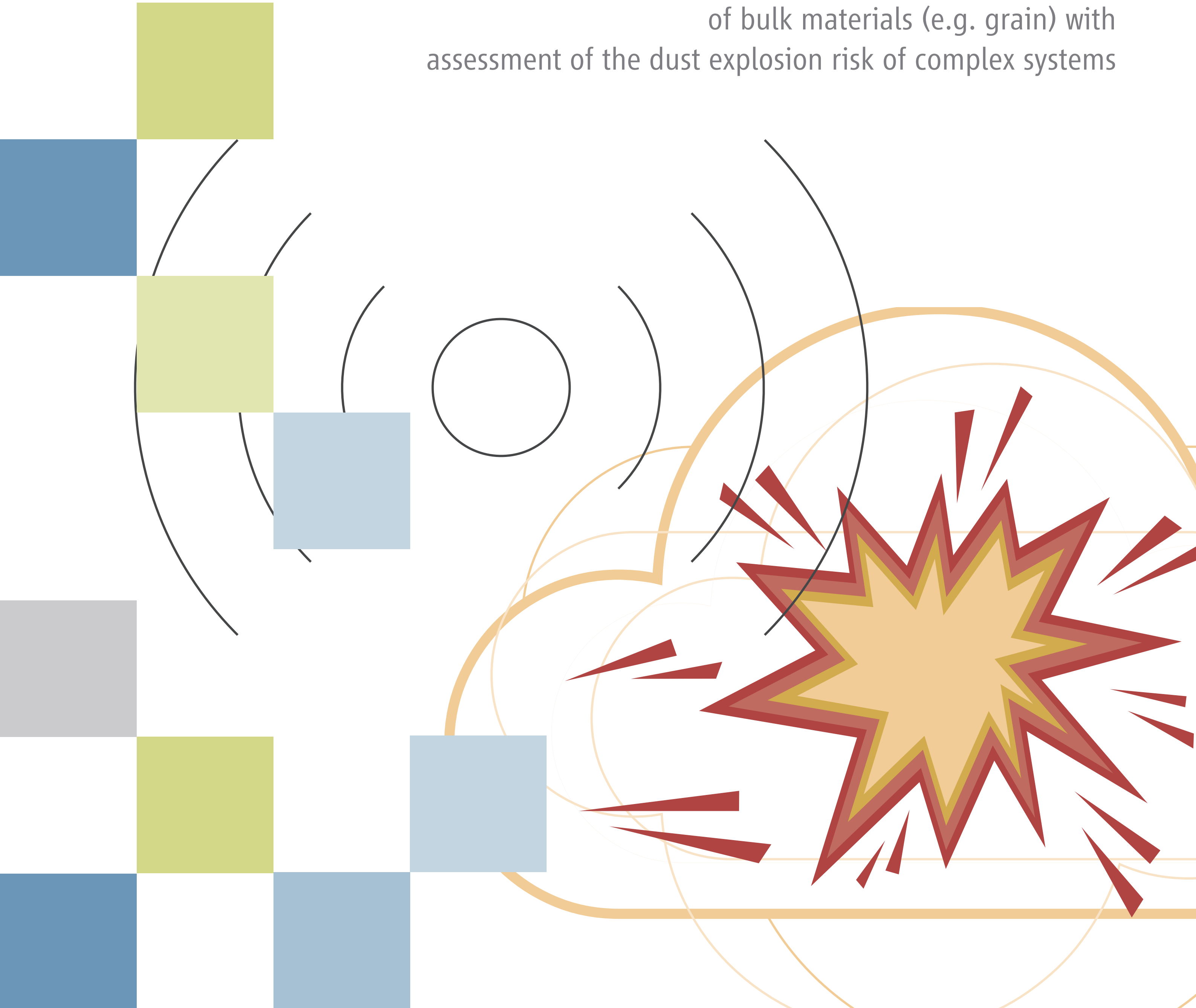
Siegfried Radandt

Digital transformation of technical systems with explosion risk

using the example of storage and processing of bulk materials (e.g. grain) with assessment of the dust explosion risk of complex systems



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Foreword

The digital transformation towards Industry 4.0 is leading to the development of new, also complex Cyber-Physical Production Systems (CPS/CPPS).

Opportunities

They bring new opportunities and challenges for safety and health at work in the world of work, in production and application. Safety in the broadest sense refers to both physical security (safety) and IT or cyber security (security).

What does this development mean for machines, plants, systems and the people working in these systems?

We experience how communication develops. On the one hand between individual machines (elements), production lines, plants, plants at different locations. On the other hand between manufacturers and users, operators, with external service providers, e.g. maintenance and repairs, consulting, with customers and control authorities. Variability and the extent to which such technical systems can be used depend on the development of intelligent networks within and across companies. This requires the development and use of big data and artificial intelligence in the sense of pattern recognition, respectively the ability of technology to recognise and apply rules.

A CPPS (Cyber-Physical Production System) can be used to improve products in terms of quality, time and production, variability of products and the use of work equipment, such as robots and cobots, and different machine applications for different process steps.

Challenges, risks

Not only do CPS and CPPS open up new opportunities, they are also more vulnerable and susceptible depending to a certain degree on its complexity. A fault or failure of one element can paralyse an entire system and also affect the safety and health of the people involved.

The use of complex systems requires an appropriate risk assessment with system and risk analysis for each individual risk: both "classical safety engineering" as well as dealing with risks for IT security, in particular through external and internal cyber attacks. Both, manufacturers and users are currently obliged to carry out risk assessments.

Are these new technological developments still covered by existing legal regulations, e.g. the EU-Machinery Directive? Or does the development towards a disruptive industry 4.0 require new regulations? This question is being addressed by experts, including in national, European and international standardisation committees, e.g. ISO TC 199 "Safety of Machinery". For our practice-oriented approach we can neglect this question.

Regardless of a possible change in legal requirements, it is a good idea to use the "tool" of risk assessment to make human-machine interaction safe, ergonomic and reliable in its results.

How can we make these new requirements understandable for our target groups = manufacturers and users of machines, devices, plants, especially in medium and small companies?

One approach for the Section Machine and System Safety is to prepare and present examples and thus explain complex contents step by step, so to speak.

One such example is the storage and processing of bulk materials (e.g. grain) with assessment of the dust explosion risks. The author, Prof. Siegfried Radandt, was the first to confront us with the effects of digitalization on safety and health at work a few years ago (2015).

We chose this example because Prof. Radandt is a proven expert in the field of machine and plant safety and explosion protection.

He was, among others

- One of the four authors of EN 292 (European predecessor standard of EN 12100)
- Chairman of several European standardisation committees: CEN/TC 114 - Safety of machinery and plants / CEN/TC 153 - Food processing machinery / CEN/TC 305 - Explosive atmospheres
- Member in important advisory bodies for: the European Commission in the field of product safety and explosion protection/the Federal Ministry of Labour and Social Affairs in Germany regarding European legislation with the focus on machine and system safety and explosion protection/ DIN, especially the Safety Technology Commission and the Standards Committee on Safety Principles/VDI in several directive committees, especially pressure relief and dust explosions (VDI 3673) and dust fires and dust explosions (VDI 2263).

We would like to take this opportunity to thank him for his many years of great commitment in the Section Machine and System Safety since its foundation in 1975 and for his wide and valuable advice and support on many issues of machinery and system safety.

This publication is a contribution of our Section to the ISSA's Vision Zero Campaign, especially to the concrete implementation of the "Golden Rule No. 2" ("Identify hazards – contol risks").

Jürgen Schulin
President

Dr. Hans-Jürgen Bischoff
Secretary General

1 Digitalization

1.1 Digitalization - definition and general uses

A silo plant for combustible bulk materials serves as an example. Figure 1 shows the principle of digitalization of this plant for bulk material (e.g. grain, seeds, fertilisers) and the communication possibilities with the end user and the manufacturers of the plant, as well as the data transfer via a cloud. The production plants are usually automated, as are other processes.

Automation is characterised by the fact that targets are reached by autonomous action, variable targets are followed, new targets are defined and maintained or, if targets are reached, activities are developed to stabilise the system despite existing faults. Sophisticated automation systems take complex action processes off the hands of humans and complete them in their own way.

The interaction of the automated machines with the respective processes generates interactions, whereby information is exchanged. On the one hand, this information concerns statements about the process status or instructions about process interventions to be carried out. The machines can also obtain information from the environment via corresponding sensors.

In this way, a wide range of communications takes place. The acquired information is processed into new information in the subsystems according to the task. Automation systems thus have the character of information systems. Digitalization is an update of automation. Digitalization means the conversion of analogue values into digital formats.

These data can be processed by information systems. Digitalization also includes the preparation of information for processing or storage in a digital system. The information is available in any analogue form and is then converted into a digital signal over several stages.

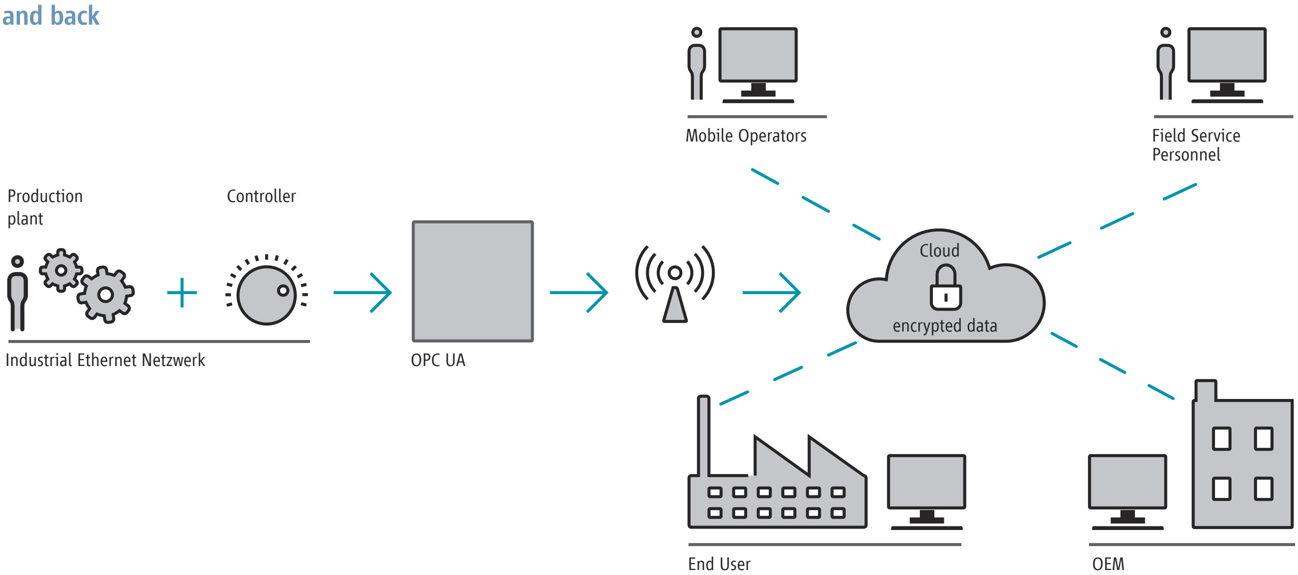
An intelligent networking of production takes place, in which all elements of the value-added chain can be controlled reliably and in real time by means of sensor technology and machine-to-machine communication.

This will lead to a high degree of change, especially for employees, who will be better able to cope with this change if they are involved in this process from the very beginning. Communication (about quantities, qualities, modifications of the end product) takes place with customers via a cloud. Likewise, communication is intended with the manufacturer/installer of the plant to ensure proper maintenance, servicing, repair. These connections are cyber-secured.

The data acquisition and processing is as follows: a communication protocol "OPC Unified Architecture", in short OPC UA, is used. This is an industrial M2M communication protocol with the ability not only to transport machine data (control variables, measured values, parameters, etc.) but also to describe them semantically in a machine-readable form.

In communication via the cloud, OEM (Original Equipment Manufacturer) is the manufacturer of components or products who produces them in his own factories but does not sell them himself. They are available to the user of the plant when required (e.g. spare parts etc.). OEM software and OEM hardware are also installed for this sub-process.

Figure 1
Data transfer from a silo into a cloud and back



OPC United Architecture – industrial M2M-communication protocol

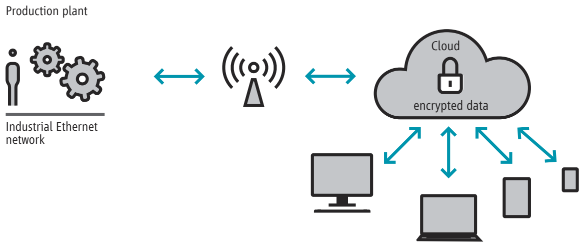
OEM: Manufacturer of components and products for communication in the cloud

Cloud storage is a cloud computing model that stores data on the Internet via a cloud computing provider who manages and operates the data storage as a service. It is delivered on demand with just-in-time capacity and associated costs, eliminating the need to purchase and manage your own data storage infrastructure. You always get as much storage as you need without having to operate another server. The organisation of the units is handled by the provider.

Cloud computing in general means the outsourcing of programs to a server. The special feature of a cloud is that there is always as much computing capacity available independently of individual units as is required for the applications.

Running your own software in the cloud is an alternative option.

Figure 2
Data transfer via a cloud to different devices



All this, of course, also implies dangers. With the right access data, others can also access the cloud. In addition, another disadvantage of the cloud should not be forgotten: without a functioning Internet, there is no cloud. Users can access the cloud via their Internet connection. This means that, for example, devices such as their own computer, but also smartphones and tablets can be used to access the cloud. There is a risk that infected devices could damage the system.

In a **private cloud**, the cloud infrastructure is made available exclusively to a single organisation. This infrastructure can be owned, managed and operated by the organisation itself. Having your own cloud storage reduces the risk of losing control over the availability of the service and the functionality of individual components. Security and data protection can also be better guaranteed.

Data should be stored in a redundant manner, ideally across multiple facilities and multiple devices in each facility. Human error or mechanical failure should not lead to loss of data.

All data should be available on demand. However, there is a difference between production data and archives.

Ideally, all data should be encrypted, regardless of whether it concerns dormant or in transfer data. Permissions and access controls should be used in the cloud as well as for local storage locations.

1.2 Sensor systems

Sensor technology plays a special role in digitalization. Sensors are used to communicate between the machines. A sensor is used for the quantitative and qualitative measurement of physical, chemical, climatic, biological and medical parameters. The sensor consists of two parts: the sensor element and the evaluation electronics. The non-electrical input variables to be measured are converted into an electrical output signal in the sensor element by scientific laws. In an electronic evaluation unit, these output signals are converted by circuit electronics or software programs in such a way that a sensor output signal is produced which is available for control or evaluation purposes. The external disturbance variables which influence a sensor element can be taken into account by calculation (e.g. consideration of temperature dependency or linearisation of non-linear relationships). This is usually done by a microprocessor. Progressive miniaturisation increasingly allows both parts, the sensor element and the evaluation electronics, to be accommodated in a single sensor. These intelligent sensors are also known as smart sensors.

Signal processing and calibration

Sensors convert the physical quantity to be measured into an electrical signal. There are three points to consider:

a) The sensor signal is usually very small. It must therefore be amplified to a standard level so that it can be processed by a control system.
b) Attention must be paid to influences of disturbance variables (e.g. influence of temperature on the characteristic curve of a humidity sensor). Characteristic curves must be filtered and linearised very often.

c) Temperature measurement has a special position here. There are measuring elements with undisturbed and linear character (e.g. PT100 and thermocouple). These elements can often be connected directly to special inputs of control systems.

Signal conditioning

With the large number of sensor elements, the output signal is generated by relatively few physical effects, which can be summarised as follows:

- Generation of a charge or a voltage (e.g. piezoelectric effect, thermocouple, photo element).
- Changing a resistance or a conductance value, e.g. strain gauge, photoresistance, changing the channel resistance of field effect transistors (FETs) by ions.
- Change of capacity or inductance and, as a result, an A.C. resistance (e.g. humidity, distance and paths).

Digitalization and sensor technology

The intensity of digitalization depends on the availability of suitable sensor technology. Usually sensors are designed according to the process description. If something changes in the production process over time, the humans have to readjust the sensor technology. Future development will be that the sensor system adapts itself by means of continuously recorded data and experience values. Several to many sensors and actuators are necessary for the regulation or control of a system.

Depending on the task, different physical principles are applied.

1.2.1 Examples of sensors

Optoelectronic sensors
are devices that use light (within a certain spectrum) to detect objects and thus trigger control, switching and regulation functions. With optical sensors, exact positioning and very long ranges can be realised independent of the material of the object to be detected.

Capacitive proximity switches
are contactless and therefore wearfree limit switches. They are used to detect both metallic and non-metallic materials, whether solid or liquid. Capacitive sensors are actuated by conductive and non-conductive materials. Due to their high conductivity, larger switching distances can be achieved with metallic objects. When detecting organic materials, e.g. grain or wood, the switching distance is strongly dependent on their water content.

Ultrasonic sensors
work according to the principle of measuring the transit time of high-frequency sound pulses. The cyclically emitted pulses are reflected by the object to be detected and return to the sensor as an echo. The integrated electronics measure the distance to the object. This measuring principle enables a largely colour and surface-independent detection of a wide variety of objects, even under adverse environmental conditions such as contamination. The ultrasonic principle complements other operating principles such as those of optical sensors.

Flow monitors and flow meters
are used to detect the flow of liquids, especially in pipes. Depending on the type of device, the flow is digitally recorded as exceeding or falling below a set flow velocity or is continuously measured via an analogue output.

Inductive ring sensors
reliably detect small metallic parts inside the ring (e.g. foreign particles in bulk materials). Ring sensors with dynamic switching behaviour detect the smallest objects even at highest part speeds.

Capacitive ring sensors
are used in particular to detect liquids in plastic or glass tubes.

Optical ring sensors
ideally complement the inductive or capacitive ring sensor series. Their advantages lie in the possibility of detecting small, fast and non-metallic objects in a transparent feed tube.

Magnetic field sensors
are used for safe and wear-free position detection on all pneumatic and hydraulic cylinders.

Temperature sensors
reliably detect temperatures and objects in a wide range of applications. Measurement by contact: the measurement is made with a thermometer or temperature sensor. Non-contact measurement: the heat radiation of a body is measured. The measurement is carried out, for example, with an infrared thermometer (pyrometer) or a thermographic camera.

Pressure sensors
are compact pressure transmitters and sensors - also with IO-Link interface.

Vibration measurement
The vibrations are caused by sine or cosine oscillations. Most vibration measuring instruments have a piezoelectric speed sensor, which means that they are dependent on a resistance that is located in the measuring instrument. This sensor converts the received signals of the vibration into electrical signals.

Speed measurement
Speed measurement means all tools and methods for measuring rotational and angular speeds. The angular velocity is obtained by measuring the angle that is exceeded within a certain time. Stroboscope tachometers use the inertia of the human eye. They produce flashes of light of variable frequency which are directed at the part to be measured. If the flash frequency and the rotational speed of the marked part match exactly, the part appears to stand still.

Measuring moisture in bulk materials
Moisture in solids is an important parameter that has a strong influence on the quality of the product, e.g. in applications such as sugar, tobacco, cereals, malt, flour, coal, sand, wood chips, dried fodder, fertilisers, powders, dyes, plastic granulates, etc. Conveyor belts, screw conveyors, silos, hoppers, etc. are particularly suitable as installation locations. Inline moisture measurement is also possible in batch processes. During the measurement, the electricity constant and the high-frequency damping of the solid are measured in the high-frequency wave range.

Continuous inline flow measurement system for bulk solids
Microwave technology is used for inline flow measurement of solid matter in metallic pipelines. It is suitable for inline measurements in pneumatic pipelines or in free-fall lines. The measuring method is based on the physical principle of the Doppler effect. The sensor builds up a homogeneous microwave field in the pipeline. The solid particles conveyed through the pipeline reflect the microwaves, and the reflected waves are received by the sensor.

Dust monitor for filter monitoring
The triboelectric measuring principle is based on the detection of moving, electrically charged dust particles which collide with the sensor rod or fly past it. The electrical charges reach the dust particles in a natural way, e.g. by friction with the inner wall of the pipe.

Solid matter adhering to the sensor rod is not detected. The filter is installed on metallic ducts or pipes on the clean air side of the filter.

Contactless point level monitoring for bulk solids
The measuring method is based on the latest microwave technology. For this purpose, the transmitter sends out a microwave signal. This signal is evaluated by the opposite receiver. Material that builds up within this field attenuates its signal effect. This is converted in a switching process. The measurement is contactless.

Contactless flow monitor for bulk solids
The measuring method is based on the physical principle of the Doppler effect. For this purpose the sensor emits a microwave field. When solids move through this field, the microwaves are reflected and received again by the sensor. This is implemented in a switching process.

1.2.2 Sensor networking

In factory automation, the networking of sensors and actuators via bus has become state of the art. Important criteria are here:

- Speed (bus cycle time < 5 ms)
- Real-time capability (predictability of the bus access)
- Transmission security

The standardised buses include among other AS-I, Interbus and Profibus DP.

The bus systems have also found their way into process technology (chemical, pharmaceutical and food industry). The criteria are here:

- Explosion protection (through intrinsic safety, Ex-i)
- Power supply of the sensors via the bus line
- Easy connection to process control systems

The standardised buses are Profibus PA and Foundation Fieldbus.

As already mentioned, sensor technology plays a special role in digitalization. Several, eventually many sensors and actuators are required for the regulation or control of a system. Sensible algorithms are required for processing the signals. An algorithm is a clear instruction for the solution of a task or a problem. Algorithms consist of a finite number of defined individual steps.

In these algorithms, all action requirements determined on the basis of risk analyses must be included as clear decision features. They also decide whether processes are self-regulating or whether intervention is required, whether parts need to be replaced or whether preventive maintenance or repair is necessary.

1.2.3
The development of algorithms

Algorithms consist of a finite number of defined individual steps. Thus they can be implemented for execution in a computer program. When solving a problem, a certain input is transformed into a certain output. Algorithms are developed for the individual sensors (types) and their tasks (detection targets) as templates for programs.

Algorithms have the following characteristic properties:

- An algorithm must not contain contradictory description, but must be clear.
- Each individual step must be executable.
- The description of the algorithm must be finite.
- After a finite number of steps, the algorithm must deliver a result.
- The algorithm must always deliver the same result under the same conditions.
- At each point of execution there is at most one possibility of continuation. The next step is therefore clearly defined.

1.2.4
Security risks due to high complexity

As a result of the intensified networking of the elements of a production plant, especially via the Internet, and the data exchange realised via this, IT security (protection against cyber security attacks) is of particular importance. Inadequate IT security can often also have an impact on the safety of machines.

The parts of a production plant (machines/machine parts) can reconfigure themselves during the running process, e.g. to achieve an increase in efficiency or to increase the flexibility of the entire system. This specific aspect must be taken into account in the risk assessment and risk reduction in the context of the safety of machinery.

The digitalization and the connection of machines, control units and other Internet of Things (IoT) devices to the Internet make the affected equipment hackable and manipulable. A major reason for this is the high complexity of an IoT project, with a large number of interfaces, communication links and different types of devices.
The range of IT components involved extends from individual sensors to cloud and data processing centre.

Each individual component can pose a security risk and can lead to dangers (threats) in the event of a cyber attack:

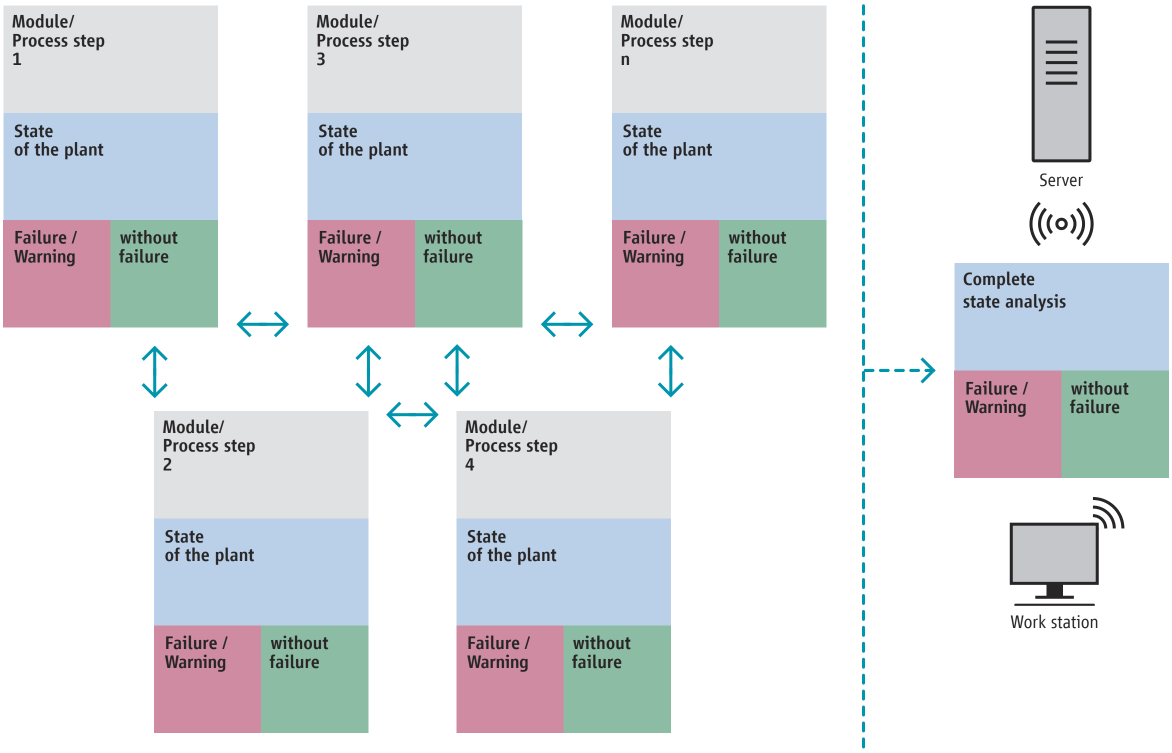
- Theft of confidential data such as know-how, intellectual property (IP), customer and process data
- Theft of intellectual property
- Fraud through false user identity during authentication
- Fake servers or fake devices in a network
- Unauthorised modification of devices in the production network
- Manipulation of servers, routers, end devices, data or clients

- Implementation of changes in the system, process or data set (e.g. changes in production processes)
- Causing of IT damages through sabotage
- Subsequently, effects on safety

These risks can be minimised with the following measures:
- Firewall, Virus Scanning Device
- Using secure passwords
- Regular updates
- Regularly check the systems for malware and security holes
- Encrypting important data
- Personnel Authorisation
- Restriction controls
- Communication controls
- Faraday systems (for controls, sensors, screens)
- Bypass server
- Decentralisation
- Communicating the importance of data security: It is important to train employees regularly so that they can behave appropriately and handle data responsibly

If the plant is very complex, it is recommended that the plant be broken down into modules in order to break down the complexity and simplify the completion of the tasks to be solved.

Figure 3
Complex system, principle of fragmentation. The modules can be arbitrarily be linked, even selectively.



This modularity counteracts the increasing plant / machine complexity.

Plant / machine concepts structured into individual function modules are more transparent. Fault diagnosis is simplified. Overall, the starting effort, commissioning times and also the effort for repair and maintenance are reduced.

A major advantage is that old modules can easily be replaced by new modules, or new modules can be added to the whole, or new overall configurations can be created.

For this purpose, modules need clear interfaces in order to keep compatibility problems (of "matching") to a minimum.

Figure 3 shows the principle of breaking down a process into individual process steps and the possibilities of putting the modules together in any way you like.

1.2.5
Process safety and security for identified risks in CPS (Cyber Physical Systems)

- Classical safety engineering for machines, plants and processes (reliability, redundant elements, functional safety, etc.) for each identified risk

- Reliability of control systems and system components (safety integrity levels SILs, redundancies, feedback systems)

- Action against cyber attacks (Faraday screens, bypass servers, decentralisation, personnel authorisation, restriction controls, communication controls)

- For each identified risk resulting from the disruption of communication lines - specifications / ergonomics (interfaces: man-man, man-machine, machine-machine, man-man-machine-machine)

The interaction of the machines with the respective processes generates interactions, whereby information is exchanged. On the one hand, this information concerns statements about the process status or instructions about process interventions to be carried out. The machines can also obtain information from the environment via corresponding sensors. In this way, a wide range of communications take place. The acquired information is processed into new information in the subsystems according to the task. Automation systems thus have the character of information systems.

As already described, communication takes place between the individual modules (plant components, machines). Likewise, communication with the manufacturer / installer of the plant is provided for in order to ensure proper maintenance, servicing, repair. These connections must be cyber-secured.

The individual elements (machines) are described with regard to function (technology), risks and measures. Sensor technologies and associated algorithms are assigned.

The development of algorithms for processing the signals of the individual sensors is performed under consideration of safety aspects and with regard to the information needs of the persons "in charge" of the plant.

2 Human Factor

The humans in the digital system

The integration of humans into a digitised system requires some considerations. The humans act according to programs and/or program themselves. Humans must also be able to control disturbances and processes not in accordance with programs. Professionals will have to face greater demands for complexity, abstraction and problem solving. Process controllers will be responsible for the implementation, optimisation and maintenance of "Intelligent Technologies".

2.1 The humans as an important part of the system

The human factor is a collective term for psychological, cognitive and social influencing factors in socio-technical systems and man-machine systems. The mental and cognitive performance and abilities of people play just as much a role as the limits of performance and ability. Because the capabilities of technical systems are constantly evolving, typical human skills such as those for cooperation, problem solving, are becoming increasingly important. Human Factor Technology is a multidisciplinary field involving psychology, engineering and ergonomics.

The central aim of ergonomics is to create suitable conditions for the execution of human work and for the use of technical equipment and tools. In addition to the human-adapted design of the work system (more precisely the work space), the improvement of the human-machine interface between user and operator (human) and object (machine) is of particular importance in a man-machine system.

The humans must be at the centre of the introduction and use of CPS (Cyber Physical System) or sensor software systems. For humans, the complexity of future CPS must remain controllable, i.e. in particular it must remain comprehensible. This requires new solutions for user interfaces.

In return, humans must be enabled to "keep up" with this development. Corresponding training, qualification and further education offers have to be developed for engineers and for the people working in production. In addition to comprehensive qualification and further training measures, organisational and design models of work which combine a high degree of self-responsible autonomy with decentralised forms of management and control are decisive for this, which grant employees extended margins in decision-making and participation as well as possibilities for regulating stress.

The person working on digitised systems must be informed sufficiently, in good time and without errors about the states of the system so that he or she can make the right decisions. The control devices must be easily accessible and intuitively understandable. Inputs are subject to a plausibility check.

In order that a user interface is usable and meaningful for humans, it must be adapted to their needs, abilities and skills.

The humans appear in two functions in the process chain model. In the role as a designer: either as a manager with superordinated design tasks or a an executing higher employee with design margin for his/her own workplace, or as a designed "personnel" resource to be used as efficiently as possible to ensure the optimal implementation of the process chains. The humans receive information from the system and is expected to act on it. Thus being a system component receiving input from the system and producing results which have an effect on the system. Mental strains/stresses are to be considered.

The actual extent of these demands depends on the personal prerequisites and coping strategies of the person concerned. Mental stress at work always depends on several factors.

The following psycho-physiological processes are necessary to enable adequate behaviour:

- Perception or signal reception by stimulating facial, auditory, tactile and cognitive functions
- Interpretation through application of theoretical and practical knowledge, which includes a quick assessment
- Decision making by means of psychological processes using the strategy of feedback assessment
- Action through psycho-motor functions (activities, language)

There are also psychological error mechanisms:

- Ignoring special circumstances.
- A task is similar to other tasks, but special circumstances prevail which are not taken into account, the task is not carried out correctly.
- Adoption of stereotypes: Due to habits, actions are directed to a familiar but unwanted path.

2.2 User interfaces

The user interface allows the operator to monitor the plant status and intervene in the process beyond operating the machine. The information ("feedback") is provided via control panels and increasingly via digital devices. A computer-based user interface or really use interface is the part of a computer program that communicates with the user.

The user interface is defined as "any component of an interactive system (software or hardware) that provides information and controls necessary for the user to perform a particular work task with the interactive system". In control technology (also Supervisory Control and Data Acquisition, SCADA in short), configurable computer-based user interfaces ensure communication and exchange (process visualisation) between a PLC (Pro- gram- mable Logic Controller) and humans and are thus an integral part of a control system.

Typical for a SCADA system is the central alarm management, the archiving of data, the creation of timer programs and a message transmission service (SMS, e-mail, text-to-speech). A SCADA contains an HMI (Human Machine Interface) system as user interface. Some of these systems, such as InTouch (Wonderware process control system for visualisation) or WinCC (Siemens process visualisation system, Windows Control Centre), contain an integrated graphic editor and a wealth of industrial symbols, e.g. motors, valves, pipes or switches.

The control technology combines the data streams of the subordinate levels, the field or individual cells, such as signals from the measurement and control technology, in order to control and monitor the entire production process.

In the form of a control system, the control technology finds its place in the control room of a plant.

In the automation pyramid, the control system belongs to the control level. However, the term control technology is defined more broadly and also includes the control and plant management level, and in some cases also the field level.

2.3 Communication at the human-machine interface

Figure 4 shows the function of a system (a plant/machine) with energy-material-signal processing. This system is used by people who need skills, abilities, knowledge, experience, education and training to communicate. A prerequisite for possible communication is that the interface to the system is designed to be appropriately "ergonomic". The system produces both the planned (intended) result and unplanned effects. It is also subject to external influences.

The human-machine interface (HMI) has the function of determining the way in which human-machine communication takes place, the way in which instructions are transmitted from human to machine and the form in which instructions are executed and results are output. The interface should provide the user with all possible functions required to perform a task and, above all, should be intuitive to use.

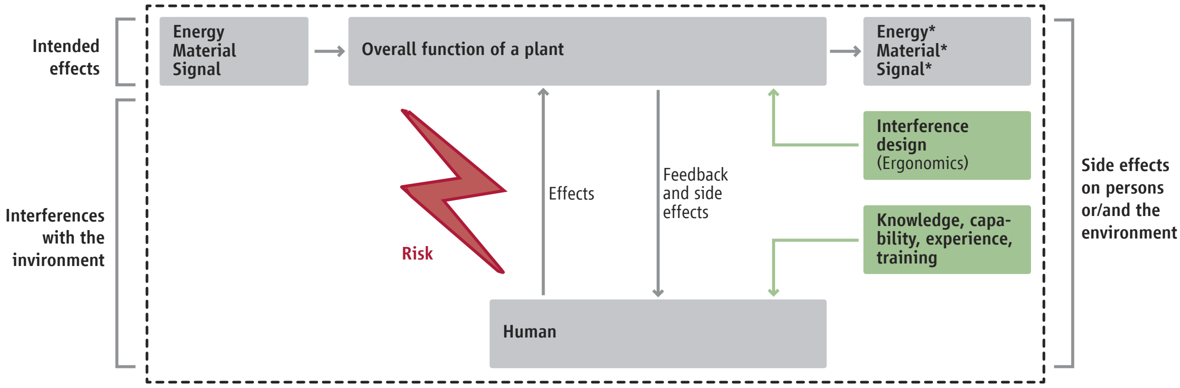
The interface is used by the human (user, operator) to operate the machine, to observe the plant states and to intervene in the processes. When the information is provided, the machine gives feedback, which is done via control panels with signal lamps, display fields and keyboards or via software.

The human-machine interfaces must be adapted to the capabilities and characteristics of the users. This includes various aspects: The presentation of information must be adapted to the user's ability to assimilate information, dialogue sequences must correspond to human cognition, such as a logical menu structure, etc. A user-friendly design requires that the work task, characteristics and abilities of the user are taken into account in the HMI.

Figure 4

Function of a system with energy-material-signal processing and communication with humans

The system consists of two blocks: the machine/plant and the human, both of which must be "designed" for a functioning system. Essential criteria for this are interfaces, design for the machine/plant, knowledge, ability, experience, training for the humans in their function/tasks. The humans act on the machine by commands/actions, in return receives feedback from the machine.



Means of communication (examples)

Use of AR (Augmented Reality):
An AR system (short ARS) is the system of technical components necessary to build an augmented reality application: Camera, tracking devices, support software, etc.

By displaying additional information, assistance with complex tasks can be provided. For example, parts of a device are “labelled” for a mechanic and receives work instructions. The computer-aided realities can be sorted into two categories: AR and VR. AR means that the real world is enriched with additional artificial content, can be viewed through glasses or displays.

VR on the other hand means Virtual Reality. In other words, a completely virtual world. If you put on special glasses, you move as a protagonist in first-person or third-person view through an artificial reality.

Hardware components for Augmented Reality are: processor, display, sensors and input devices. Various technologies are used in Augmented Reality rendering, including display systems such as Smart Glasses worn on the human body.

For example, a Head-Mounted Display (HMD) is a display device on the forehead. HMDs display images of physical and virtual objects simultaneously. Modern HMDs often use sensors for six degrees of freedom for monitoring, which allow the system of virtual information to be aligned with the physical world and adjusted accordingly with head movements of the user.

SmartGlasses AR (Augmented Reality) glasses

Displays can be rendered on devices like glasses. A head-up display (HUD) is a transparent display that presents data for viewing without users deviating from their usual way of seeing.

This is generally how a head-up display works, but it is also expected to register and track the superimposed perceptions, sensations, information, data, images and part of the real world.

A handheld display includes a small display that fits in the operator's hand. The two main advantages of Handheld AR are that it is portable and the camera function is available.

Computers analyse the perceived visual and other data. Augmented Reality uses an image generated by the computer.

The control device receives data from the sensors that determine the relative position of objects over the surface. This results in an input to the computer. The computer has a memory and processor. The control device takes into account the scanned environment and then generates images or video. The fixed markings on the surface of an object are stored in the computer. The process of a production plant can be monitored and controlled via the computer.

For a long time, machines were mainly controlled by switches, levers, steering wheels or keys, later on, keyboards and mice were added. In the meantime we have arrived at the age of the touch screen. Body sensors in wearables, which automatically collect data, are also modern interfaces.

At the same time, voice control is making rapid progress: users can already control digital assistants such as Siri, Alexa or Google Assistant with their voice. This means significantly less effort for them. Such systems also use chat bots whose communication with humans is becoming increasingly better thanks to artificial intelligence.

Requirements for the hardware:
- Sensors for recording the real environment and orientation in space (e.g. RGB camera, GPS, gyroscope)
- Interfaces for recording user input (e.g. touch screen, microphone)
- Computing power / processor for processing, calculation of data
- Interfaces for the output of data and information (e.g. screen, headphones, vibration)

Requirements for the software:

Technology for ...
- Evaluation of the camera images (image analysis)
- Evaluation of other sensor data (GPS, acceleration sensors, gyroscope)
- Connection of existing data sources and resources (database connections, etc.)
- Administration of user inputs and process control (e.g. game engine)
- Combination of camera image and digital, visual extensions (image processing)

3 Safe and Secure System

3.1 Analysis of incident risks and development of protection options (problem solutions)

The path to a "safe" system is the analysis of possible faults and undesirable incidents and their effects on the system behaviour and the development of appropriate measures to prevent them. Undesirable incidents are sought in systems with procedures and functional sequences, in processes and technologies, work, handling and organisational procedures and environmental conditions.

It must be ensured that the respective interfaces are part of the consideration. Deviations and time-related changes compared to the planned processes and conditions must also be considered. The error is defined as a "characteristic value which does not meet the specified demands" and the "failure to meet a requirement".

A general distinction is made between two types of error, the expected error and the unexpected error.

The occurrence of an error can depend on certain conditions, so-called error prerequisites, and can therefore be systematic. Are the conditions known under which an error occurs, it can be reproduced. Only errors with known causes can be avoided. The consequences of an error are usually undesirable. Therefore, errors are often - but not exclusively - classified according to the severity of the error effects. Incident risks in the narrower sense shall be undesirable incidents and/or incidents with undesirable effects (exceeding the acceptance limits).

Undesirable incidents are:

- Conditions of origin of processes and states
- Processes and states themselves
- Effects and impacts of processes and states that can lead to damages to persons and things.

The undesirable incidents can therefore be defined as a single incident or as an incident within an event sequence. The undesirable incidents are established for an observation unit or for an observation state. Causes can be located in the observation unit itself or outside it (interface observation).

To determine the risks associated with undesired incidents, probabilities and effects must be determined. The problem of risk assessment in the time dimension is that the future cannot be anticipated, but every risk decision is aimed at the future. A reduction of risk can be achieved, as already described, e.g. by modularisation. Modularity (also known as the building block or building block principle) is the division of a whole into parts called modules, components or process steps.

What applies to technical systems?

Technical systems are planned as determined systems. Only the predictable and intended system behaviour is taken into account in system design.

Experience shows, however, that all technical systems also exhibit stochastic behaviour, i.e. that they unintentionally change their behaviour and properties due to external influences not taken into account in the design and/or due to internal system changes. The period of time until the occurrence of an unintentional change in behaviour and/or often also in properties cannot be determined exactly, it is a random variable. We search for and forecast possible errors and undesired incidents in systems.

Principles of incident analysis

a) Occurrence-oriented incident analysis.
What happened?
- Dividing incidents into sub-incidents - inside and outside the system
- Person-time-diagram, chronological: Who? When? Where? How?
- Collect incidents: systematically, sporadically or individually?

b) Cause-oriented incidents analysis:
Why did it happen?
- Areas of causes to be identified outside humans (e.g. technology, method, process, ergonomics)?
- Areas of cause to be identified in humans?

Different procedures are required depending on the possibility of errors and their origins, factors influencing errors and their interactions.

Since risk analyses are not possible without usable information, it is necessary to think about the information properties. The information characteristics are characterised by the information content, the truth, the degree of confirmation, the verifiability, the probability, the objectivity, the age. Data for the probability of occurrence of an incident of certain types of incidents and the severity of their effects can be:
- statistical: empirical, retrospective, factual
- prognostic: speculative, prospective, probabilistic

In this respect, the probability plays a role in the information content, in which the logical hypothesis probability and the statistical incident probability are of the greatest importance. This in turn results in strategies for dealing with risks with the aim of making such negative incidents and occurrences as unlikely as possible and, if they occur, to keep the effects as low as possible: the approach of successful prevention.

A risk network is characterised by dynamics and therefore makes it difficult to assess individual risks within the network.

Preventive measures trigger changes in the risk network because influencing occurrences and assessing risks simultaneously requires system changes.

A subsequent risk option that is then required, i.e. a new risk assessment of the changed system, provides information as to whether the risk network as a whole is actually changed positively or whether focal points are shifted, individual risks are minimised and other risks arise anew.

3.2 Risk assessment

The risk assessment is a sequence of logical steps which allows the systematic investigation of hazards (incident risks) emanating from technical systems. Where necessary, risk assessment is followed by risk reduction. Risk assessment is therefore risk analysis with determination of causes and risk estimation and risk evaluation. Against the background of the new technological developments, the classical risks are also running. The innovations lead to a greater complexity of risk analyses. The following questions, among others, play a role here:

- What can deviate from the planned in the production process? With what consequences?
- What system-related measures are to be taken to minimise risks?
- What tasks do people have to perform to ensure that the system works?
  - Normal operation of the system
  - Special functions, such as maintenance, malfunctions, repairs, cleaning
- What qualifications do these people need to deal with the unexpected?
  => What stresses and strains arise from this?
- How can the manipulation of systems be prevented?
  => externally and internally (how are the "entry gates"/ system accesses to be secured?)

There is no regular risk of injury for the people/employees working in the system (exception: cooperation with robots), but there is a possible excessive mental strain. How should the employees be prepared for this? The risks can be understood as disturbance potential which can call into question the realisation of the company's objectives. The aim of risk management is to identify these disruptive potentials qualitatively and quantitatively and to reduce them to a harmless, acceptable residual potential.

For most problems, system considerations are required, whereby the system behaviour in particular must be analysed. The methodical approach must cover the interaction of humans, work equipment and environment. The starting point for the analysis is problem orientation. It takes place in the following steps:

1. Recognition and analysis of the problem according to its causes and extent by means of diagnosis and prognosis and comparison with the objectives;
2. Description and classification of the overall problem into individual problems and determination of the dependencies;
3. Differentiation of the problem and structuring it according to objects, time reference, degree of difficulty and relevance for the objectives;
4. Detailed analysis of the causes and structuring according to possible solutions.

The basis of all risk analyses is the system analysis. It must therefore be carried out with particular care. The system analysis includes the examination of the system functions, in particular the performance targets and the permissible deviations of the environmental conditions which cannot be influenced by the system, the auxiliary sources of the system (e.g. energy supply), the components of the system and the organisation and behaviour of the system.

Technical systems should fulfil a large number of functions and be safe at the same time. The humans and their influence on safety must also be the subject of basic safety considerations (human factor). The safety of a system is thus given if no functional or action sequences with dangerous effects on persons and/or properties occur. The digitalization of the systems thus results in a number of new safety-related issues that make it necessary to supplement and modify the safety measures already in use in automation.

3.3
Risk management

Risk management adapted to the new risks is necessary. Risk management includes all measures to ensure that a company's risk and safety situation is appropriately managed. It is the systematic application of management principles for identifying, assessing, evaluating, managing and monitoring risks.

The time-dependent changes of the work systems which make it necessary to adapt the measures to characteristics, conditions, situations and the like require methods which make it possible to recognise complex safety-relevant interrelationships, to describe complex safety problems and to offer complex solutions. Various methods are available for the analysis of problems.

Each of the analysis methods answers certain questions particularly well and is less suitable for others. In order to be able to correctly classify the statements of the different analyses within the system view, a complex thought pattern is required. Such a pattern includes the following steps:

1. **Determining and defining the unit of consideration**
   Here it is a question of the actual task and differentiation of the system. It can be a fictitious system or a real system. The specifications are time, space and state.

2. **The problem analysis**
   Here all problems that exist in the defined system are searched for and described, including those that do not originate in the system itself.

3. **Causes for the problems**
   This step lists all possible causes that lead or may lead to the problems found.

4. **Determine causal relationships**
   The interdependencies of mechanisms of action are shown and correlations between causes are determined.

5. **Define priorities and formulate objectives**
   To take this step, an assessment of the effects of causes must be carried out.

6. **Measures to address the problems**
   All measures for each problem are listed. As a rule, the known catalogues of measures are used which contain both technical and non-technical measures. As there are often several possible measures for solving a problem, a pre-selection of the measures is already made here. However, this is only possible to a limited extent in this step, so the selection of measures must be completed in the 7th step and in the 8th step.

7. **Clarify contradictions and set priorities**
   Since measures for individual problems can sometimes contradict or even exclude each other, decisions for or against a measure must be taken or compromises sought after clarifying the contradiction.

8. **Determine measures for the defined unit of consideration**
   From the measures for the individual problems, those measures applicable within the defined overall system are now selected.

9. **Question about the solution for the defined system**
   The question here is whether the measures found for possible implementation are solutions to the problems of the system.

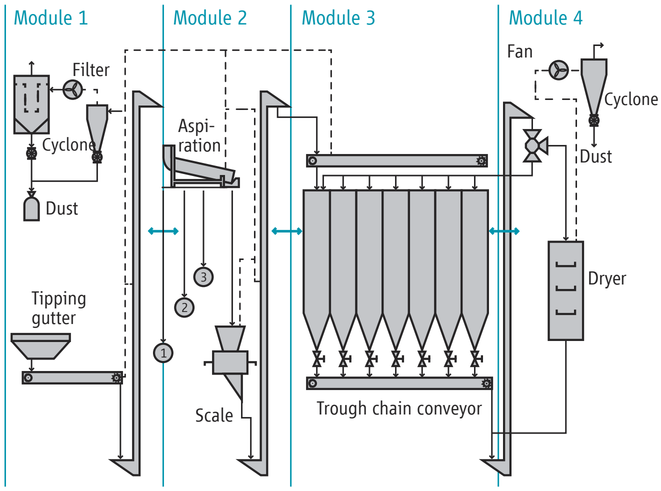
10. **Asking whether new problems arise**
    In this step, the question is asked whether the problem solution will create new problems.

4 Exemplary Consideration of the Storage and Processing of Bulk Materials

The complexity of technical systems, increased by their digitalization, can be presented in a clear and comprehensible way, above all through concrete examples. We show this in this brochure using the example of the storage and processing of bulk materials (grain, etc.) with assessment of the dust explosion risk. Bulk material is a powdery, granular or also lumpy mixture, which is available in a pourable form.

The properties of bulk material are determined by the grain size and the grain distribution as well as bulk density. A distinction is made between free-flowing and cohesive bulk materials. The bulk solids mechanics deals with storage and transport conditions of bulk materials.

Figure 5
Modularisation (subdivision) of a plant



Examples of possible process steps (modules)

- Reception of the bulk material
- Cleaning
- Processing (e.g. grinding)
- Further processing (e.g. weighing, granulation, pelleting)
- Storage (e.g. ensiling), packaging, delivery of the finished product

If flammable and dust explosive bulk materials are conveyed during these process steps and stored in containers or silos made of steel, or other metals such as aluminium or stainless steel, concrete, plastic or flexible fabrics, then explosion protection measures are required. Figure 5 illustrates one possibility of modularisation.

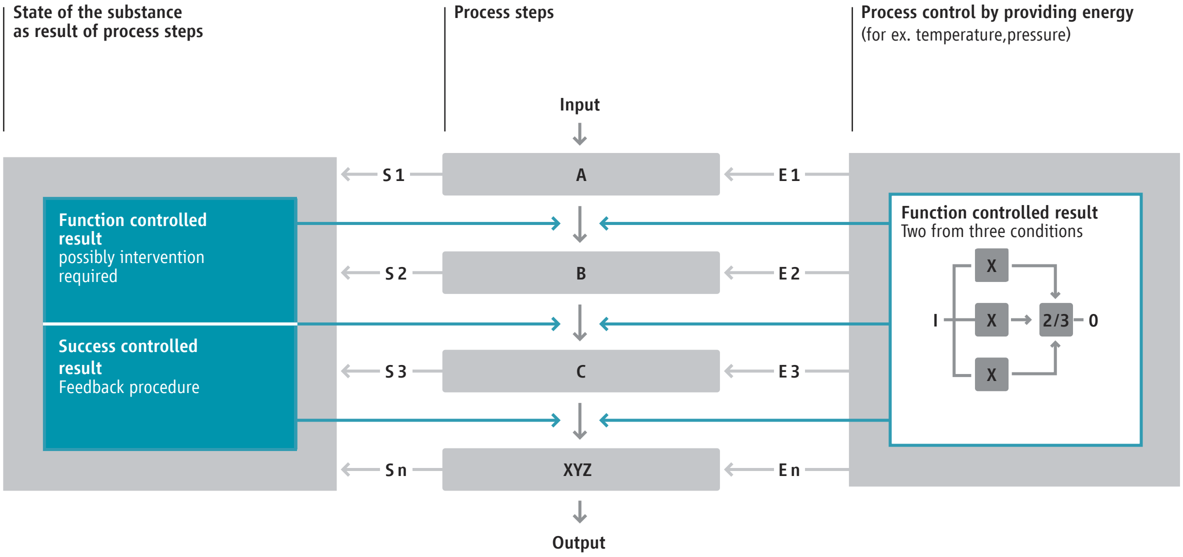
Detailed extended module description

Module 1: Unloading (rail/ship/truck); reception of raw material
Module 2: Cleaning systems, scales
Module 3: Storage (silos), alternatively storage sites (open: stockpile, mixed bed)
Module 4: Dryer

Further modules can be

- Processing / further processing
  - Pelletizing, granulation
  - Screening systems, air classifier/air sorter systems
  - Mill systems (various types), grinding plants (pin mills, impact pulpers, hammer mills)
- Conveyor systems:
  - Bucket elevators, screw conveyors, chain conveyors, belt conveyors, pneumatic conveying, (downpipes and path distributors)
- Drying systems
- Packaging systems
- Loading, shipping of the finished product

Figure 6
Functional analysis of a system



For all modules, an assessment of the explosion risk and a risk treatment is performed. These are taken into account:

- Material properties (bulk material, dust)
- Possible ignition sources
- Explosive atmospheres
- Measures (prevention of explosive atmospheres, ignition sources, protective systems)

When digitising such plants, the corresponding safety criteria must already be considered in the algorithms.

The presentation of sensors and the description of algorithms in this publication is only exemplary to show the principles. Furthermore, the use of sensor technology in plants during operation is too diverse to be dealt with in detail here. In later examples the aspect of digitalization/sensor technology is not described. The procedure must be similar, i.e. sensors must be used at the relevant process points / process steps. By dividing the plant into modules/process steps, the task becomes clearer and easier.

The functional analysis as a basis for further assessments

The overall process is divided into individual process steps. The individual process steps (modules) are checked with regard to the completion of the task provided for in the process step. The control can be function-related (has the intended function been performed correctly?) or success-related (has the result been achieved in this step?). Redundancies and feedback systems with interlocks between the individual steps can be used to reliably achieve the objectives of the process steps.

In this functional analysis of the system, the energy state (E) and the material (product) state (S) dependent on the process step are determined for each process step (A-XYZ). From the functional analysis, information about possible risks (weak points, fault potentials) for the system can also be derived. The results are the basis for designing process safety.

The necessity of sensors and actuators for the regulation or control of the process steps as well as the physical principles to be applied depending on the task was dealt with in Chapter 2.

Figure 7
Possible modularisation of a grinding plant

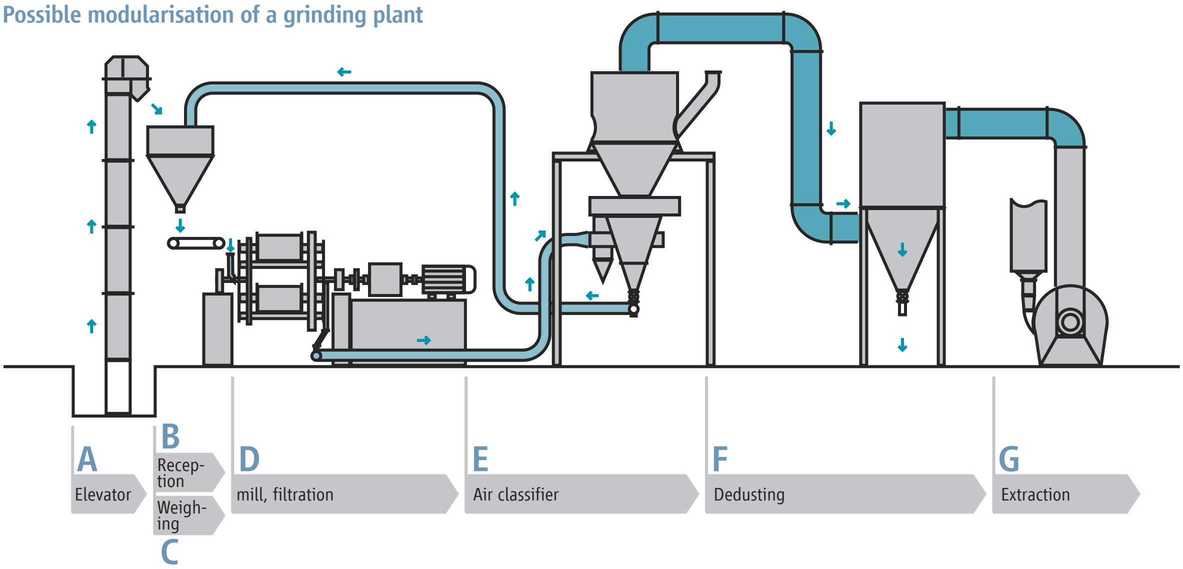
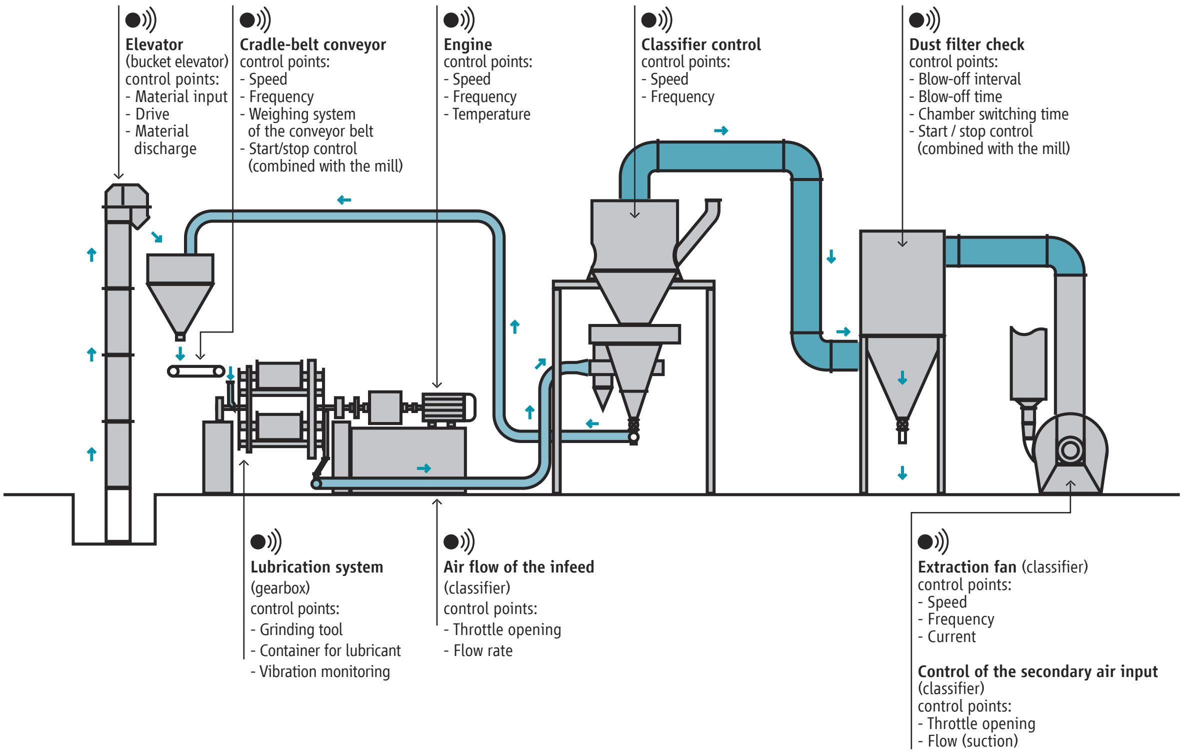


Figure 8
Control points for the placement of sensors



4.1
Example of a grinding plant

Figure 7 shows the possible modularisation of a grinding plant (planetary mill) with fine dust separation. The bulk material is fed by means of a bucket elevator. Figure 8 shows the control points for placing sensors of the mill and air classifier system.

A control point requires one or more sensors, depending on the task set by the algorithm. The sensors are placed at the following control points:

A. Elevator
- Control points see specific elevator descriptions (example of a digitalized elevator)

B. + C. Scale belt conveyor check point
- Power consumption
- Speed
- Frequency

Queries: energy supply, motor condition, bearing-shaft damage, wear, unacceptable power increase, etc

- Weighing system of the conveyor plant
- Start/stop control (the combination with the mill)

D. Planetary gear mill control point

Mill motor:
- Power consumption
- Frequency
- Speed

Queries: energy supply, motor condition, bearing-shaft damage, wear, unacceptable power increase, etc.

- Lubrication system: Gearbox lubrication

Queries: lack of maintenance, leaking housing, gear damage

- Lubrication system: grinding and roller unit

Queries: lack of maintenance, roller damage

- Temperature of the mill

Queries: lack of maintenance, bearing-shaft damage

E. Air classifier control point
- Power consumption
- Speed
- Frequency

Queries: energy supply, motor condition, bearing-shaft damage, wear, unacceptable power increase, etc

Control point of the second air inlet (air classifier)
- Opening of the throttle valve
- Flow rate

Queries: flap mechanics, flow control

Air flow of the feeding device (air classifier)
- Opening of the throttle valve
- Flow rate

Queries: flap mechanics, flow control

F. Dust collector control point (air classifier)
- Blow-off interval
- Blow-off time
- Switching time chamber
- Start/stop control (the combination with the mill)

Queries: Differential pressure control, dust cloud formation in EX area

G. Extraction fan control point
- Power consumption
- Speed
- Frequency
- Flow rate
- "Runs" (or does not run) and asks about the condition of the equipment

Queries: Blockage (deposition), true running of impeller, bearing-shaft condition

Figure 9
Algorithm - processing the data and designing the communication with other machines. One algorithm for each measuring station

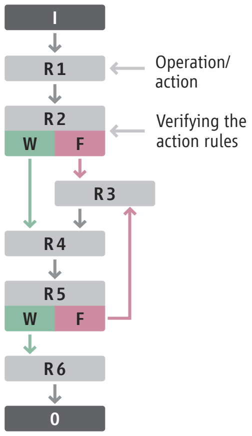
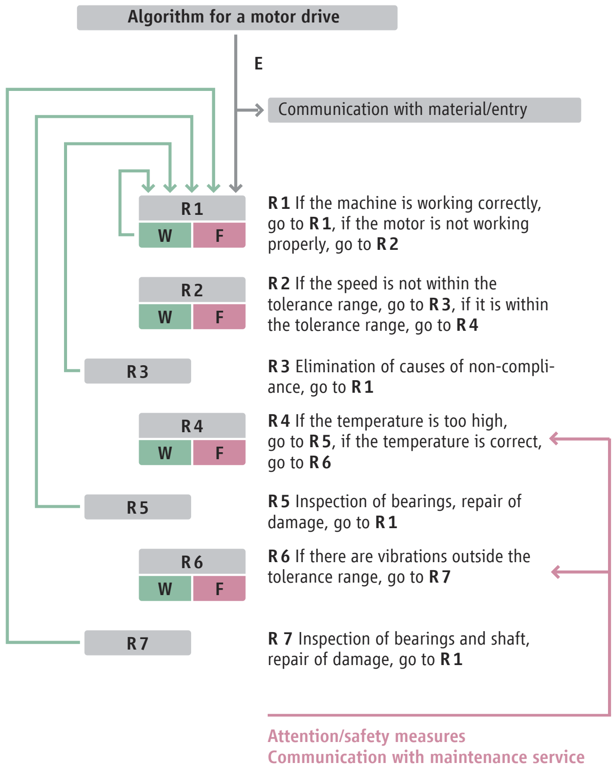


Figure 10
Specific algorithm for a motor drive



Legend for Fig. 9 and Fig. 10

R: Action rule
Operation/action or verification of the action rule

W: Logical condition
The verification of the rule is given

F: Logical condition
The verification of the rule is not given

Further algorithms are exemplarily assigned to the specific machines (or modules). For the motor drive, the specific algorithm can then look like the one shown in Figure 10.

Information relevant for explosion protection in this example are temperature monitoring and vibration monitoring, because they are parameters for the protective measure "avoidance of ignition sources".

This critical (risk indicating) information from the sensors leads to various actions (e.g. maintenance measures) to ensure safety.

4.2
Complex silo plant for combustible bulk materials

The modules
Reception of the bulk material, cleaning, processing (e.g. grinding), further processing (e.g. pelleting, granulation, staining), storage (e.g. ensiling), packaging, delivery of the finished product. The individual process steps and the corresponding machines are evaluated.

Reception of the bulk material

Emptying packs
Products in packs are typically fed directly into the process. Different feeding and discharging stations can be used for this purpose.

Manual feeding stations
Such feeding stations are usually used for feeding bags into a receiving container (bag feeding station). The sacks are cut open and manually fed. Empty bags are disposed of in containers. Details: Bag feeders have a coarse grating to prevent the whole bag from entering the process. However, the grid is not suitable to prevent the entry of smaller objects such as knives or keys. Regularly used feeding stations usually have an extraction system via a central extraction unit.

Feed stations that are used less frequently usually have a door or flap to close. An extraction fan is automatically started when the door is opened. Such stations often have an integrated filter. As soon as the sack is emptied (and the flap is closed), the extraction fan is automatically stopped and the filter elements are cleaned by compressed air. The product is normally discharged from the receiving container via a rotary valve into a pneumatic conveyor, a screw conveyor, trough chain conveyor, belt conveyor or directly into the plant (e.g. a mixer).

Automatic bag feeding stations
In such plants, the bags are fed onto a short belt conveyor by means of a robot (sometimes manually). The sacks pass rotating knives and fall into a rotating sieve. Most of the product falls through the sieve into the receiving container. The emptied parts of the sacks arrive at the other end of the sieve, together with the rest of the product, in a compacting device (sack compactor). There the compressed bag parts are sent for disposal in sealed plastic bags. The machines are usually equipped with integrated filters. As with manual feeding stations, the product is discharged via a cellular wheel, which allows the product to be transported further into the process.

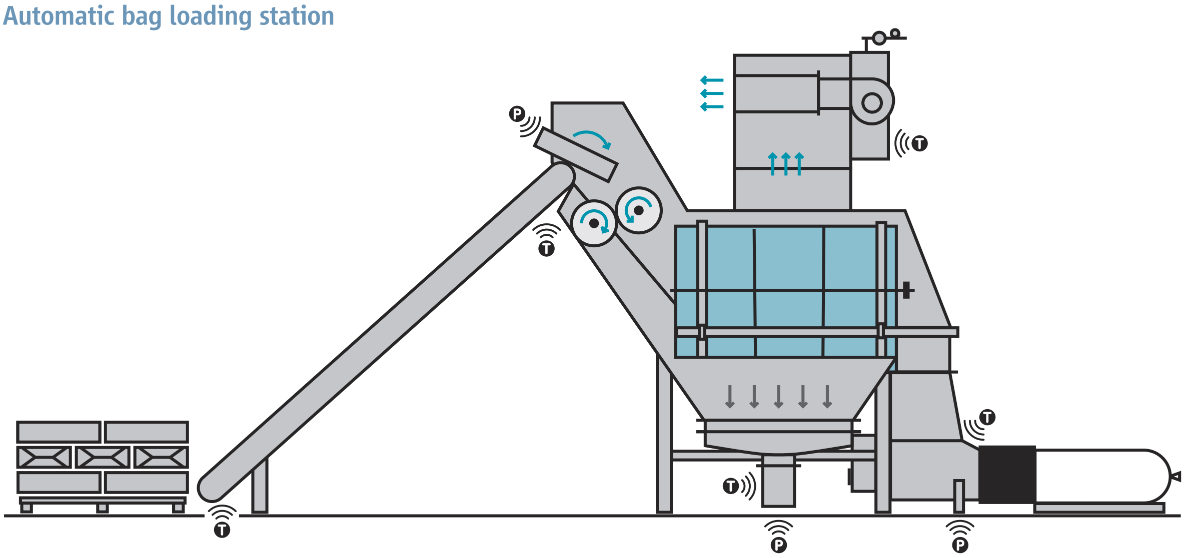
Sensor technology
- Sensors control the bag transport, the tearing tools, the bag waste (discharge), the extraction and filter, the product discharge
- Pack inspection (number/time, weight/unit = light barrier in the discharge/tilting area)
- The sensors control the process and the technology.

Process
Bulk material quantity at the outlet (weight, quality such as foreign matter content, comparison of quantity at the inlet / quantity at the outlet: weighing by means of scales and storage container (tolerance: 3-5% to bag weight) or baffle plate scales for inline mass flow measurement. Mass flow measurement of the bulk material is carried out gravimetrically - i.e. free-falling or by microwave flow measurement. Bag waste quantity and compression (bag weight + 5%)

Technique
- Conveyor belt drive: motor frequency monitored
- Drive tearing tool (bearing control temperature)
- Motor protection/current consumption also for knife wear (high current consumption = wear) Note: fixed speed of the blades
- Empty bag compression (pressure)
- Bag emptying basket: Power consumption friction wheel
- Extraction performance and filter function
- Rotary valve: power consumption, temperature of the bearings

In some of the illustrations in this publication, sensors are shown in different ways for better understanding:
P))) Process sensors
T))) Technique sensors

Figure 11
Automatic bag loading station



The probability for the occurrence of an explosive atmosphere depends very much on the particle size or the fines content of the products involved as well as on the product moisture and the ability to form dust clouds. Although the explosion is partially untamped and there is almost no pressure build-up, the effects of such explosions must be considered.

During unloading operations there are usually people on site who are endangered by the fireball, unloading areas are often dusty, which can lead to secondary dust explosions. Explosions can propagate into receiving containers and lead to explosion pressure development there.

Emptying of FIBCs by gravity
The FIBC (class C big bag) is suspended above a (large) reception container. The discharge of the FIBC is opened and the contents of the FIBC are quickly discharged into the receiving container. The receiving container is sucked off, either via an integrated filter (top filter) or via a central dust extraction system.

Gravity discharge via dosing container
The FIBC is placed on a (small) dosing container. When the FIBC is opened, only a small part of the contents flows into the receiving container. This is normally fed into the process via a rotary valve. Such receiving containers are usually extracted via a central extraction system. Depending on the product, the outlet of the various receiving containers may contain other devices, such as sieves to remove lumps, or crushers (lump breakers) or a mill, as well as permanent magnets to remove magnetic metals.

Figure 12
Bulk material reception by rail – The bulk material falls from the wagon over a grate into the bulk hopper and from there it reaches the conveyor. Sensors control the product flow and function (drive, accumulation etc) of the trough chain conveyor and the product transfer to the elevator. A foreign particles check takes place. The signals from the sensors determine the further transport of the bulk material via the elevator for processing.

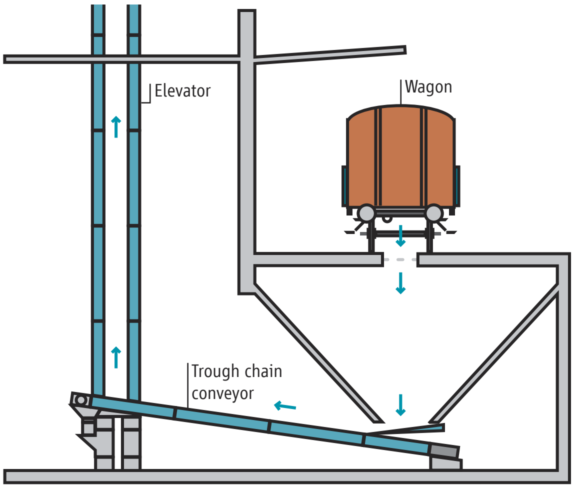
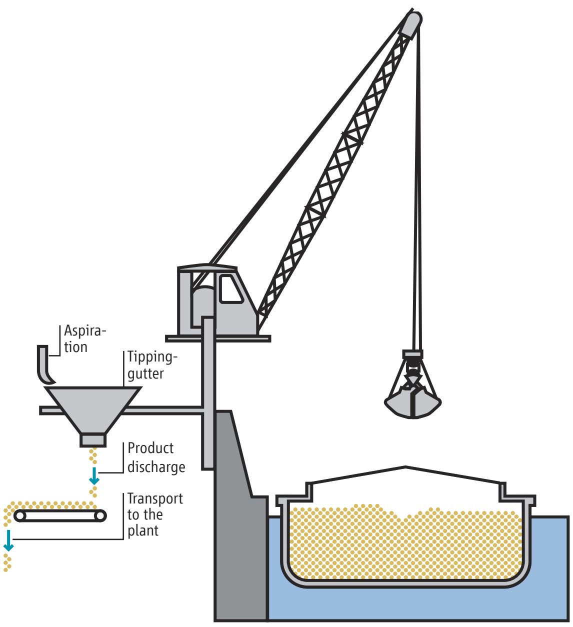


Figure 13
Ship unloading by crane – From the bulk gutter or receiving container the material is transported to a bucket elevator by belt conveyor, screw conveyor or trough chain conveyor. The bucket elevator takes the material to another belt or chain conveyor, which transports it into the silos. For storage in horizontal silos (= large halls) bucket elevators are not usually used, but belt or chain conveyors are. See assemblies conveyor belt, screw conveyor, trough chain conveyor, bucket elevator.



Sensor technology

Process

- Bulk material quantity (loose goods), bulk material throughput with suction conveying
- Bulk material quality (grain size, purity, moisture)
- Foreign particles (metals, stones etc.)
- Aspiration, fine dust discharge (extracted from bulk material)
- Filling status of the receiving container (recipient)
- Bulk material discharge quantity: comparison of bulk material quantity obtained

Technique

- Drive (motor) Conveyor belt / drive (motor) Elevator
- Current consumption, frequency monitoring (upper limit)
- Bearing checks (temperature, vibration)
- Transfer device (input) Elevator
- Rotary valves drive
- Speed control lower deflection
- Misalignment control cup belt
- Suction nozzle mechanism (nozzle height adjustment, joint for height and lateral adjustment)
- Function rotary blower
- Suction nozzle capacity (flow rate)

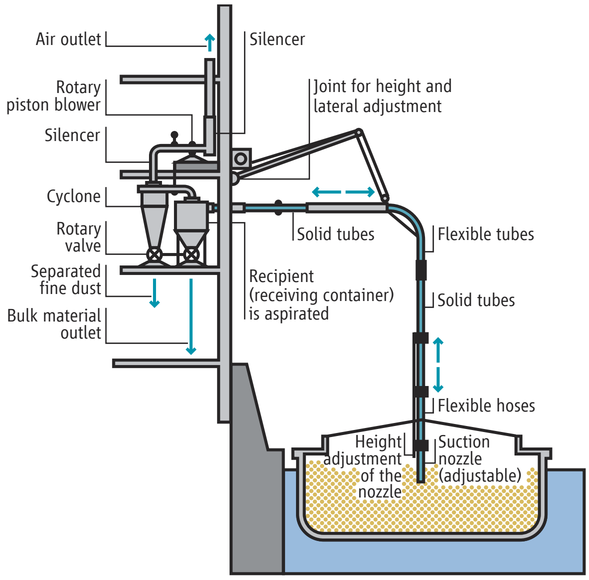
Loose bulk material reception

Bulk goods can be delivered by rail (Fig. 12), truck, ship (Fig. 13) or sea containers.

A truck can usually be unloaded in two ways:
With the help of a blower, which can be integrated on the vehicle, the material is pneumatically conveyed into the silo. Or the material is unloaded into a bulk gutter by gravity.

The ship can usually be unloaded in two ways:
The material is transported to a receiver by means of a suction line (suction conveyor) or the ship is emptied by means of a grab.

Figure 14
Bulk material reception by ship – The bulk material sucked out of the ship is collected by a cyclone pre-cleaned. The product flow is monitored by sensors. The rotary valve for ultra-fine dust discharge is also monitored with regard to function (drive) with sensor. The fill level and the flow rate (rotary valve) of the receiving container are monitored by sensors. The signals determine the further transport of the bulk material for processing..



For both unloading options there are small dredgers inside the ship to enable the complete emptying of the ship.

During the filling of the bulk gutter, explosive dust clouds may occasionally form inside the bulk gutter. Depending on the filling process, homogeneous or inhomogeneous dust clouds can occur, which can cover the entire gutter volume or only a part of it. The existing aspiration system significantly reduces the dust concentration and thus the risk of explosion. In addition, the occurrence of explosive atmospheres is not to be expected above the gratings if retaining flaps prevent the escape of dust.

The following ignition sources can occur during operation:

a) During the filling process smoulders may be introduced.
b) Dust escaping from the bulk hopper may ignite at the hot exhaust system of the delivery vehicles. For this reason, the escape of dust must be prevented.

To reduce the danger of ignition sources in the other parts of the plant, after reception, foreign particles separators (magnetic separators and sieves) must be installed at the corresponding reception elevator.

Depending on the dimensions of the ship and its position relative to the quay, the unloaders often cannot reach the entire floor space of a cargo hold. Due to cargo removal, ballast operations and tidal changes, the position of the ship and thus the accessible loading space changes during the unloading process. With many mechanical conveying principles, the conveying capacity also drops sharply as the immersion depth of the unloading head in the cargo decreases.

With the respective conveying principles, therefore, no efficient residual discharge is possible. Particularly in the residual emptying phase, feeders (bulldozers, wheel loaders, excavators or similar) are therefore used to feed the remaining load to the unloader.

Sea containers are unloaded in two ways

a) tipping over like a lorry or railway wagon; or
b) Unloading by gravity through a connected sluice into a pneumatic pressure or suction conveyor

4.3
Silo plants

The process consists of:

- Filling of containers/silos with bulk materials by means of free-fall or conveyor elements
- Separation of the bulk material from the conveying air by means of filters
- Storage silos for bulk materials
- Level indicators for full, intermediate and/or empty signal, or continuous measurement
- Discharge device for bulk materials (mass flow preferred)
- Discharge of bulk materials into conveying elements or other process containers/process elements

If bulk materials are manufactured or processed in a production process, they must be stocked as raw materials, buffered as intermediate products or stored as finished products.

The bulk material is to be discharged from the respective storage container and usually fed to the downstream processes by means of a mechanical conveyor. It is important to note that the individual devices such as storage container, discharge and conveying element are designed to meet the bulk material and process requirements. Equally, care must be taken to ensure that the aforementioned devices are matched to each other in terms of process technology.

Silo equipment

Pneumatic or mechanical silo filling, exhaust air filters, safety fittings, fill level monitoring, weighing technology, discharge aids, shut-off fittings, dosing and conveying devices, silo loading telescope, inerting connection.

Process engineering design with determination of the required flow profile

- **Mass flow** for "first in/first out" and segregation-free emptying
- **Core flow** as a cost-effective solution without special conditions
- **Piston flow** for extremely gentle emptying with minimum grain abrasion
- **Blending silo** for homogenisation and conditioning

Pneumatic pressure conveying is always advantageous when several receiving containers are to be filled from one feeding point.

Silos or containers are usually filled by pneumatic pressure conveying through pipes with diameters from 80 to 100 mm either from silo trucks with their own compressors or by stationary blowers or transmitter vessels. Cooling of the heated air is necessary. With round containers, the filling pipe is in most cases inserted tangentially just below the roof end, which results in a rotational material entry with a "pre-separating" effect (see also explosion pressure relief with tangential filling). It may be more practical to arrange a so-called blow-in dome on the silo ceiling, e.g. also for angular containers or multi-chamber silos.

The arrangement of blow-in domes has the great advantage of a relatively low air, material and discharge velocity into the container. This also considerably reduces turbulence in the upper part of the silo and thus the dust load for an attached filter. These are also explosion-related advantages.

For silo container ventilation, filters with mechanical, motorised and compressed air cleaning technology can be considered.

Feeding by means of mechanical conveyors
The mechanical feeding systems are characterised by very high product throughputs and low drive power. However, they require a lot of space and become very complicated in branched production lines.

The risk of explosion in silos

Explosions in silo cells can follow different patterns. They depend on the characteristics of the dust, the location of ignition, the distribution of dust concentration within the cell, the filling level, the filling method, the type of relief devices and the height diameter ratio of the silo cells.

If a silo cell is only partially filled with a dust-air mixture, if the dust cloud remains e.g. limited to less than 1/4 of the lower silo area, then the pressure and the rate of pressure increase during an ignition in the silo outlet are significantly lower than if the dust cloud has spread over the whole volume.

Once the filling process has started, not only does the dust cloud spread, but the fill increases and the free volume decreases. Inevitably, with a constant pressure relief area, the reduced pressure becomes lower and lower.

Two influencing factors play an important role here, namely the reduction in volume and the change in the height/diameter ratio.

Filling processes in practice often involve mechanisms of dust cloud generation where the dust clouds are "inhomogeneous". This influences the explosion pressure.

Tests have shown that the explosion sequences are clearly influenced by the filling method.

Orienting tests, in which the silo was filled via downpipes, have shown that compared to pneumatic flight conveying, there is a significant reduction in explosion severity. The resulting explosion pressures in the incident of an explosion are significantly lower. In some cases an explosion is no longer possible.

The silo cells may be endangered by spontaneous ignition processes during longer storage. The inertisation in case of fire, which is common today, requires openings or connection pieces.

Dangers

- **During filling,** there is a danger of ignition of any dust-air mixture that may be present due to imported smoulders or due to explosion transmissions.
- **When emptying,** there is a danger of explosion due to the collapse of bridges in connection with smouldering fires.

Protective measures

- Pressure relief
- Decoupling
- Fire temperature monitoring

Special features for grain silos

Important for the selection of protective measures is the assessment whether an explosion can be entered via transporters or aspiration pipes. When filling with grain, the lower explosion limit of the dust/air mixture is rarely reached (among other reasons because the product is aspirated as soon as it is received). However, caking on the walls pose a risk if they are whirled up or have a tendency to self-ignition.

Once the filling process has begun, the air flow (aspiration) causes the dust cloud to spread, but it is usually of low concentration.

During filling, there is a danger of ignition of a possibly existing dust-air mixture due to smoulders introduced. This should be prevented in advance.

When emptying, there is a danger of explosion due to the collapse of bridges in connection with smouldering/smouldering fires. In this case, emptying under an inert gas atmosphere must be provided for. Silos are always ventilated and the product cooled, which makes spontaneous ignition processes more difficult. A temperature measuring system can be useful.

An inerting system (connections) must be provided to ensure effective fire fighting in the silo cells. In case of fire in one of the silo cells, the possibility of emergency emptying must be provided.

Existing sweeping screws can become a source of ignition in case of failure by heating (bearings) and friction (screw). At the time of emptying the silo no explosive dust-air mixture is normally to be expected, but deposited dust can ignite and cause a fire. Inspection, maintenance and servicing are required. The starting of the sweeping auger during the filling process must be prevented.

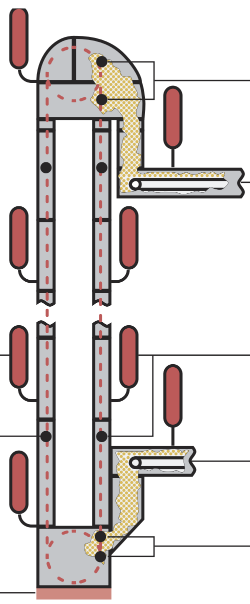
Special features for flour silos

A frequent/continuous explosible atmosphere is present within all silo cells, conveyors such as elevators, screw conveyors and chain conveyors, the screening machines, the flour drying plant as well as the downpipes and aspiration filters. The occasional occurrence of a hazardous atmosphere must be expected in the aspiration pipes on the raw gas side.

A pressure relief of the silo cells is often difficult because the silo cells are integrated in buildings and a pressure relief into the silo floors would pose a higher risk.

The silos are often equipped with hopper top filters, which has safety advantages compared to central filters. The protective measure "avoidance of ignition sources" is used, i.e. ignition sources from upstream machines and aggregates must be prevented. The filter media are monitored, deposits are removed immediately. The control is documented in the maintenance plan.

Figure 15
Example of a digitised elevator (here equipped with an explosion suppression system)



4.4 Transport Systems

Elevators

During operation in elevators, explosive dust-air mixtures are usually not to be expected in bulk material conveyance such as grain, since the material conveyed does not itself form an explosive mixture. Deposits in the elevator cannot be excluded. For this reason, sufficiently large quantities of dust can be whirled up by vibrations during the start-up processes and - as experience has shown - if an ignition source is present, initiate an explosion. Ignition sources in elevators can be e.g.: smoulders, hot surfaces due to belt and bucket friction, wedged foreign particles, hot-running foot bearings, heating of material between belt and deflection rollers. Explosion transmission from other parts of the plant is also possible. Elevators can transmit dust explosions to the upstream and downstream plant elements. Elevators can rupture, and flames and dust/air mixtures that escape in the process can lead to secondary explosions in rooms. Elevators are among the plant elements that pose the highest risk.

Protective measures

- Sufficient distance between fixed and moving parts

- Bulk material feed
  - Prevention of the entry of foreign particles through foreign particles separators, e.g. gratings, sieves, metal separators

- Elevator foot
  - Overfill protection to prevent the bulk material and belt from heating up
  - Avoiding damage to the cups

- Elevator foot and head
  - Speed monitoring to detect friction/slip and thus heating of cylinder, shaft, bearing
  - Bearing temperature monitoring to detect hot running of the bearing
  - Misalignment monitor near the deflection roller to prevent the belt from rubbing against the wall

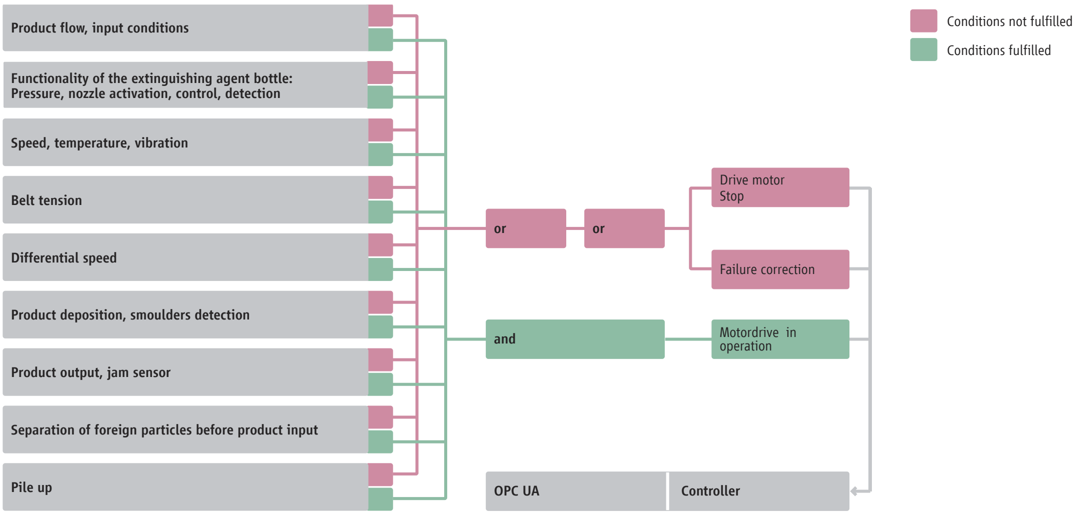
- Elevator head
  - Pile up sensor in the bulk material discharge to avoid heating of the bulk material and the belt
  - Avoiding damage to the cups

- If necessary: explosion pressure relief, explosion suppression

Figure 16

Functional conditions for the safe operation of the elevator

Conditions are listed in the picture shown. All of them must be fulfilled = sum of the green parts for the successful functioning of the elevator. One unfulfilled condition only will cause the motor drive to stop until the appropriate fault correction(s) has/have been made.



Criteria for sensor technology

- Frequency monitoring
- Speed, temperature, vibration
- Speed within the normal range ±% deviation (empty speed control)
- Temperature within the normal range +% increase
- Vibration in the normal range, does not signalise bearing damage
- Speed too high, unacceptable increase in power (stop command)
- Temperature too high, motor overheating (stop command)
- Vibration critical, indicates that bearing damage is beginning to occur (bearing check)
- Slip too high, danger of overheating (differential speed)
- Belt tension
- Tensile forces of the belt within the standard range ±% deviation
- Ageing of the belt within the permissible range
- Cup fastenings in order
- Belt without damage (e.g. cracks)
- Tension forces of the belt too high, load on the axles too high
- Ageing of the belt with risk of defect (belt breakage)
- Cup fastenings not in order, danger of grinding
- Belt with damage, danger of defect (belt breakage)

Trough chain conveyor

At low relative speeds (below 1 m/s) in normal operation, chain conveyors are not initially regarded as effective ignition sources.

Due to the low speed (< 40 min-1), no ignition-effective processes are to be expected in case of bearing failures (e.g. due to lack of lubrication) at the chain trough conveyors.

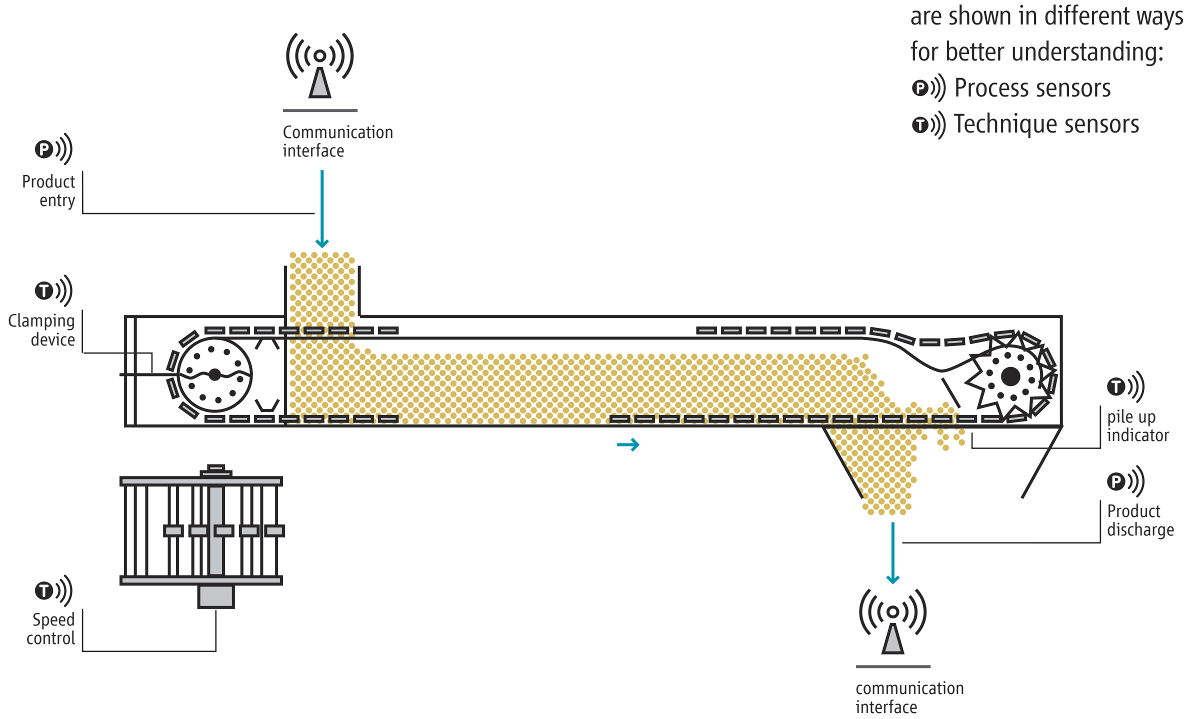
Frictional heat, caused by blockages in the outlet area of the conveyor, can lead to smouldering fires in products with a low glow temperature or high burning rates with a low smouldering temperature or high combustion class. An ignition-effective process can also occur if the chain slips on the drive wheel when the conveyor chain is blocked. These are conditions which must be classified as foreseeable defects.

If chain conveyors are equipped with a bulwark monitoring system in the outlet area, an approaching blockage can be detected and a necessary shutdown process can be initiated.

Speed monitoring at the deflection stations or running monitoring at the conveyor chain are suitable for detecting / monitoring blockages or breaks in the conveyor chain.

Figure 17
Example of a digitalised trough chain conveyor

In some of the illustrations in this publication, sensors are shown in different ways for better understanding:
P Process sensors
T Technique sensors



On this basis, ignition-effective processes caused by bulges, blockages or breaks in the conveyor chain are not to be assumed during normal operation and in case of foreseeable malfunctions.

In the trough chain conveyor, explosive dust-air mixtures are generally only to be expected at the feeding points.

Protective measures: Aspiration at feeding points, conveying speed < 1 m/s, overload protection (pile up switch).

However, in the case of a malfunction, sources of ignition can arise through friction and bulging if the chain speed is > 1m/s. Trough chain conveyors can transmit explosions.

Protective measures
- Aspiration at feeding points
- Conveying speed < 1 m/s (for all trough chain conveyors in operation)
- Overload protection (pile up switch/flap)
- Speed monitoring
- Pressure relief / decoupling

Probability of the occurrence of ignition sources: Normally not, only in rare cases of malfunctions.

Belt conveyor

During operation, there are usually no explosive dust-air mixtures in belt conveyors, but there are often dust deposits that can be stirred up.

Ignition sources in belt conveyors are conceivable due to hot surfaces, only if the relative speed between fixed and moving parts is > 1 m/s, rollers jam, bearing damage is not detected, the belt rubs against caking or foreign particles get jammed in the deflection points.

Belt conveyors can transmit dust explosions between the receiving, cleaning, silo cells, warehouses and loading. Flames and dust can escape and lead to secondary explosions in rooms. The latter is particularly serious in large warehouses and silo cells.

Dangers
- Large dust deposits on the belt base due to poor cleaning possibilities
- Room Dusting
- Jammed rolls

Protective measures
- Regular cleaning
- Temperature monitoring
- Misalignment control
- Slip monitoring

Screw conveyor

During operation, there are usually no explosive dust-air mixtures in screw conveyors.

In screw conveyors, ignition sources in the form of hot surfaces can form if the circumferential speed of the screw is > 1 m/s, whereby in particular the running of the screw flights against the wall or the wedging of foreign particles between the screw flight and the wall can lead to hot surfaces. Warming of intermediate bearings and heating of the products due to clogging also pose risks. Tubular screw conveyors can also be used for explosion decoupling if appropriately designed.

The ignition source variants listed below are to be regarded as foreseeable disturbances.

- Flanged bearings at the ends of the screw can cause overheating inside the screw due to heat transfer and cause a smouldering fire if there is insufficient lubrication.
- In the case of screw conveyors with intermediate bearings, hot surfaces can occur in the bearing/ bearing support as well as on the mounted shaft in case of bearing failure.
- A foreign particles wedged in the conveyor can lead to hot surfaces due to friction.

Protective measures

- Bearing designs with bearings offset from the screw housing prevent heating caused by insufficient lubrication (foreseeable malfunction) from being transferred to the flammable product inside the screw.
- Lack of maintenance or lack of lubrication can be prevented by using automatic lubrication cartridges. This is especially recommended in places which are difficult to access.
- Intermediate bearings made of elastomer, PFTE, graphite or ceramic have proven to be a suitable protective measure due to their behaviour at higher temperatures.

In special cases, e.g. products with low glow temperature and/or high burning number (> 3), it may be necessary to install temperature monitoring at the intermediate bearings. Here, too, the use of automatic lubrication cartridges can be advantageous.

Pneumatic conveyors

Experience has shown that the danger of explosion is low with these conveyors. The dust load is usually above the upper explosion limit, the turbulence is high, and as there are no moving machine parts in the dust conveying area apart from the slow-running discharge elements (airlocks), the risk of ignition is low. The further transport of smoulders into other areas is possible.

Explosion dangers can arise from electrostatic charges on the conveyor pipes, which can lead to sparkovers if conductive conveyor pipes are interrupted by sight glasses or seals at individual points and are not earthed. Likewise, non-conductive coatings inside metallic conveying pipes can lead to charges.

Down pipes and two-way distributors

In pipe switches/distributors and pipes/downpipes, an explosive dust/air mixture is only present temporarily (during the transport of filling material). Transitions from downpipes or conveyed material to other plant elements (transporters, containers, silo cells, pipelines) can be critical, because at these points both explosive dust-air mixtures are generated and ignition sources can be introduced.

With cleaned products this risk is low.

Electrostatic discharge sparks can occur as operational ignition sources, if not all distributors and down pipes are electrically conductively connected and if they are lined with highly insulating materials.

The product conveying lines are assigned to zone 21.

The pipes themselves do not pose a danger as they do not contain any ignition source, provided they are earthed. Explosions can propagate through pipes and thus reach further parts of the plant from the point of origin and trigger secondary explosions there, some of which occur at higher pressures than the initial explosions.

The deposition of dust in pipes increases this danger; it is reduced by a pipe routing that is favourable from the point of view of flow.

Pipes and tubes for the transfer of bulk materials Pneumatic transport

When pneumatically transporting flammable bulk materials with air, a potentially explosive atmosphere due to fine dust is generally to be assumed inside the pipes and tubes used for transport.

The pneumatic transport of bulk material is a high charge generating process. Therefore, various requirements are valid for the wall construction of the pipes and tubes to avoid effective ignition sources.

In the following, pipes and tubes are differentiated with regard to their wall construction and the materials used.

According to the relevant definitions, only the volume resistance (specific resistance) may be used to characterise the wall material as conductive. A characterisation via the surface resistance alone is not permissible.

Especially at drop heights > 3 m, conveying by gravity can also be a high charge generating process. In this case the same requirements apply as for pneumatic transport.

In some of the illustrations in this publication, sensors are shown in different ways for better understanding:
P Process sensors
T Technique sensors

4.5 Processing

Grinding plants

In the case of high-speed mills such as pin mills, impact mills, cutting mills, hammer mills, the occurrence of ignition sources must always be expected.

Possible ignition sources can arise from, for example

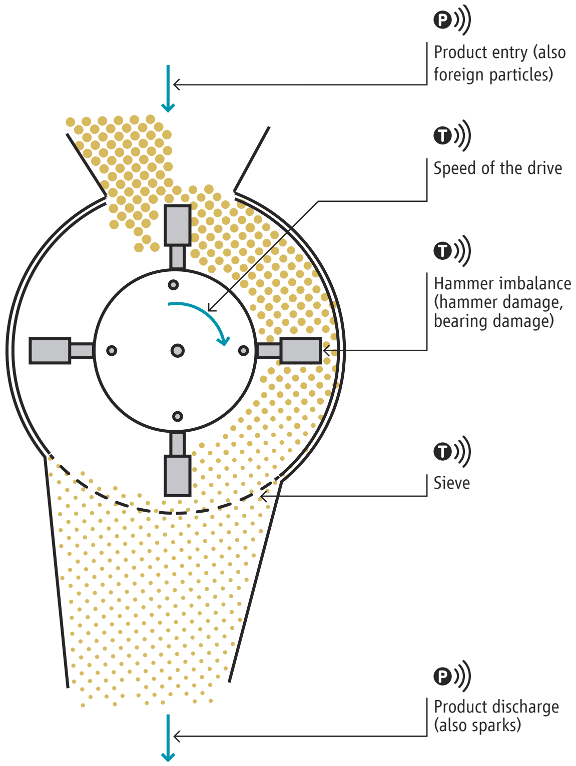
- Entry of foreign particles into the mills
- Loosening of parts inside the mills
- Moving parts tarnish on the mill walls or screens
- Overheating of bearings
- Heating of ground material by friction

Only in exceptional cases can the measure "Avoidance of effective ignition sources" be used exclusively, e.g. if the minimum ignition energy and ignition temperature of the dust to be processed is extremely high. Dangers are sparking and overheating of high-speed mills due to their grinding tools or foreign particles. Due to the high concentration of substances, no explosive atmosphere is usually to be expected, provided that sufficient product supply is taken into account when feeding the material. However, a dilution of the material flow when filling the mill secondary vessel may lead to the formation of an explosive atmosphere. The occurrence of an ignition source in the grinding chamber cannot be excluded in principle. A further ignition source can be caused by overheated rotor bearings.

Hammer mills must always be considered as possible ignition sources due to their mode of operation with high relative speeds.

Due to their mode of operation, ignition-effective processes inside the hammer mill can therefore be assumed during normal operation. In the case of the hammer mill, the fire incident is the primarily case of damage.

Figure 18
Example of a hammer mill with digitised sensors



Hammer mill

Sensors

- Product entry (also foreign particles) = all-metal separator (inductive)
- Motor of the drive:
  - Current consumption/frequency monitoring
  - Speed
  - Hammer imbalance (hammer damage, bearing damage): Temperature + vibration monitoring
- Product discharge (also sparks) discharge quantity + spark monitoring

Explosion events usually only occur as a consequence of glowing/burning particles in downstream components, such as elevators or silo cells. The simultaneous encounter of ignition sources and a dangerous atmosphere in the immediate working area of the hammer mill (grinding chamber, secondary container, possibly aspiration filter) cannot be avoided. The most common trigger of an ignition-effective process is the entry of sparking foreign particles, followed by beater/sieve damage and heating processes due to clogging of the hammer mill sieve / -outlet. Furthermore, bearing damage or excessive heating of the bearing at the bearing of the main shaft of the hammer mill is to be considered as a possible ignition source.

This can be caused by a lack of lubrication or as a result of overload due to rotor imbalance.

Therefore, suitable monitoring measures must be provided in the hammer mill and in the upstream and downstream equipment, in particular to prevent the transmission of burning or glowing particles or their forwarding.

Protective measures for hammer mills:

- The entry of foreign particles must be prevented
- Regular inspection of the condition of the clubs and sieves is very important for safe operation and should be documented
- Bearing failure/heating of bearings can be detected at an early stage by monitoring the temperature of the bearings
- If equipped with a temperature sensor at the grinding chamber of the hammer mill, imminent fault conditions, such as screen clogging or failure of aspiration, can be detected at an early stage
- Unbalance phenomena in connection with club accidents can be reliably monitored with vibration detectors
- Spark detection systems, if necessary in combination with spark extinguishing systems, have proven themselves many times over for this type of machine for protection against fires and explosions in downstream containers or conveyor elements

Pin mills

The relative speed is between 30 and 120 m/s. Bearing failure can result in hot surfaces which, in the event of rare defects, can produce glowing particles inside. Foreseeable defects are foreign particles or broken pins which can cause ignition processes in the machine itself or in the downstream machines. In addition, strong vibrations can occur which can lead to bearing damage.

Blockages in the outlet area can cause overheating inside the machine and cause an ignition-effective process.

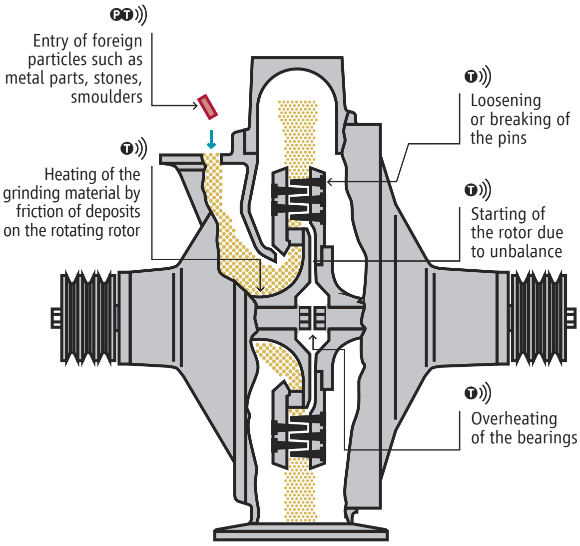
Protective measures for pin mills

Monitoring with sensors

- Product entry (also foreign particles) = all-metal separator (inductive)
- Motor of the drive:
  - Current consumption/frequency monitoring
  - Speed
- Entry of foreign particles such as metal parts, stones, smoulders = all-metal separator (inductive), infrared detection
- Loosening or breaking of the pins
- Starting of the rotor due to unbalance (vibration monitoring)
- Overheating of the bearings (temperature and vibration monitoring)
- Heating of the grinding material due to friction of deposits on the rotating rotor (full detector, glow nest monitoring infrared)

A magnet and a sieve should be installed upstream for protection at the points where foreign particles can occur. The condition of the pins must be checked at regular intervals adapted to the conditions of use. Vibration monitors are suitable for monitoring unbalance phenomena.

Figure 19
Example of a pin mill with digitised protection monitoring by sensors



In some of the illustrations in this publication, sensors are shown in different ways for better understanding:
P Process sensors
T Technique sensors

Impact detachers

The grinding material is crushed between the fixed baffle plates and the impact bars of the rotating rotor.

The relative speed of the cylinder and disc pulper is between 20 and 100 m/s. Bearing failure can result in hot surfaces which, in rare cases of malfunction, can produce glowing particles inside.

Foreign particles can cause ignition-effective processes in the machine itself or in the downstream machines and are to be regarded as a foreseeable defect.

Protective measures for impact detachers

- Observe lubrication and maintenance intervals based on the manufacturer's instructions.
- A magnet should be connected upstream for protection at the points where foreign particles can occur.
- Where a bulge or blockage is likely to cause unacceptable heat build-up, appropriate full detectors which detect a blockage in the discharge area should be used and interlocked.

On this basis, no ignition-effective processes are to be expected during normal operation and in case of foreseeable malfunctions.

Figure 20
Example of an impact detacher with digitised monitoring by sensors
- Product input
- Motor (speed, temperature, bearing)
- Rotor with tool (vibration)
- Glow nest detection (infrared)

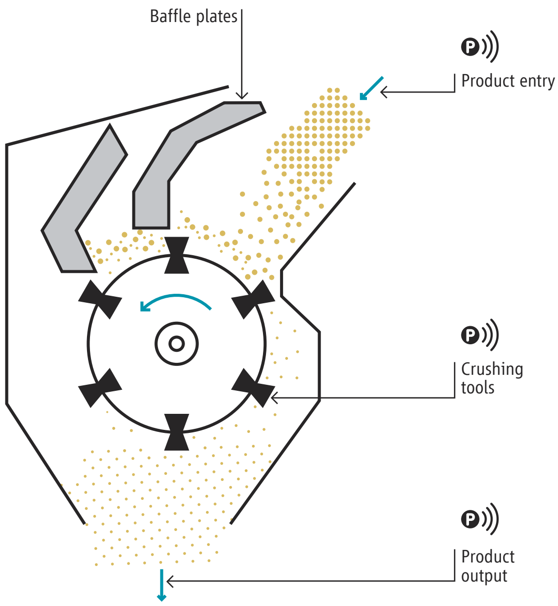
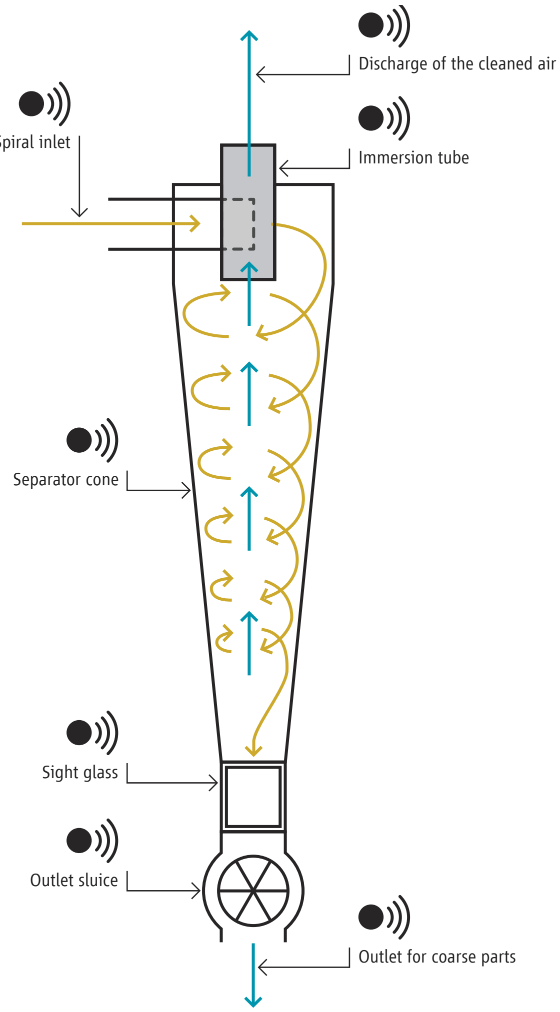


Figure 21
Cyclone - Centrifugal separator – In this type of separator the risk of explosion is relatively small, as the lower explosion limit (LEL) is only reached in a small area on the container wall and there are no effective ignition sources. Monitoring with sensors:
- Product entry (air volume, product quantity)
- Discharge (residual dust concentration)
- Rotary valve (drive, product outlet)



4.6
Cleaning systems

Filter technology

Dedusting plants cause particularly fine dust to be produced and represent a potential danger. The fan is to be arranged behind the separator (fabric filter) on the clean air side.

As a rule, the occurrence of explosive dust-air mixtures can be expected inside filtering separators.

The protective measure "avoidance of effective ignition sources" can only be considered as the sole protective measure at filtering separators if the separated dusts have a minimum ignition energy of EM ³ 10 mJ (this is the case here).

In these cases, the following individual measures in particular must be taken into account:
- Grounding of all parts of the plant which may become dangerously charged, e.g. support cages - individual metal support rings generally do not pose an ignition danger for tube diameters below about 200 mm due to their low capacity. The same applies to tube clips. It is not necessary to equip the filter with conductive filter material for explosion protection reasons. If conductive filter bags are used, they must be included in the earthing measures
- To prevent spontaneous combustion processes which could be caused by dust deposits and possibly higher temperatures
- Avoid entry of effective ignition sources, e.g. smoulders, explosion transmission from connected plant components

Filtering separators (fabric filters)
This type is the most common. When cleaning the filter, ignitable dust concentrations and high electrostatic charges can occur. Support baskets and clamps made of metal must be sufficiently grounded.

In the case of dusts that are particularly susceptible to ignition, electrically conductive filter fabric should be used (resistance < 108 m).

As sparks entering the filter can cause smoulders, spark detection and extinguishing systems may have to be installed in endangered extraction lines

Dangers

- Dust/air mixtures present during operation
- With filtering separators, danger of explosion, especially during cleaning; danger of ignition due to smoulders introduced and as a result of electrostatic charging
- For electrical separators, danger of ignition due to flashover
- With wet working separators possible substance dependent reaction with water
- In the case of fans on the raw gas side, danger of ignition due to mechanical faults or foreign particles
- Danger of ignition due to the whirling up of deposited dust in the pipes, e.g. during start-up and shutdown
- Danger of ignition due to imported smoulders, sparks and electrostatic charges
- Explosion propagation in branched piping systems

Protective measures

- So-called "dust chambers" should be avoided
- In case of filtering separators, regular removal of dust, electrostatic grounding of the supporting elements
- Electrical separators should - if possible - be operated wet
- Arrange fans on the clean air side
- Constructive explosion protection
- Installation of the separators outside of operating rooms
- Avoidance of dust deposits through sufficient flow velocity, fluidically favourable pipe routing and sensible sequence when starting and stopping the plant (e.g. delayed shutdown of the extraction system).

All mechanical parts require inspection and maintenance, as they can become sources of ignition in case of malfunction. Filters without own free volume do not normally form a dangerous explosive atmosphere, but the dust collection container must be assessed with regard to the risk.

Sieves

- Ignition source only possible by spark discharge of insulated conductors
- Explosive atmosphere normally not or only for a short time
- Electrostatic grounding sufficient as a measure
- Regular maintenance and servicing is required
- Foreign particles are removed in advance by magnetic separators

A minimum distance of 500 mm is maintained between vibrating classifiers and stationary parts, taking into account the mechanical strokes. Vibration transmission to the building is reduced. Sieves also serve to separate foreign particles.

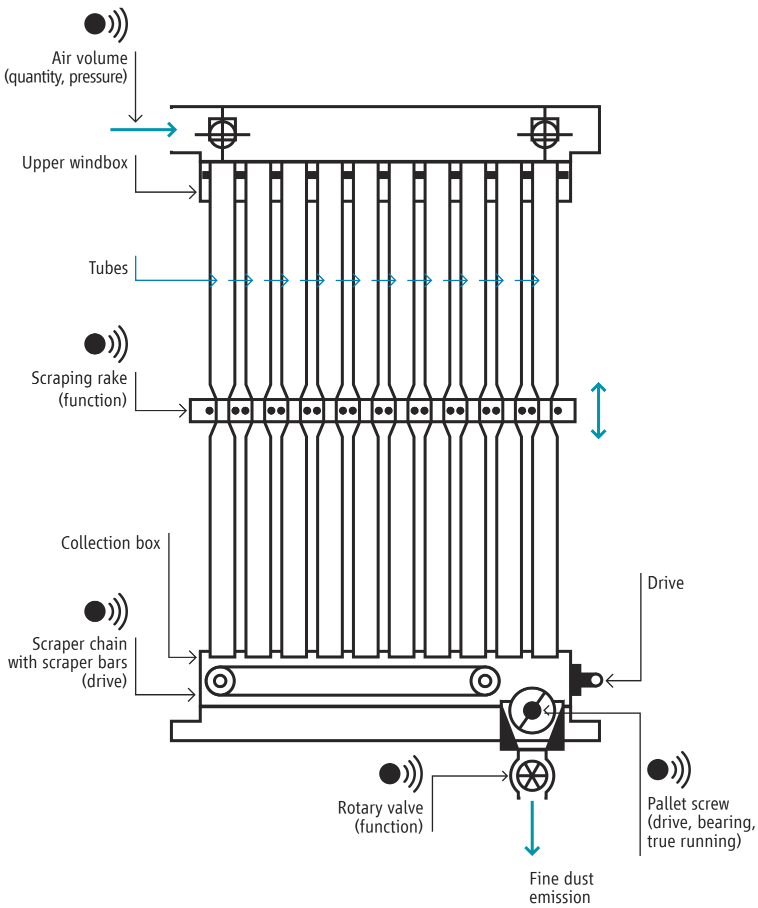


Figure 22
Pressure bag filter
In pressure bag filters, the risk of the formation of a dangerous explosion atmosphere is very low. However, care must be taken to avoid fires.

Monitoring with sensors:
- Air inlet (air volume, pressure)
- Rotary valve function
- Function swabbing
- Function scraper box (drive)
- Pallet screw (drive, bearing, true running)
- Rotary valve function

Figure 23
Nozzle filter

With nozzle filters, an explosive mixture can form during cleaning. In the presence of an ignition source (e.g. a smoulder) an explosion can be ignited. However, filter fires are more frequently observed.

Monitoring with sensors:
- Motor drive of blower unit (speed, temperature, pressure)
- Air inlet (quantity, pressure)
- Rotary valve (drive, temperature)
- Cleaning frequency

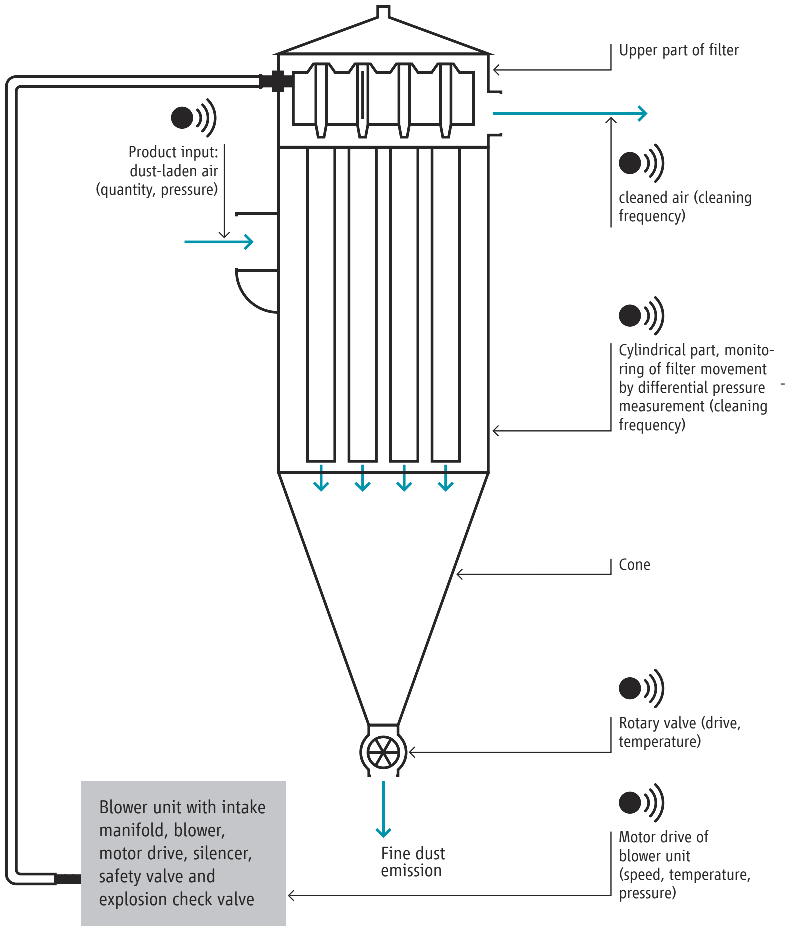
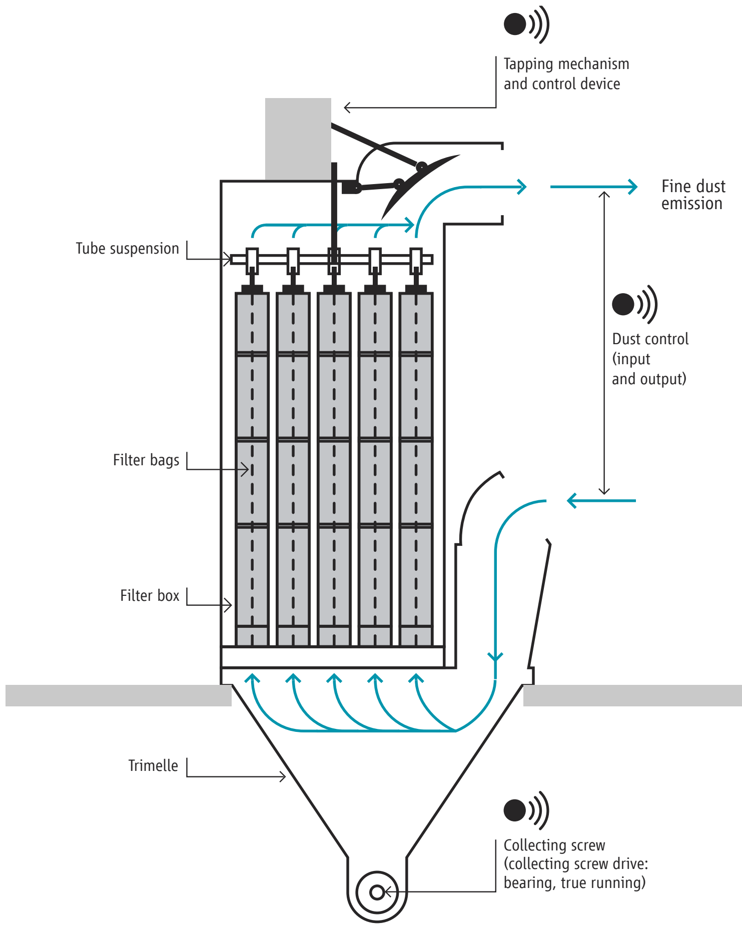


Figure 24
Suction bag filter

With suction bag filters, the risk of explosion is again lower because the dust concentration on the suction side does not usually reach the LEL. With the exhaust, however, explosive dust-air mixtures can occur when cleaning. Fires due to self-ignition of the product which has been stored for a longer period of time cannot be excluded if the filters are not cleaned regularly.

Monitoring with sensors:
- Cleaning mechanism (drive, intervals)
- If necessary, differential pressure control
- Collecting screw drive (bearing, true running)
- Dust control (input and output)

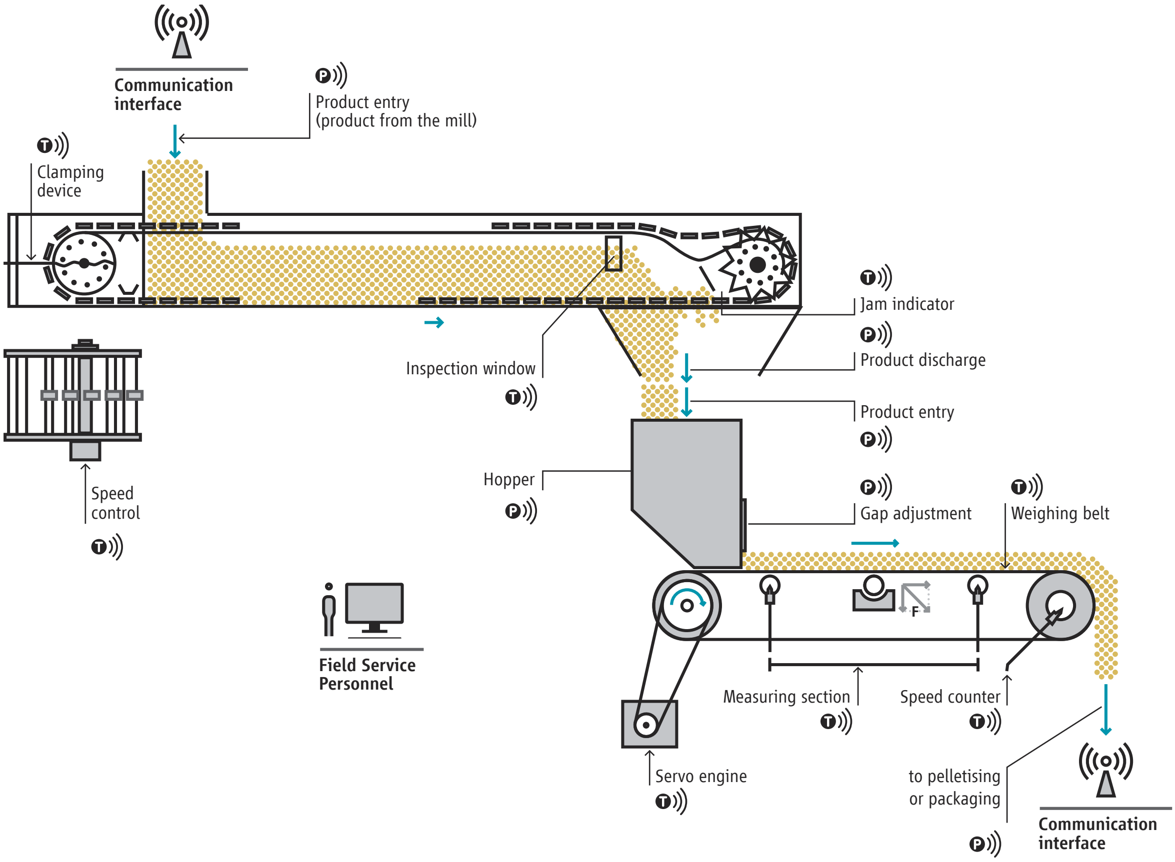


In some of the illustrations in this publication, sensors are shown in different ways for better understanding:
Ⓟ)) Process sensors
Ⓣ)) Technique sensors

4.7
Other ways of processing the dusts

4.7.1
Weighing

Figure 25
Functional sequence of the digital monitoring controls of a weighing system



weighing belt: determination of the product quantity

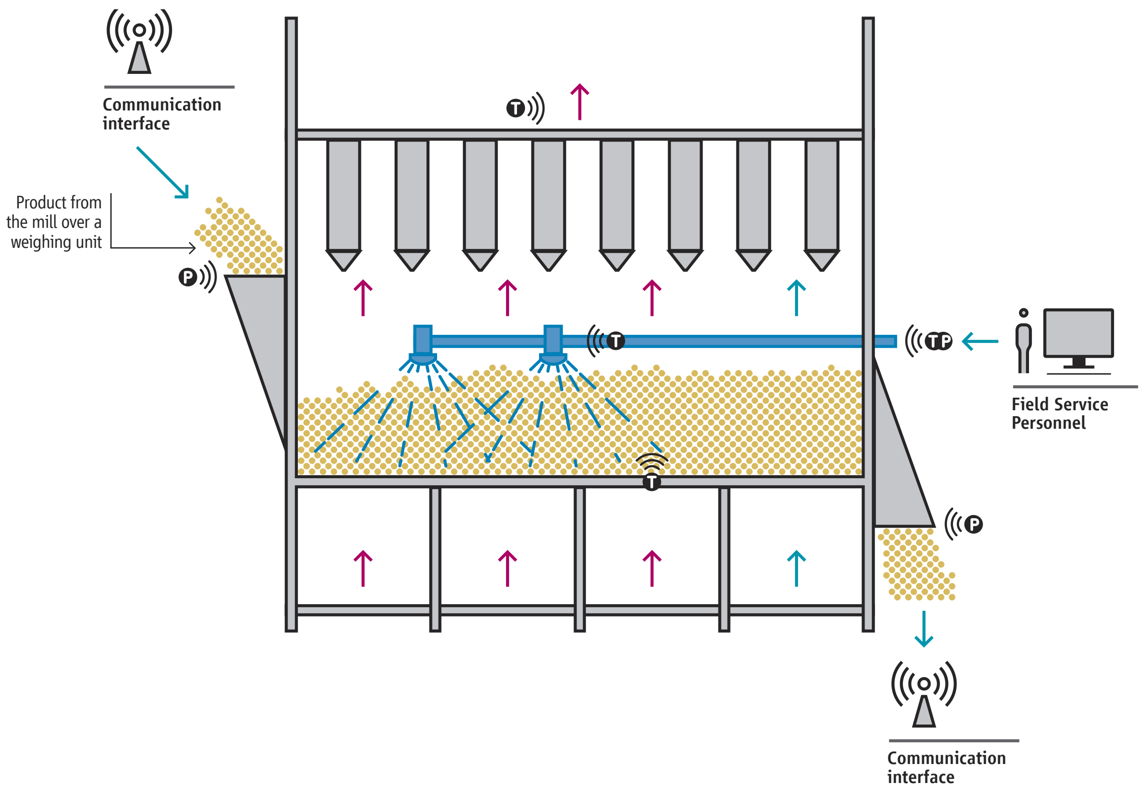
4.7.2
Granulation

Explosive dust-air mixtures can only occur to a small extent in the drying phase or if the wet granulation in the granulator fails. Only moist product is transported into the subsequent plant elements, deposited abrasion dust will not lead to an explosive mixture if cleaned regularly. If deposits remain for a longer period of time, smoulders could occur.

Ignition source in case of foreseeable malfunction
- Smoulders formation and its onward transport
- Bearing damage, overheating
- Wedging of foreign particles in the gaps between moving tools and stationary parts

Measures
- Removal of product caking
- Control, maintenance

Figure 26
Functional sequence of the digital monitoring controls of a granulation device



In some of the illustrations in this publication, sensors are shown in different ways for better understanding:
Ⓟ))) Process sensors
Ⓣ))) Technique sensors

4.7.3 Packaging

During filling and emptying of packaging materials in the process industry, fires and explosions occur time and again. This can be attributed to a wide variety of reasons:

The filling and emptying of packaging materials is usually carried out open (under atmospheric conditions). If the bulk material is flammable and fine-grained, or if the refilling operation is carried out in the presence of flammable gases or vapours, such as when solid matter is introduced into a solvent presented, the formation of an explosive atmosphere can hardly be avoided. Depending on the operational situation, this may be a dust-air atmosphere or a solvent-vapour-air atmosphere or a hybrid mixture. Even with coarse-grained bulk material, fine-grained product can form, for example, due to abrasion during transport.

If an explosive atmosphere cannot be avoided, the only protective measure to prevent an explosion is to avoid all effective ignition sources.

Ignition sources which are not directly related to the decanting process, e.g. open flames, welding, smoking, electrical installations, must be excluded by organisational measures and appropriate choice of equipment and installations.

However, there are ignition sources which are directly connected to the filling or emptying process. One such ignition source is static electricity.

In many cases, electrostatic charging of packaging materials and filling goods is directly connected to operational processes and operations. It represents an ignition source which can be effective under normal conditions, i.e. without any malfunction, but also in the case of deviations.

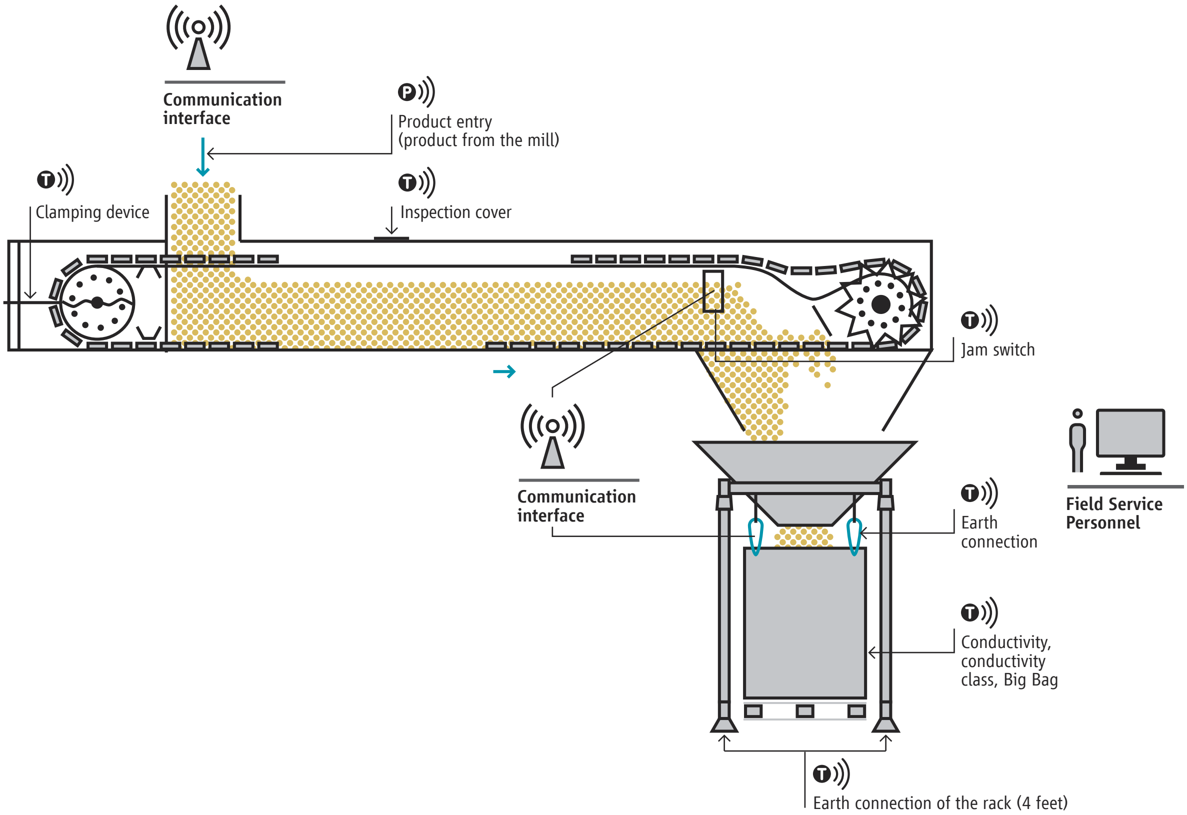
As stated in the above described points, during open filling, emptying and decanting operations, fuel and oxygen (formation of an explosive atmosphere) as well as the ignition source electrostatics are operationally brought together in time and place and thus the danger triangle is closed. It is therefore not surprising that fires and explosions occur repeatedly during these operations, unless additional protective measures are taken.

Often the measures to prevent electrostatic charges are of an organisational nature, such as grounding of mobile packaging materials and of input or output aids. The reliability of these measures is therefore strongly influenced by possible human error.

The phenomena of electrostatics, such as induction, are not always easy to understand and they cannot always be predicted. To assess the dangers due to electrostatic charges, both basic physical knowledge and experience from the process industry are required.

Often process engineering or apparatus engineering are modified and innovated without considering the consequences regarding electrostatic charges and without taking into account the ignition dangers due to electrostatics. For example, the supplier of bulk material changes over to a new packaging material without informing the customer sufficiently, or the production plant changes the raw material supplier and receives the product in a different packaging material.

Figure 27
Functional sequence of the digital monitoring controls of a granulation device



Big bag filling

Bulk materials and bulk containers must be handled or operated in such a way that dangerous charges are avoided. Dangerous charges can accumulate both on the bulk material and on the bulk material container. Flexible bulk material containers are used during storage and transport as well as in production processes, e.g. to hold bulk materials, granulates. Electrical charges can be generated during filling and emptying and can accumulate on the bulk material itself or on the surface of the FIBC. From charged FIBCs, objects or persons can be charged by induction.

The types A, B, C and D are distinguished. Type A can mainly only be used in areas without an explosive atmosphere (as no electrostatically conductive material is used in the fabric, charge dissipation to earth is not possible).

Types B, C and D avoid dangerous charges by using different physical principles. Under certain conditions, static electricity can cause ignitable discharges. Discharges from charged, insulated electrical parts can easily lead to ignitable sparks.

Using the different FIBC's:			
Bulk material	**Environmental conditions**		
MIE of dust	No explosive atmosphere	Explosive dust / air atmosphere	Explosive gas / vapour-/ air atmosphere (Groups IIA, IIB)
MIE > 1000mJ	A, B, C, D	B, C, D	C, D
1000mJ > MIE > 3mJ	B, C, D	B, C, D	C, D
3mJ > MIE	C, D	C, D	C, D

Typical values for the energy of spark discharges in practice			
Loaded object	**Capacity C (pF)**	**Potential U (kV)**	**Energy W (mj)**
Flange	10	10	0,5
Small container (50 l)	50	8	2
Person	150	12	11
Metal keg (200 l)	200	20	40

With charged parts made of non-conductive materials, these usually contain plastic and some other materials, tuft discharges are possible. In special cases with fast running separation processes (e.g. films moving over rollers, drive belts) or by a combination of conductive and non-conductive materials, sliding stem tuft discharges are possible.

Bulk cone discharges can also occur from bulk material.

Depending on their discharge energy, spark discharges, sliding stem tuft discharges and cone discharges can ignite all types of explosive gas, vapour, mist and dust atmospheres. Cluster discharges can ignite almost all explosive gas and vapour atmospheres.

In the case of explosive dust atmospheres, they are only to be considered if the minimum ignition energy is less than 1 mJ.

Figure 28
When extracting non-conductive dust, the unearthed extraction bonnet charges

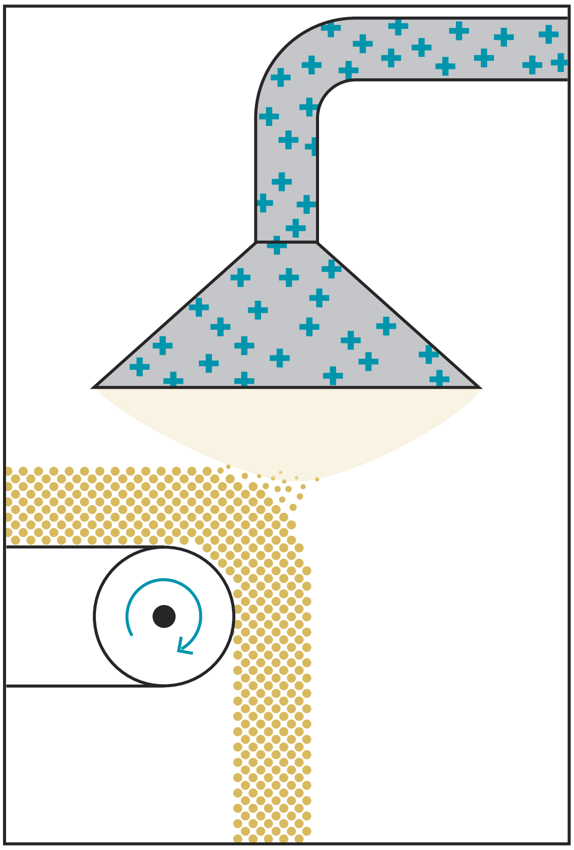


Figure 29
In a bag filter, the non-conductive and ungrounded filter bags are charged

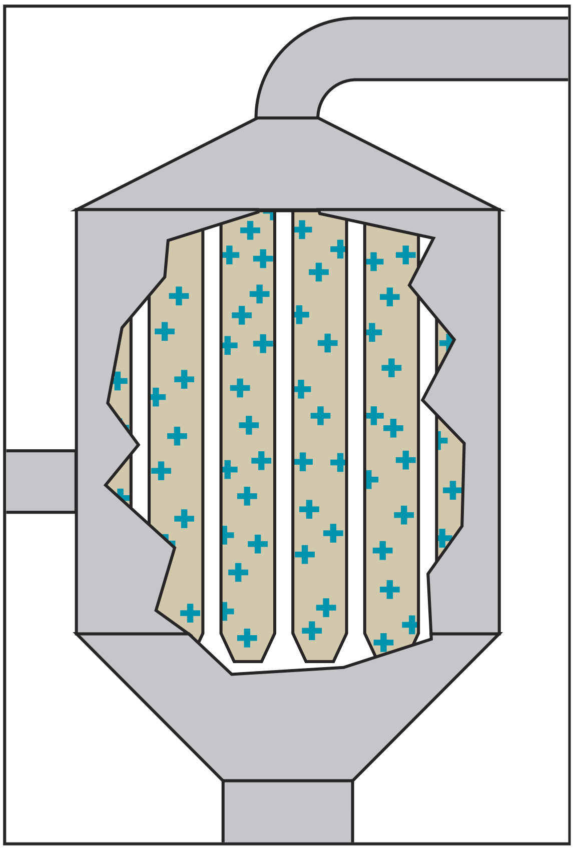
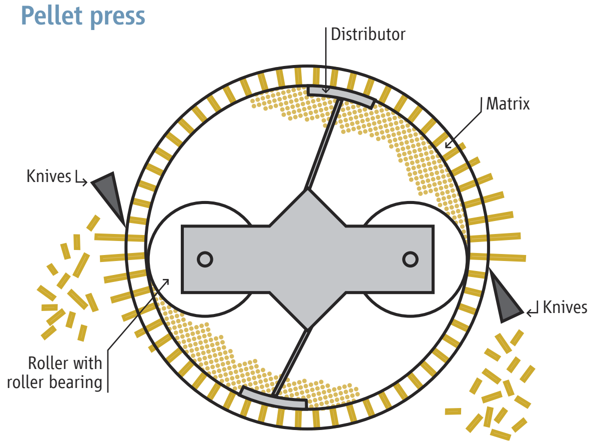


Figure 30
Pellet press



4.7.4
Pelletisation

The production technology is the pressing of moist mass. By compressing pellets, the bulk density can be significantly increased compared to the original material and the dust formation during storage, transport or use can be reduced. Due to the size-related properties, conveying systems can be operated reliably. Pelletising also prevents segregation (e.g. with animal feed). The risk of dust explosion is significantly reduced.

Pellet press

The pellet press usually consists of a feed screw, a mixer, the actual press, the cooler and the sieves. As the product in the mixer is moistened with steam, molasses, fat etc. before pressing and thus binds fine dust, there is no or only for a short time dangerous explosive atmosphere inside the press.

Due to the high contact force and the high temperature, the danger of fire predominates. Sparks or glowing particles can be produced which are carried away by the transport.

With the aid of a conveyor system, the starting material is fed to the press pre-container. The pre-container is equipped with a jam indicator to ensure an optimal product supply for pressing. From the pre-container, the raw material is fed to the press via a feeding screw and the conditioning unit, where e.g. steam is added as a binding agent. The material passes between the pressure rollers and the press mould via a distribution device. The rotating press mould and the co-rotating press rollers squeeze and drive the material under high pressure through the holes of the flat or ring-shaped die with holes according to the desired pellet diameter.

The heat generated during pressing (up to 130°C) activates the binding agents. The pellets ejected through the die are cut to the desired length by means of adjustable scraper blades. The hot pressed cubes fall through a discharge sluice into the pellet cooler.

The cooler is often connected to high performance separators with a connected low-pressure fan for cooling air discharge. A temperature sensor must be provided as a control device at the outlet of the cooler, and a spark detection device must be provided at the air inlet from the cooler into the filter. Fine dust from the cooler is separated in the connected high-performance separators.

Pellet mills pose a fire danger. Temperature monitoring is required.

At the outlet of the pellet press, detectors are used to detect embers, which reliably detect embers from a temperature of 300°C or more.

Extinguishing behind the pellet press is recommended to prevent the fire from spreading to other parts of the plant.

Behind the cooler, a spark detection system ensures that embers are not transported to the downstream storage silos or the loading area.

Dangers
- Overheated bearings
- Formation of glow nests or glowing particles
- Mechanical sparks and hot surfaces, e.g. due to foreign particles or contact between die and roller
- Overheating of the product in the press in the event of a stalled material flow

Protective measures and sensors
- Monitoring of the press room temperature and temperature monitoring of the roller axes
- Upstream magnetic separator (e.g. in the feed hopper of the press)
- Speed monitoring of pan grinder die
- Bulwark against blockage of the feeding screw conveyor
- Switching off the press on overload by means of shear pins (mechanical plant protection) or via other protective systems, e.g. overload clutch
- potential equalisation
- Automatic central lubrication
- Regular cleaning of the die room and press inlet and outlet

Pellet cooler

In the pellet cooler, the product has a moisture content of over 10%. Due to the gentle transport there is hardly any abrasion. Dangerous explosive atmosphere is therefore not present in the cooler.

Basically to avoid fires in coolers is the main priority. The product, which may be overheated in the press, can contain smoulders or glowing particles, which quickly ignite to a fire due to the high air flow in the cooler. There is also the risk that products with too high temperatures or so-called 'hot spots' (beginning glowing fire) are stored in the downstream silos due to malfunctions.

In the event of a fire in the pellet cooler, there is no unnecessary hurry, provided the exhaust air flap has been automatically closed by the exhaust air temperatures, IR sensors or IR camera systems. Therefore, a manually triggered water extinguishing system is sufficient.
It is important to be able to discharge the product under observation or with water wetting, without having to transport it over the actual conveyor system (elevator).

Dangers
- Entry of glowing nests or glowing particles from the press
- Self ignition of deposits
- Electrostatic charge

Protective measures
- Manual water extinguishing system (at least connection pipe and the possibility of entering water via tubes)
- Automatically closing exhaust air damper => define performance level according to DIN EN ISO 13849 and DIN EN 61508
- Temperature monitoring of exhaust air, IR sensors if necessary
- A camera monitoring of the pellet surface that triggers alarms and closes the exhaust air flap in the event of a local/small-scale temperature increase may be more useful

Such systems represent the state of the art:
- Flow monitor blower
- If necessary, fire gas detection CO, H2, NOx
- If necessary, spark detector with ejection or extinguishing before the cooler inlet
- Provision of a sensible way of discharging the smouldering product downwards or via a (mobile) belt to the outside to enable extinguishing
- Regular cleaning of cooler and cooler inlet

4.8
The assessment of machine elements as components for machines

The following examples show constructive designs of elements in category 2, i.e. that these elements are suitable for use in zone 21.

Seals for moving parts

Unlubricated seals, sleeves, bellows and diaphragms which are exposed to abrasive contact during normal operation or during expected malfunctions must not contain light metals. Suitable are sleeves made of elastomer, PTFE or similar material as well as of graphite and ceramic.

Stuffing box gaskets may only be used if an increase in temperature above the maximum surface temperature can be excluded.

Lubricated seals, for which a refillable lubricant must normally be available to prevent hot surfaces at the interface with the equipment parts, must be designed in such a way that there is always sufficient lubricant or must be protected by the following measures:

- The provision of an effective device for monitoring the presence of lubricant;
- Or by the provision of a temperature monitoring device which warns of a temperature rise;
- Or the equipment must be so designed that a dry-running test can be carried out without exceeding the maximum surface temperature of the equipment and/or without causing damage which would impair the effectiveness of the explosion protection properties of the equipment.

Monitoring may be either continuous or by means of appropriate checks and tests.

Requirements for moving parts

Unintentional vibration by moving parts, which can lead to the formation of ignitable hot surfaces or mechanical sparks, must be avoided.

Unintentional vibrations can be caused either by the unit itself or by the place where it is installed. Ignitable hot surfaces or mechanical sparks that may be caused by this must be avoided. In particular, the prescribed speed range for operating the unit must be specified.

The distances between non-lubricated moving parts and fixed parts must be such as to avoid frictional contact which could cause an ignitable hot surface and/or mechanical sparks.

Moving parts for which the presence of a lubricant is essential to prevent an increase in temperature above the maximum surface temperature or the generation of ignitable mechanical sparks must be so designed as to ensure the presence of the lubricant.

This can be achieved by means of a splash lubrication system or an automatic lubrication system or a manual system that monitors the oil level.

Requirements for bearings

Bearings are basically divided into three groups: Elements with plane sliding movement, elements with rotating sliding movement and rolling elements.

The bearing must be designed for the intended use, e.g. speed, load and changing speeds and loads. Unintentional vibration by moving parts, which can lead to the formation of ignitable hot surfaces or mechanical sparks, must be avoided.

The correct fitting of the bearings in their housings and on the shaft (tolerances, roundness and surface quality), taking into account the vertical and axial loads on the bearings with respect to the shaft and housing, must be ensured, as must the axial and radial load on the bearings due to thermal expansion of the shaft and housing under the most severe operating conditions.

Bearings in which the presence of a lubricant is absolutely necessary to prevent a temperature rise above the maximum surface temperature or the generation of ignitable mechanical sparks must be designed in such a way that the presence of the lubricant is ensured. This can be achieved by using sealed bearings for the entire service life, splash lubrication or an automatic lubrication system or a manual system that monitors the oil level. Where this is not possible, alternative measures must be taken to monitor the ignition risk, e.g. temperature sensors that trigger an alarm before an ignitable temperature is reached or a temperature sensor to monitor the possible ignition source.

Requirements for gear drives

In the case of gear drives, unintentional vibrations caused by moving parts, which can lead to the formation of ignitable hot surfaces or mechanical sparks, must be avoided.

The distances between non-lubricated moving parts and fixed parts must be such that frictional contact, which can cause an ignitable hot surface and/or mechanical sparks, is avoided.

Moving parts where the presence of a lubricant is essential to prevent an increase in temperature above the maximum surface temperature or the generation of ignitable mechanical sparks must be designed to ensure the presence of the lubricant.

If the equipment includes devices for varying the transmission ratios (manual or automatic), these devices must be so arranged as to ensure that they cannot generate temperatures above the maximum surface temperature or ignitable mechanical sparks.

Requirements for belt drives

Energy transmission belts must not be able to develop an ignitable electrostatic discharge during operation.

The correct belt tension must be maintained on drives which, by loosening or slipping of the belt on the pulleys, can produce hot surfaces with temperatures above the maximum surface temperature.

On drives which, due to the standstill of the output shaft and simultaneous rotation of the drive shaft, can produce hot surfaces with temperatures above the maximum surface temperature, possibilities must be available to determine the standstill of the output to prevent ignition.

Requirements for clutches

Clutches must be fitted or monitored so that no fixed or moving part exposed to the potentially explosive atmosphere exceeds the maximum surface temperature of the unit.

In the case of plastic or other non-metallic parts of a clutch, the material or arrangement must preclude the possibility of ignitable electrostatic discharge. (e.g. friction disc clutches, centrifugal clutches, fluid clutches). During the time of full engagement with a temperature that exceeds the maximum surface temperature, no slipping or similar relative movement between the input and output parts shall occur, which could possibly lead to a hot upper surface of the clutch.

Requirements for brakes and braking systems

Emergency brakes
Brakes designed only for an emergency stop of the equipment must be so designed that, even at maximum energy output, no part exposed to the potentially explosive atmosphere exceeds the maximum surface temperature or generates ignitable mechanical sparks.

Service brakes (including friction brakes and fluid-based retarders)
Service brakes must be designed in such a way that, even at maximum energy output, no part exposed to the potentially explosive atmosphere exceeds the maximum surface temperature or generates ignitable mechanical sparks.

Parking brakes
Parking brakes must be fitted with a lock which prevents the drive from being activated if the brake is not fully released. Alternatively, a control device must be installed.

4.9
Explosion protection of an entire plant

Questions on the complex assessment of explosion risks

The assessment is divided into the different risk areas of the overall plant.

Questions about the risk area building
- Geometry
  - cellars, galleries, staircases, shafts, halls
- Stability
  - insulation, relief
- Surroundings
  - neighbouring rooms, neighbouring buildings, traffic ways

Questions about the risk area rooms
- Volume (surface)
- Geometry (length/cross section)
- Connections (doors, openings, plants)
- Floors (ceilings, openings)
- Wall stability (concrete, masonry, panels)
- Function (production, warehouse)
- Dusting

Questions about the risk area plant
Open/closed system
- Interfaces
- Connections
- Stability
- Energy states
- Process-product-characteristics
- Change of the characteristics through procedures (pressure, temperature, humidity)

Questions about the substances

a) type of substance, state of the substance, property of the substance
   - Utility dust, waste abrasive dust, organic, metallic
   - Grain size, moisture
   - Self-igniting, minimum ignition energy, ignition temperature, glow temperature, combustion class, carbonization gas formation, caking behaviour, LEL

b) Where can explosive dust-air mixtures be expected?
   - Constantly, frequently, predominantly (zone 20)
   - Occasionally (zone 21)
   - Short term (zone 22)
   - Deposits

Questions about ignition sources

a) Where can explosive mixtures and potential ignition sources be expected to occur simultaneously?

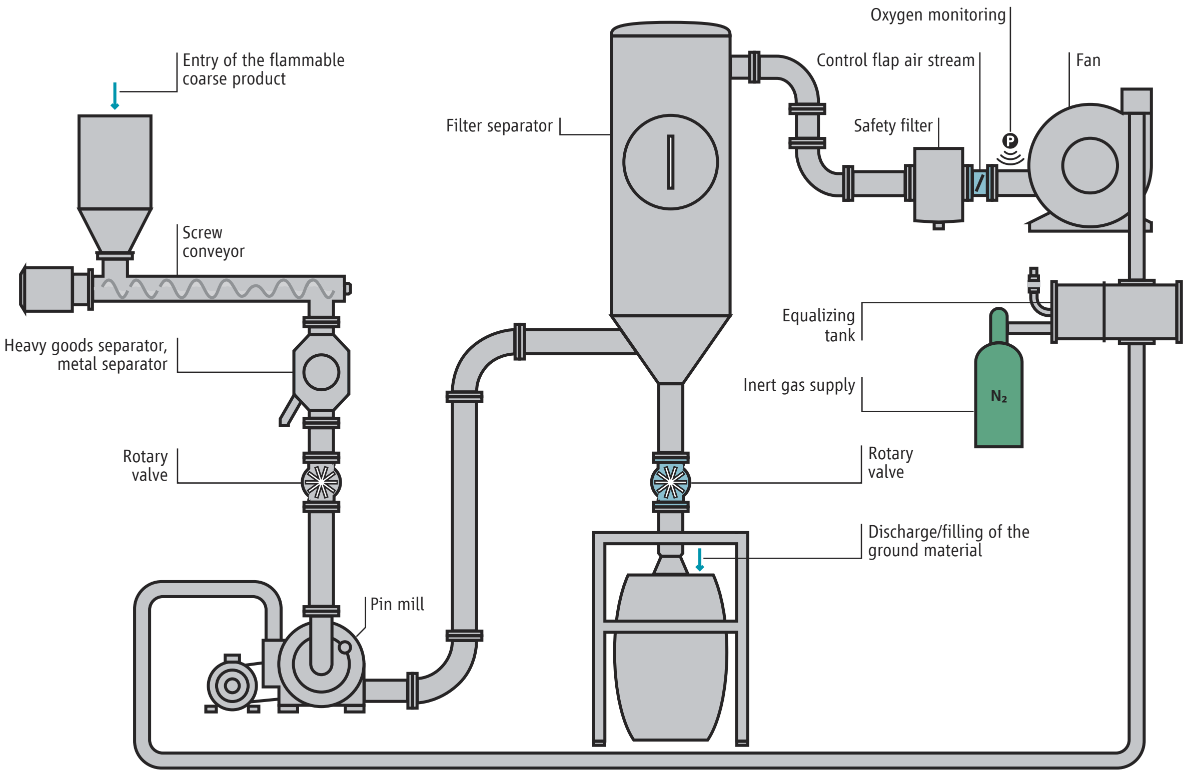
b) Where are ignition sources and the possible transport of these ignition sources into areas with explosive mixtures to be expected?

Questions about deposited dust
Where does deposited dust increase the risk potential?
- Storage of bulk goods, bagged goods, containers
- Open transporters
- Filling stations
- Filter blow-out openings
- Inspection openings
- Leaks

Questions about interfaces
Where are the interfaces of the equipment to rooms?
- Filling stations
- Air intake lines
- Exhaust air ducts
- Inspection openings
- Silo floors

Questions about room explosions
Which rooms must be able to be vented in the event of an explosion?
- Risk of explosion due to fire
- Explosion risk during maintenance
- Risk of explosion in the incident of an explosion relieving equipment by itself of an explosion relieving equipment
- Risk of explosion due to transmission from other areas

Figure 31
Plant example for a high-speed mill where the plant is inerted



Methodological approach to explosion protection

Primary explosion protection
Measures which prevent or reduce the formation of dangerous explosive atmospheres (avoidance of explosive atmospheres).

Secondary explosion protection
Measures to prevent the ignition of dangerous explosive atmospheres (avoidance of effective ignition sources)

Tertiary explosion protection
Measures which limit the effects of an explosion to a safe level (constructional explosion protection).

The following examples show modules for grinding and fine dust separation using the different protection systems.

They are excerpts from the ISSA brochure "Dust explosion protection on machinery and apparatus", which is available on our website **www.safe-machines-at-work.org**.

Constructional explosion protection

Explosion protection measures that are in principle available

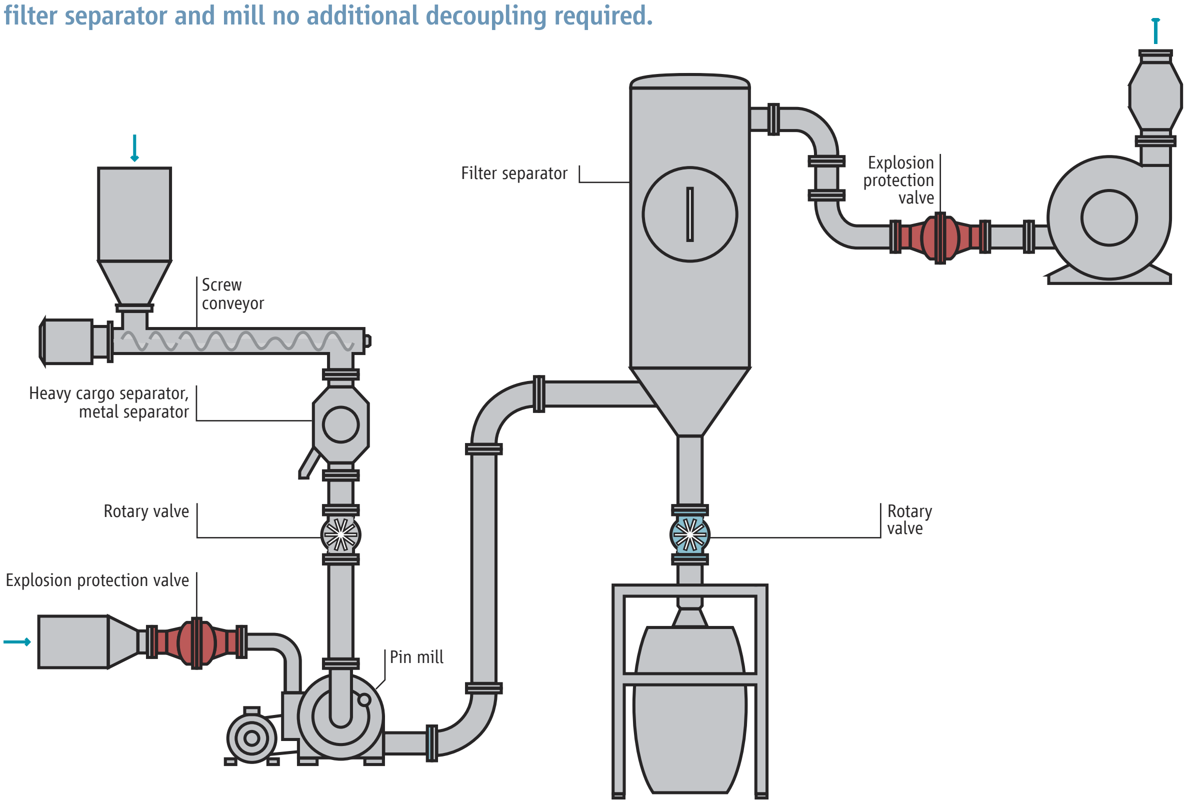
- Explosion pressure and explosion pressure shock resistant construction
- Explosion pressure relief
- Explosion suppression
- Decoupling

The selection of explosion protection measures is based on the "pros" and "cons", the effectiveness and the limits of applicability within an overall risk assessment with regard to the plant to be assessed. The safety level to be achieved is derived from the overall risk and the various possible combinations of measures.

Conditions under which a protective system functions reliably depend on

- **the system configuration**
  - e.g. container volumes, pipe lengths and diameters, type of transport elements
- **the process conditions**
  - e.g. dust distributions, volume flows, pressure fluctuations, flow velocities
- **the ambient conditions**
  - e.g. temperatures, humidity (e.g. condensation water)

Figure 32
Plant example for a high-speed mill. This plant is designed explosion-proof for the maximum explosion overpressure in combination with decoupling measures. With short distance (in this case < 6m) between filter separator and mill no additional decoupling required.



The characteristics of the dust-air mixtures depend on

- the dust cloud concentration
- the dusting properties
- the sedimentation behaviour

They determine the development of p_{ex} (explosion pressure) and dp/dt (delta pressure/delta time) and thus the type of explosion processes.

Pressure resistant / pressure shock resistant construction

- Container must be designed for maximum explosion pressure (for most dusts in the range of 5-10 bar overpressure, also less, depending on the process) Determination of p_{max}.
- Adjoining plant components must be decoupled in terms of explosion protection and explosion pressure resistance or must also be explosion pressure resistant
- Wear, corrosion and material fatigue must be taken into account. This applies in particular to pipe bends in pipelines for the transport of bulk materials due to the high wear

Pressure relief

- Plants, parts of plants or rooms with explosion risk are provided with defined weak points in order to reduce the explosion pressure
- Correct dimensioning (calculation) required
- Correct placement of recognised bursting discs, flaps and the like required

Where pressure relief is applied to equipment in enclosed spaces, it is necessary for the protection of the spaces and the persons working in them,

- to lead the pressure relief via a pipeline (so-called blow-off pipe) in a safe direction to the outside, or
- to reliably prevent the flame from escaping from explosion pressure balanced equipment by means of tested equipment (flame arresters, such as quench pipes, Hoerbiger valves)

Disadvantages

- Loss of efficiency, danger of "blocking" by product
- Negative effects of pressure relief and flameless pressure relief (quench pipe)

Figure 33
Plant example for a high-speed mill, designed for a reduced explosion overpressure by explosion pressure relief in combination with explosion decoupling

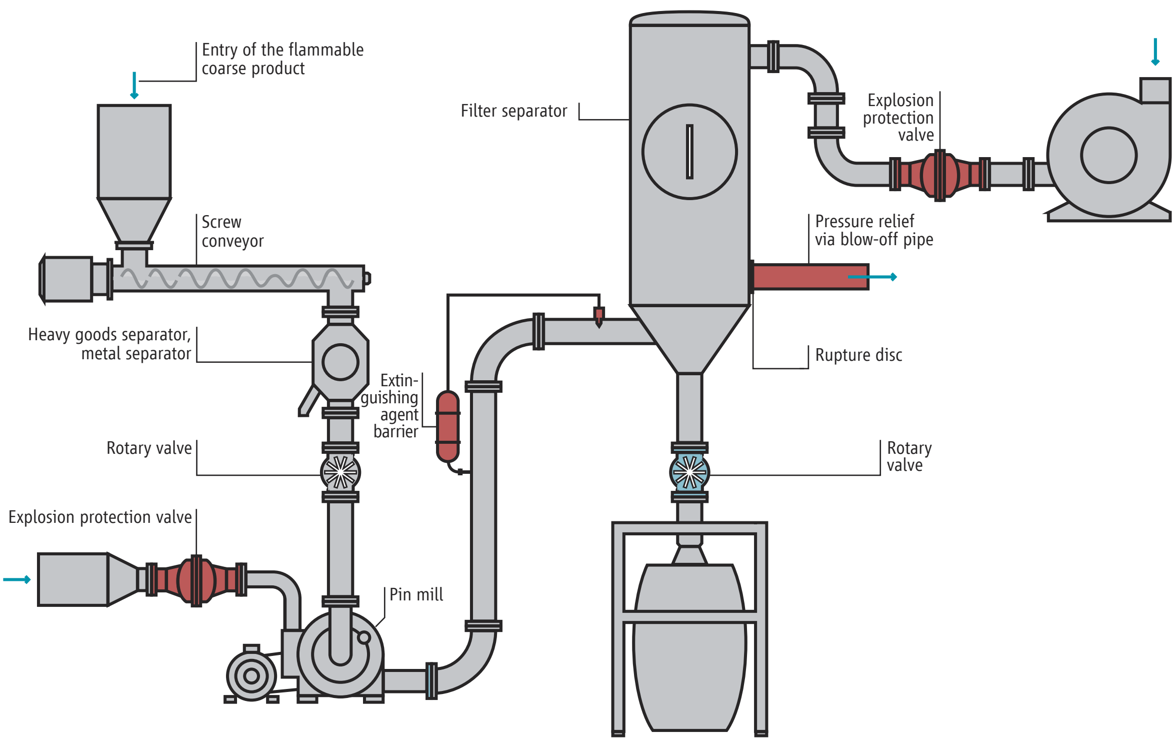
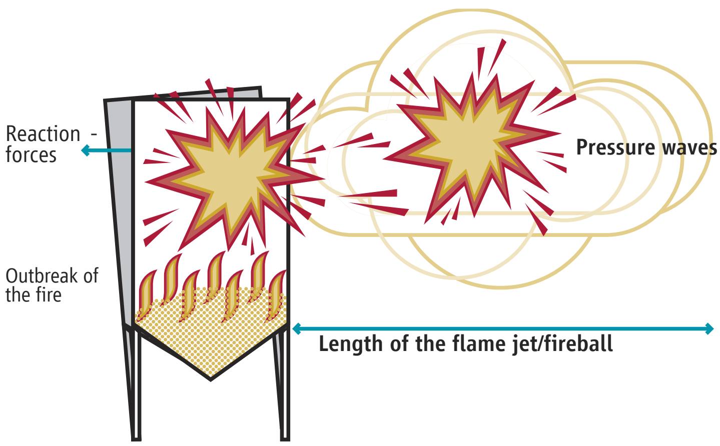
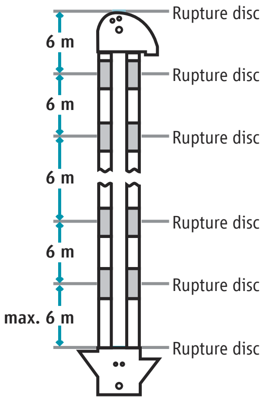


Figure 34
Effects of pressure relief

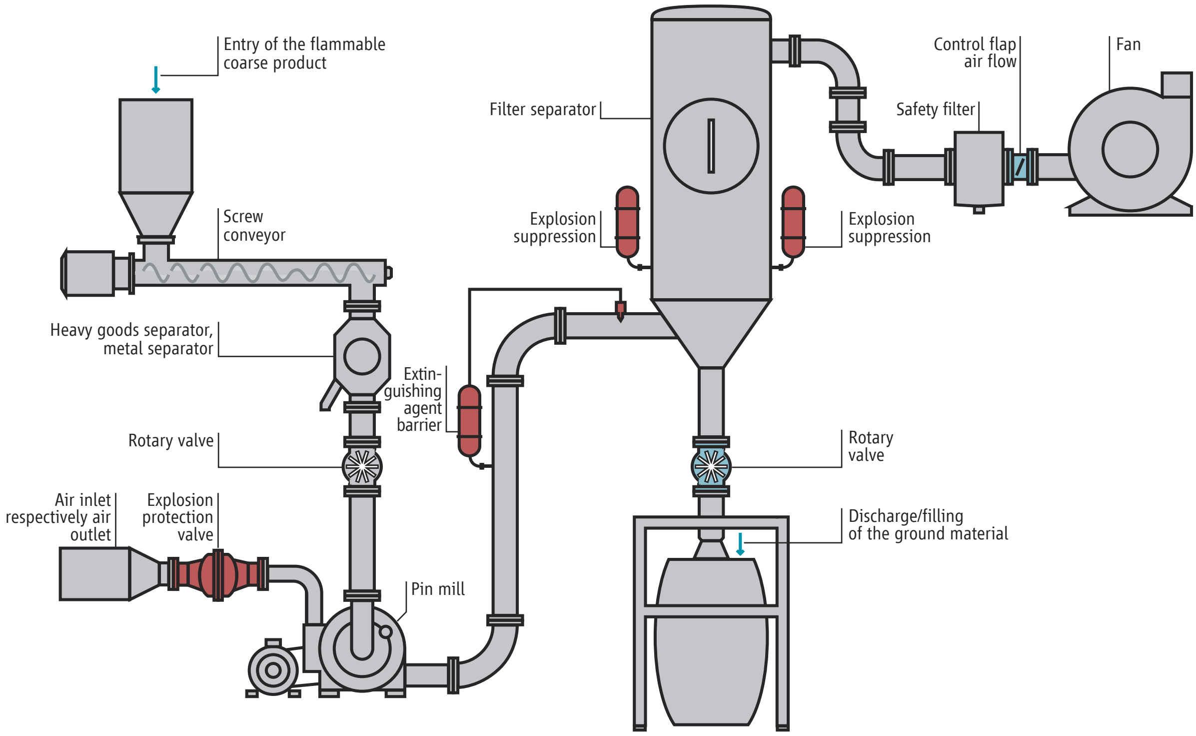


Special case: Pressure relief of an elevator



	$K_{St} \leq 100 bar\ m\ s^{-1}$			$100\ bar\ m\ s^{-1} < K_{St} \leq 150 bar\ m\ s^{-1}$		
Explosion resistance p (bar)	**Foot**	**Head**	**Distances Shaft L (m)**	**Foot**	**Head**	**Distances Shaft L (m)**
0.5	No	Yes	6	Yes	Yes	3
1.0	No	No	No	Yes	Yes	6
1.5	No	No	No	No	Yes	6
2.0	No	No	No	No	Yes	No

Figure 35
Plant example for a high-speed mill, where safety is ensured by explosion suppression in combination with explosion decoupling.



Explosion suppression

If an ignition occurs in a plant, the pressure wave of the beginning explosion reaches a sensor within a few milliseconds. Immediately after registration, this sensor opens the extinguishing agent container and thus causes the extinguishing powder to flow out, which then penetrates the fireball and suppresses the explosion. In less than 100 milliseconds the total process is completed, the expected explosion overpressure has been reduced to a maximally reduced explosion overpressure and the risk of destruction of the equipment has been eliminated.

Advantages

- No leakage of material, no effects to the outside
- Suitable for toxic and other dangerous substances
- No restrictions on installation concerning the location of the plant
- No fire as a result of an explosion

Disadvantages

- Investment costs
- External energy required for activation
- Monitoring and maintenance required
- Must be planned and installed by competent suppliers

Factors influencing effectiveness
Factors determining the explosion action

- Free container volume
- Container shape (surface and length ratio)
- Dust characteristics, combustion speed
- Homogeneity and intrinsic turbulence of the ex-atmosphere
- Interaction of the combustion wave with internal obstacles, reflected waves
- Initial pressure and temperature

Decoupling devices

The use of decoupling devices is always necessary if the unprotected part, which may be pressureless, has to be safely separated from the protected part in which effective ignition sources and thus explosions are expected to occur, or if equipment is connected by longer pipes so that flame jet ignitions or high pressure peaks are to be expected. It is particularly problematic if a large vessel can discharge into a small vessel or if vessels of higher strength are connected to those of lower strength.

For explosion decoupling, different systems are available whose mode of operation and functionality are different. When selecting a suitable system, the respective process-engineering and instrumentation frame conditions must be considered. Passive systems that can be used are the relief vent and the explosion protection valve. Also the rotary valve or feed vessels in connection with conveying elements, such as pipe screws, can be counted among the passive elements.

The explosion check valves used are no recognised explosion decoupling devices. However, they can reduce the risk of a backward explosion transmission.

The bursting pots for decoupling the filters are suitable if they are installed vertically and discharge to the outside.

Figure 36
Risk of bursting of the secondary container in case of explosion transfer

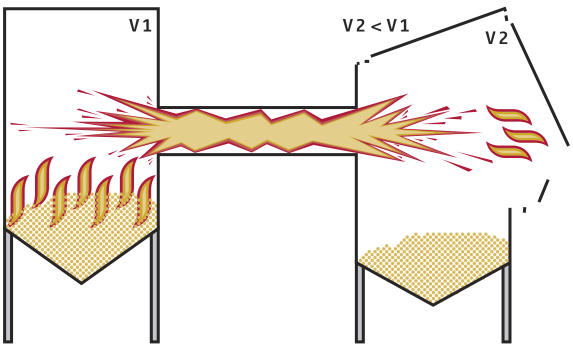
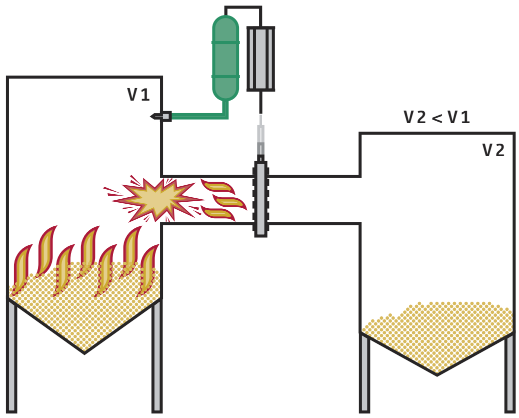


Figure 37
Protection of the connected container by decoupling but calculated p_{red} can be 1.5 - 3 times higher during the closing process.



Relief vent

The expansion of dust explosions via connecting pipelines can in many cases be prevented by installing a relief vent.

For example, a dust-conveying pipe can be led through a relief chimney into the downstream separator, e.g. a filter system.

The relief chimney is characterised by a special pipe routing in which the conveying direction is reversed by 180°. Relief chimneys can practically prevent explosion transmission in both directions.

However, experimental studies show that this is not always the case.

Flame transmission must be expected in the in case of weak explosions with low pressure manifestations, where the pressure relief devices do not respond or respond late.

Even in the case of violent explosions, flame transmission cannot be reliably excluded. However, explosion pressure and flame velocity are reduced to such an extent that excessive explosion pressures in the connected plant section (filter) are avoided. The filter can thus be protected by explosion pressure relief.

Figure 38
Protection of the connected container by installation of a relief chimney

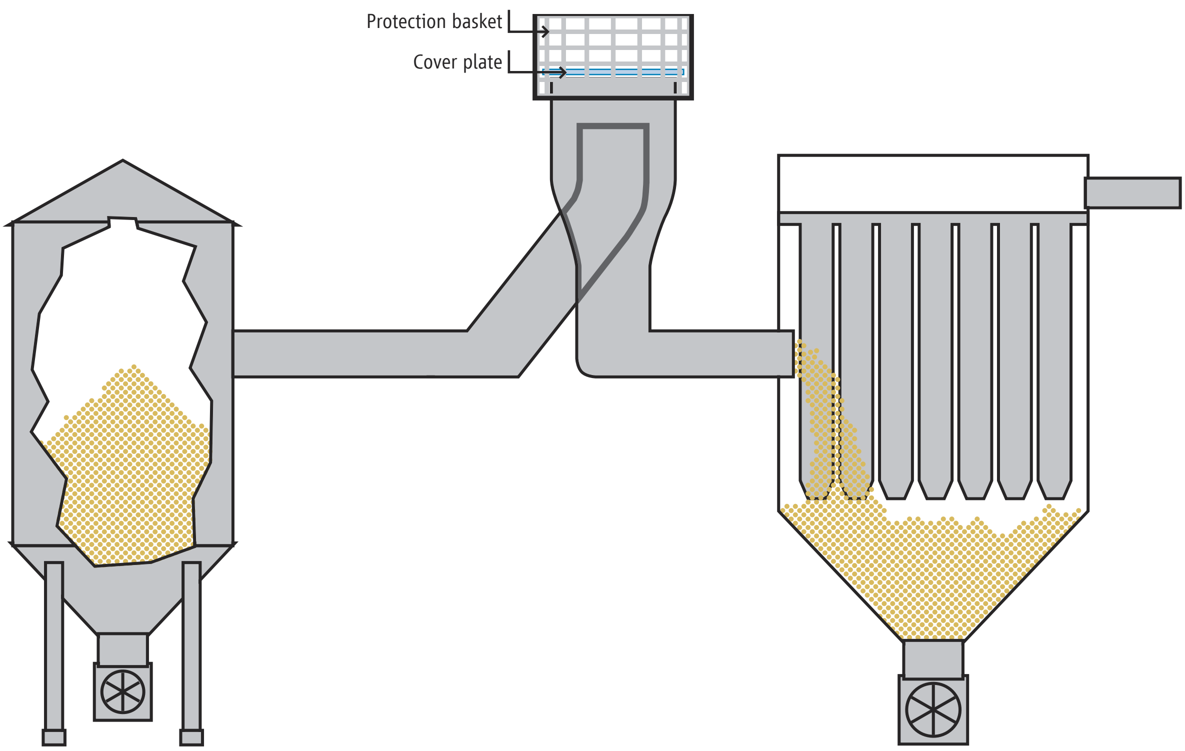


Figure 39
Aspiration plant with explosion decoupling

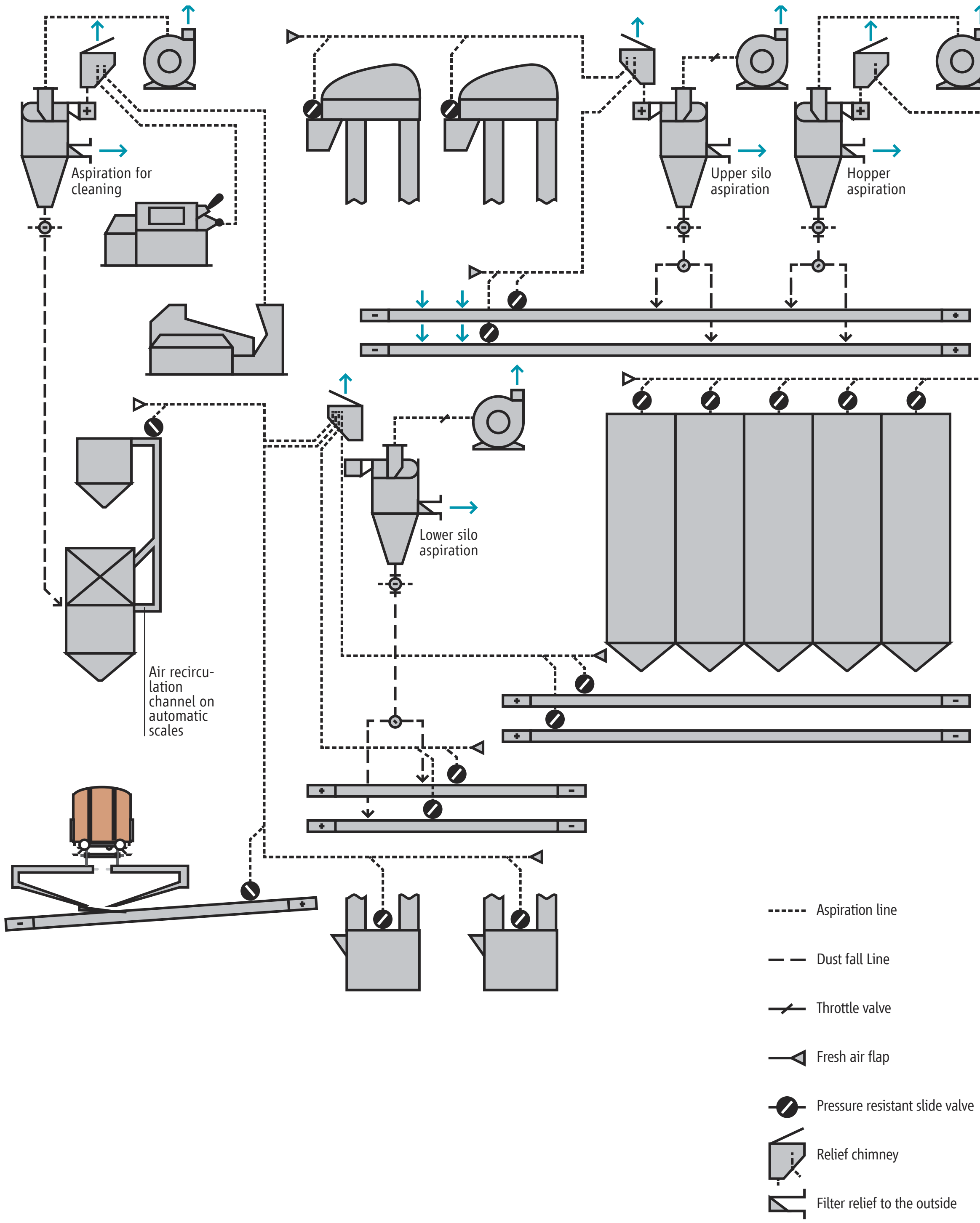


Figure 40
Rotary valve

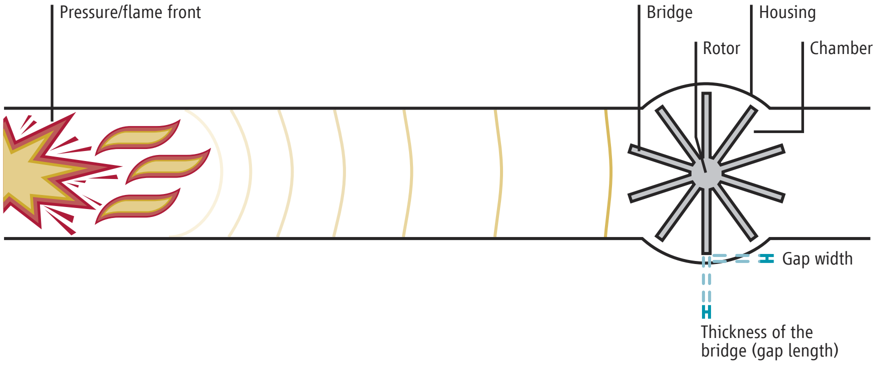
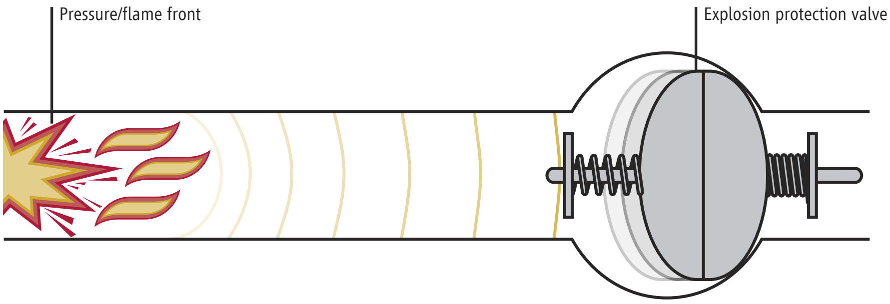


Figure 41
Explosion protection valve



Rotary valves
Rotary valves can prevent the spread of explosion flames if designed accordingly. Also, a sudden pressure load on downstream systems can be avoided to a large degree. They are suitable for protecting product inlet and outlet openings on containers and equipment.

On the other hand, they can be used at product transfer points to decouple the upstream and downstream plant areas.

Explosion protection valve
Explosion protection valves are primarily suitable for installation in pipelines with low dust loads.

Typical examples of use are on the clean air side of filter systems, where these valves are used to protect the fans arranged on the clean air side from impermissibly high pressure loads during previous filter explosions. The valve is closed by the kinetic energy of the pressure wave. Low-pressure flames pass through. Explosion protection valves cannot be used if flame propagation cannot be tolerated in very weak explosion events. Furthermore, they can only be used if the air flow is only very slightly dust-loaded.

No "sticky" dusts
The closing behaviour can change negatively if the installation is carried out directly after pipe bends, because in this case the closing body is unsymmetrically loaded by expansion flow or pressure waves. The active systems require certain control devices for their release. In the event of an explosion, these control devices release the external energy required to operate the active systems.

The active systems include the quick-closing slide valve, the activated explosion protection valve and the extinguishing agent barrier. In combination with a suppression system, the extinguishing agent barrier can also replace the relief device.

Quick-closing slide valve
- Compared to valves, quick-closing slide valves have the advantage that their closing element is outside the pipeline cross-section when open. The pipeline cross section thus remains free and can be executed without pockets and without dead corners, so that no dust can be deposited.
- For this reason, quick-closing slide valves can be used in pipelines regardless of the dust load. Design and mode of operation of the offered slide valves are similar.
- Flame and pressure detection can be applied.
- For weak explosion sequences: flame detection

Figure 42
Quick-closing gate valve

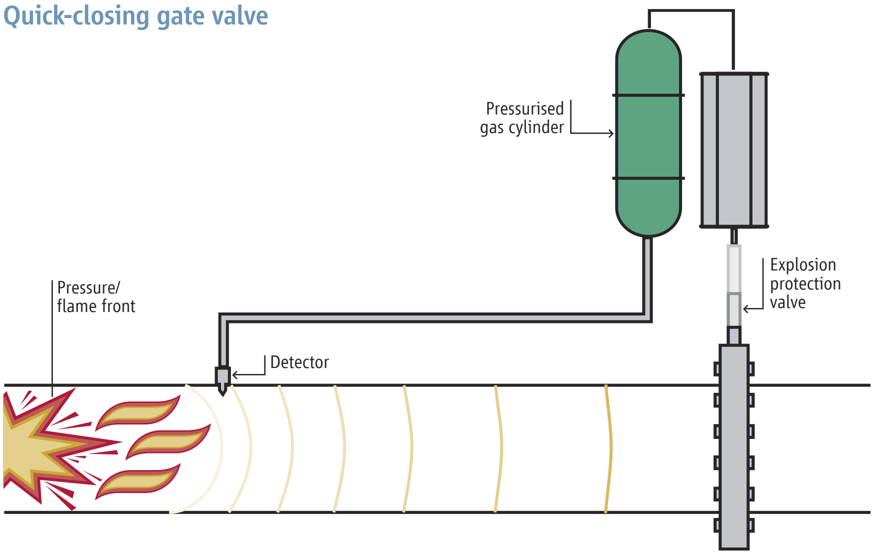
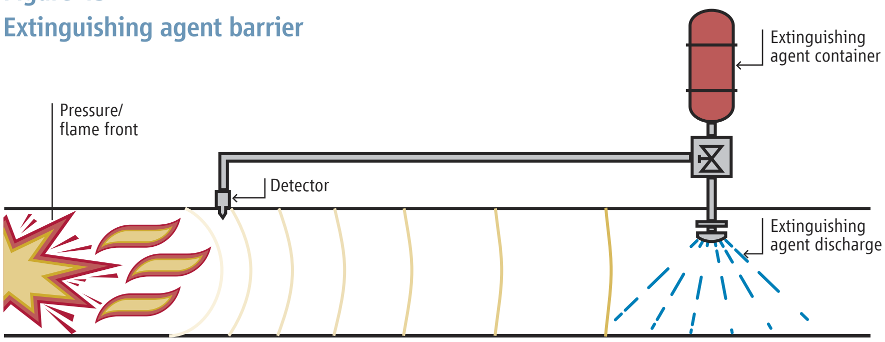


Figure 43
Extinguishing agent barrier



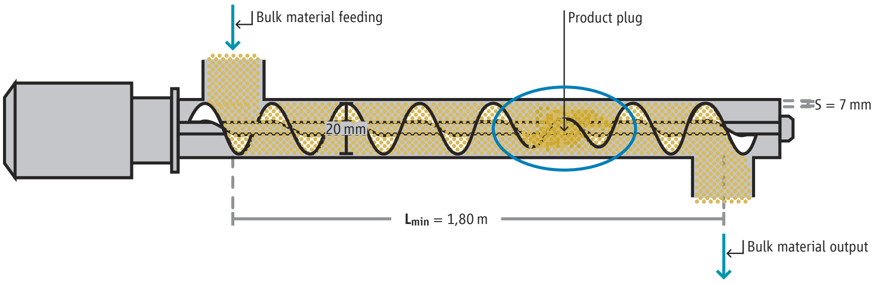
Feedback effect of mechanical decoupling devices

- The design of the pressure relief of a vessel to be protected is generally done according to EN 14491 on the basis of dust-specific characteristics: KSt and p_{max}
- This ensures that a defined reduced explosion overpressure in this container is not exceeded
- In the case of valves for decoupling pressure-balanced containers, the p_{red} can double (or even exceed) the value at the moment of closing, if the pipeline is not too long (e.g. 6m)

Extinguishing agent barrier

- The flame front is detected, detonator-operated valves of extinguishing agent containers are opened, extinguishing agent is forced into the pipeline and extinguishes the flame
- There must be a certain distance between the installation location of the detector and the installation location of the extinguishing nozzle, which results from the response time and the explosion/flame velocity
- The explosion pressure is not affected by the extinguishing process, the stability of the pipeline must be adjusted to the expected explosion pressure
- Restrictions of effectiveness are to be expected if there are additional fittings (conveyors, buckets etc.) within pipes, shafts or ducts
- It cannot be reliably excluded that the flames can pass through the extinguishing barrier in the case of unfavourable arrangements

Figure 44
Screw conveyor with and without product plug for explosion decoupling



Screw conveyors with and without product plug for explosion decoupling

Findings

- The formation of a product plug depends on bulk material properties.
- There are product plugs remaining when the flowability factor ffc < 5 (e.g. cellulose, icing sugar, milk powder, wood flour, wheat flour).
- Without plugs, no flame passage for dusts with minimum ignition energy MIE > 100mJ (e.g. wood flour)
- With plugs no flame passage for dusts with minimum ignition energy MIE > 5mJ (e.g. cellulose).
- With plug no flame propagation for dusts with minimum ignition energy 4mJ < MIE > 5mJ; 5 < ffc < 10 if
  - Running empty is technically prevented
  - 2 helix turns are removed
- Flame propagation is probably prevented due to heat extraction and excessive dust concentration

Explosion detection

- Pressure detection
  - Mechanical detectors (membranes)
    - Insensitive to dirt
    - Vibration sensitive (2 detectors 90° shiftet)
    - readjustment necessary
  - Electronic detectors
    - Reaction to static pressure values and to pressure rise speeds
    - No danger from resonance vibrations
  - Flame detection
    - Response time < 2ms
    - Monitoring of visibility

Optical detection

- Early detection can be achieved with sensors based on UV, IR or visible radiation
- It is important to place the detector in such a way that the angle of detection allows monitoring of the entire protected hazardous area
- The performance of an optical sensor is also affected by any obstructions to visibility, which can be avoided by installing several detectors
- When used in dusty atmospheres, optical sensors must be equipped with air blowing devices to keep the optical lenses clean

Pressure detection

- Threshold detectors provide an electrical signal when a preset overpressure, p_a (the system's trigger pressure), is exceeded
- Dynamic detectors deliver an electrical signal to the CIE system unit. Typically they have both slew rate and pressure threshold trigger points that can be tailored to the application conditions
- Although this type of detector minimises the risk of false triggering of the decoupling system (due to pressure variations other than the explosion pressure rise), care must be taken to ensure that such detectors are installed in accordance with the detection response criteria applicable to the specific application and the geometry of the protected plant.

Fire monitoring of other machines

In production machines, pneumatic transport equipment and mechanical conveying systems, fires and explosions are repeatedly caused by sparks or concealed smoulders. An essential component of technical fire protection can be a spark extinguishing system to protect the machines and transport systems.

In the area of the dryer, the inlet and outlet must be monitored with spark detectors to detect smoulders. The detectors detect the slightest infrared radiation and report this to the spark detection centre, which triggers an extinguishing process. The middle sections of the dryer can be monitored either with flame or thermal detectors. They make contact to the extinguishing control system installed in the dryer, which is activated section by section depending on the dryer design, similar to the way a deluge system works.

A useful supplement to this is monitoring of the dryer exhaust air by means of spark detectors, which also act on the extinguishing system in the dryer.

In all conveying lines to filters and silos, spark detection and a spark extinguishing system after the fan can be useful if the risk analysis shows a risk of ignition.

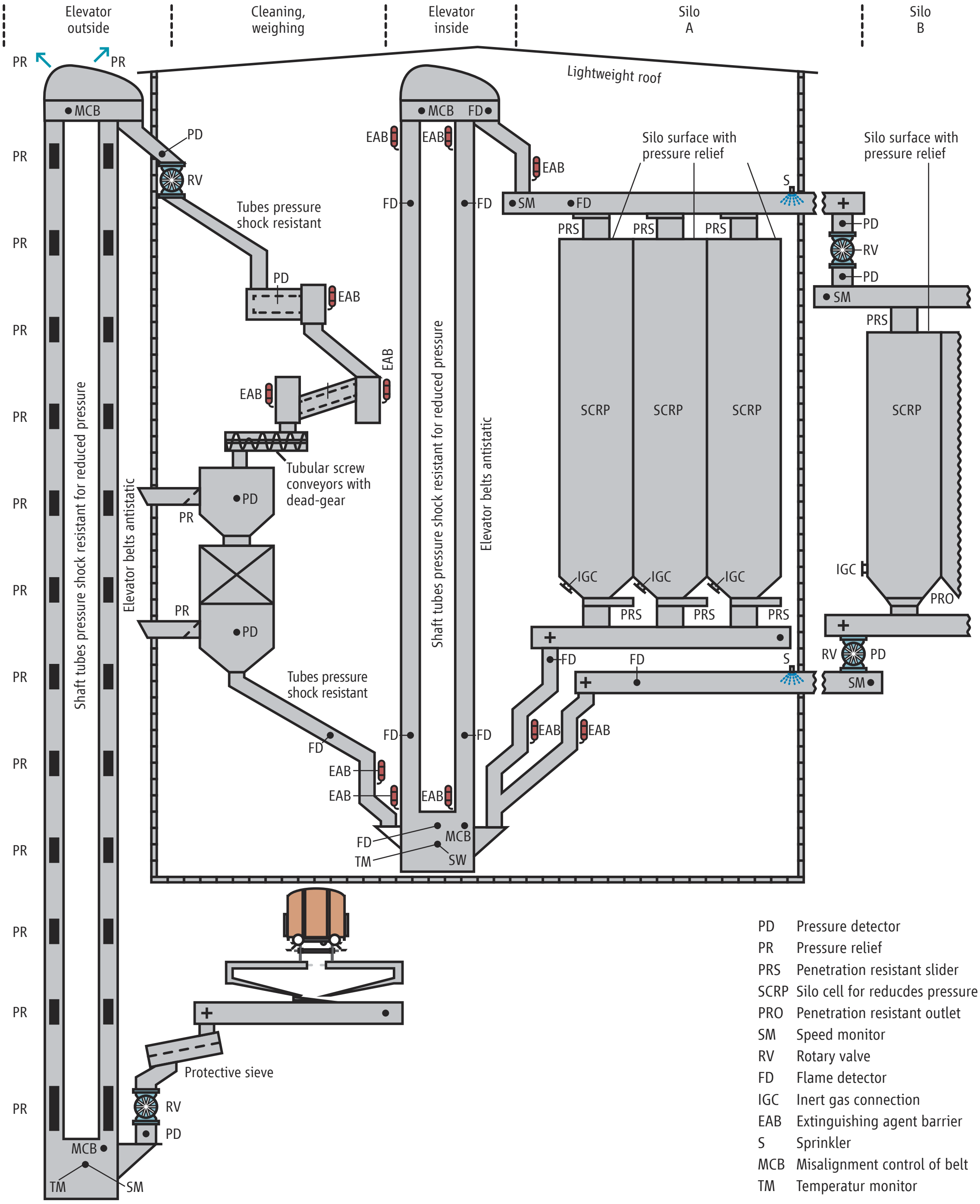
Elevators are equipped with a spark detection device to enable a machine shutdown in connection with an inspection, e.g. via a cross conveyor.

The hammer mills are monitored at the outlet by means of spark detectors. It is mandatory that a fire extinguishing system is installed behind the hammer mill, which also includes the downstream filters. This prevents a fire flashover.

Both behind hammer mills and behind the pellet press high product temperatures occur during the start-up process. Special detectors are able to differentiate between these production-related short-term high product temperatures and dangerous glowing nests.

Silo system with fire and explosion protection equipment

Figure 45
Silo system (with use of many previously described sensors/detectors)



Short summary

The apparently simple example of the storage and processing of bulk materials (here: grain) with assessment of the dust explosion risk alone has proven to be complex.

We have described the essential points of a mill plant, exemplified the additional requirements resulting from digitalization and illustrated this with figures.

The additional requirements for a plant (mill) with regard to explosion protection are dealt with in a further brochure. There we discuss in detail the individual process steps in a modular presentation. This serves for flexible use in different plants and a better understanding of the tasks.

The ISSA brochure "Explosion Protection Modules" is largely completed. Information about the publication (ready for download) will be available on our website:
www.safe-machines-at-work.org

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