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Strategy for ISO 4126 into 2030 – Future Standardization of Pressure Protection Systems

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ISO 4126 is the leading standard for protecting pressurized systems against excessive pressures. It includes nine parts for safety valves, bursting disks, pilot-operated valves, and controlled pressure relief systems. Single and two-phase flow is covered. The standard does not fully reflect the current state of technology applied in many companies, especially the zero-emission trends. For years, a direct discharge of fluids from safety valves or bursting disks into the environment has been tried to avoid. Liquids shall be discharged into separators or drums, and quenches are installed to condense discharged vapors. The sizing scenarios upstream of the safety system and the effluent system on the downstream line are not considered in ISO 4126. Both heavily influence the sizing and often the type of safety device. Nowadays, mechanical safety devices are adapted to the process to dynamically optimize the set pressure for economic production and to reduce the mass flow rate in case of an emergency to a minimum extent. Innovative overpressure protection systems are combined from mechanical controlled pressure protection systems, and electronic safety-related control systems (SIS) adapted to the process. Long and complex inlet and outlet lines direct the fluid into an effluent system. The next generation of intelligent devices will probably try to avoid any relief if possible, using a safety-related control of the process, e.g., limiting the feed stream or increasing the cooling. It is time to adapt the standard to these latest technologies and sizing methods applied already in Industry. The paper will be focused on the deficiencies of the existing standard ISO 4126 and propose a strategy for necessary changes during the upcoming years up to 2030. The strategy reflects the view of the CSE Center of Safety Excellence.

1. History of ISO 4126

A major goal in European harmonization was to separate product from application standardization. It was not allowed to specify a safety valve or bursting disk and give sizing recommendations in the same part. This led to misleading titles and curious sequences of topics like in part 7 of ISO 4126 “common data” with a part for “sizing of safety valves” for single-phase flow followed by a section for “minimum requirements for helical compression springs” (ISO4126-7, 2019). After that, an appendix entitled “Thermodynamic properties” is limited to tables of steam pressure coefficients, although such data have been available for a long time as equations for simulation tools. A second example is type testing of safety valves and bursting discs, an essential requirement of the pressure equipment directive, to validate the stable function of high integrity safety devices (PED, 2014). For years, type tests were not standardized; this topic was spread over several parts of the standard ISO 4126. The current strategy is 17 years old. It is time to rethink the standardization of safety equipment in ISO 4126. According to the business plan from 2005, parts 3, 9, and 10 of the standards were to be created - this had long since been implemented.

The high integrity of safety devices in ISO 4126 is mainly represented by specific requirements on the devices and sizing procedures for single and two-phase flow. Manufacturing, type testing, packaging, transport, installation, inspection, and other topics of the life cycle of a safety device are not considered. A complete view of a pressure protection system and its stages along a life cycle, comparable to topics already standardized for high integrity protection systems, including electrical, electronic, and programmable electronic systems (IEC 61508), was not implemented in the strategy of ISO 4126.

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The past has shown that especially plant operators have increasingly withdrawn from the process of standardization in case of pressure protection. Manufacturers dominate several working groups of ISO 4126 because plant engineers are missing; specific process knowledge and deep understanding of upcoming topics in pressure protection, e.g., functional safety, seem to be underrepresented in some parts. It is becoming increasingly difficult for plant engineers and operators to recognize the results and apply the modifications of periodical reviews of the current nine parts of the standard. Especially the chemical and petrochemical industry is invited to increase their activities.

2. The State of Technology for Pressure Protection

Current trends in pressure protection, namely, to avoid emergency relief or to prohibit hazardous substance dispersion into the ambient (ZERO emission), to use intelligent safety devices, and to reduce the consequences of relief scenarios, are not represented in the standard. Essential parts are missing here. The understanding of pressure relief today is quite different from the times when valves discharged directly into the atmosphere, Figure 1. There is hardly any safety equipment in the chemical and petrochemical industry without a downstream vent line and - in the case of liquid media - without an effluent system. Today, when sizing vent line systems, all components, i.e., piping, safety device, and effluent system, are considered as an integral unit and not separately each component. The safe function of each component is most often inter-dependent, and the dimensioning of the components has become more complex. For example, effluent systems will not work correctly if the safety device has been sized far too large. According to ISO 4126, safety devices are still sized separately without considering the other components. This is no longer up to date and does not correspond to state of art.

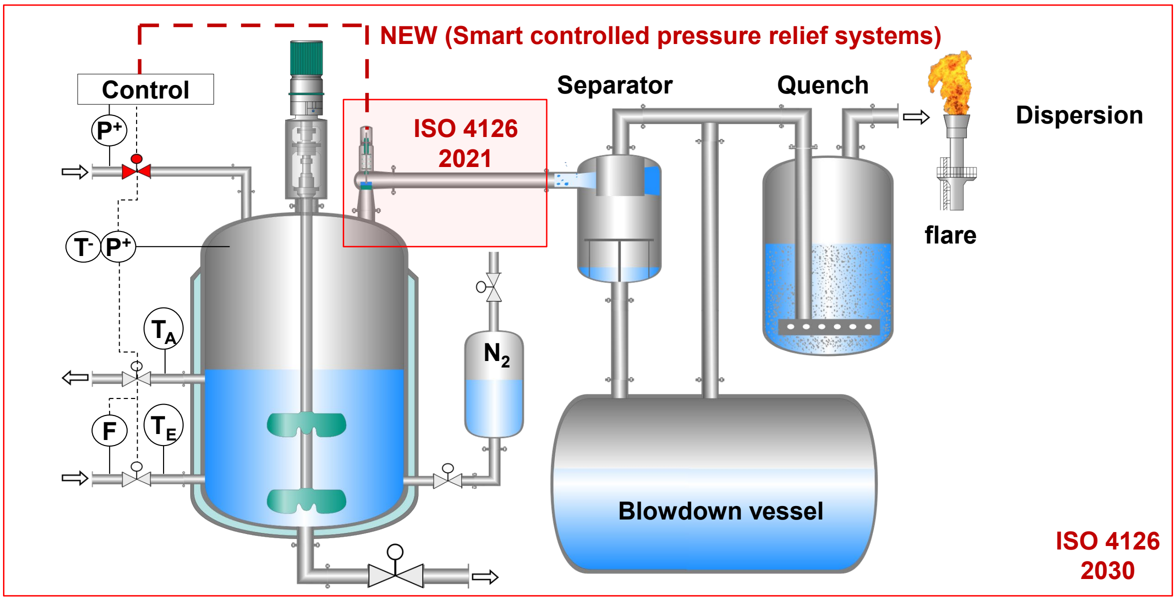

Figure 1: the State of Technology for industrial pressure protection systems (end-of-pipe technology)

Several groups worldwide develop more detailed and precise guidelines for pressure protection systems. Since 2015 the European Industrial Sizing Group (EURISG) has been active at the CSE Center of Safety Excellence to harmonize internal guidelines and views not treated in current standards (EURISG, 2022). And typical industrial sizing cases where standards are not yet applicable or inaccurate are considered. Sixteen important chemical, petrochemical, and digital industry companies meet three times per year at the CSE to cooperate within the EURIG group. More than 1000 pages of reports have been worked out, often used to train young professionals, and validate internal sizing procedures. The intensive harmonization of internal guidelines by EURISG is a measure for the future need for standardization.

3. Future requirements – strategy 2030

Plant operators need a comprehensive solution for the stable functioning of pressure protection systems in their plant environment and not just the supply of a safety device. The entire life cycle of the pressure relief system, from planning and design to manufacturing, type testing, packaging, transportation, installation, and

maintenance and inspection, shall be considered (Dechema, 2017). This is where ISO 4126 can make a significant contribution in the future.
ISO 4126 (ISO4126, 2019), entitled "Safety devices for protection against excessive pressures" is currently limited to a tiny part of pressure protection, mainly requirements on piping, safety valves, and rupture discs. It should be much broader and more specific to fulfill today's high integrity pressure protection requirements (see Figure 1. Safety devices are embedded in integral emergency overpressure protection concepts, including an independent layer of protection as operational measures to (1) repeatedly produce precisely certain products and in case of abnormal operation to (2) alarm and re-direct the pressurized system in a regular operation, and (3) to avoid any pressure relief by DCS measures, before any emergency relief systems come into play, Figure 2.

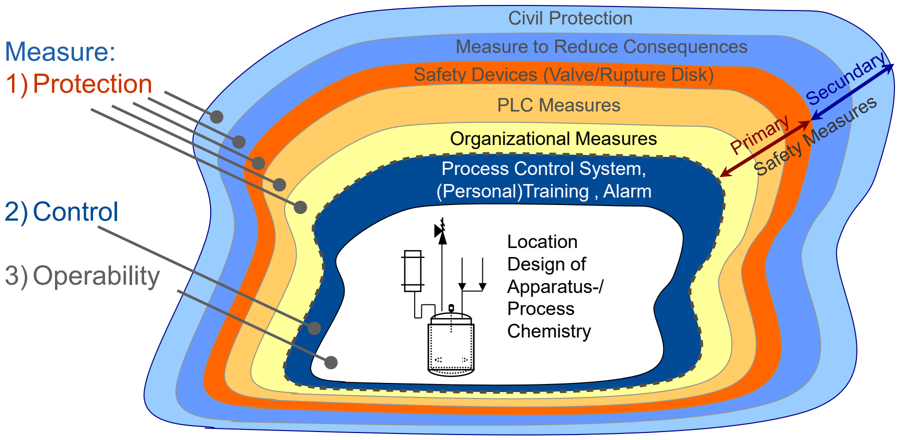

Figure 2: Safety devices as part of overpressure protection concepts based on an independent layer of protection

Future standardization of ISO 4126 shall be thought from a perspective of measures to avoid overpressure protection and to realize a zero-emission concept. The likelihood of a pressure relief shall be dropped down to values even lower than the best of today's concepts. Currently, the standard is limited to safety devices completely decoupled from the plant environment. Overlaps and interfaces to standards regarding other independent layers of protection, e.g., functional safety, shall be specified to match the requirements of both standards. All interest from manufacturers, consultancies, inspectors, and plant operators shall be equally balanced. Any part of the standard shall purely define requirements without fixing specific methods or procedures to avoid blockages of future innovations. Unfortunately, current standards are far beyond this requirement. Methods and procedures should be mainly implemented as informative annexes and options to fulfill the mandatorily given requirements of the main part. A focus on mandatory requirements also allows coping with national and regional regulations.
A proposal for the future development of ISO 4126 is outlined in the following. The standard can be divided into three main areas, including several existing and new parts, see Figure 3:

- Product
- Life Cycle Operation
- Testing

There are already several established standard parts in the **product area**. Future changes can certainly be expected for controlled safety devices in part 5. Mechanical safety devices and functional safety protection systems are moving closer together. Component type testing meets statistical consideration of random failures – these different concepts need to be harmonized. Low-pressure valves and the topics of quality management, manufacturing, and packaging/transportation are currently not represented at all. Is extensive component testing sufficient without regulating the manufacture of pressure relief devices along these lines? Well-known manufacturers have already developed high-quality management guidelines in their companies to guarantee the quality of each device comparable to the device tested in a type test. Requirements for such quality management – not the management system itself – are essential features for the high integrity of safety devices and should be part of the standard.
The **area of operation or life cycle operation** is the least developed in ISO 4126. Currently, there are only parts for sizing safety valves and bursting discs. Unfortunately, considering life cycle operation leads to specific difficulties: as soon as a safety device is installed in a plant, the specific plant environment comes into play. It is

decisive for the sizing and stable function of the device. Figure 3 already lists key parts of this environment. They start with the design scenario, the strategies to avoid any discharge of hazardous substances, and the effluent systems. Special topics such as property data determination (e.g., for mixtures under-sizing conditions), consequence analyses, maintenance and inspection, and noise emissions should be standardized. In the area of life cycle operation, most parts of the standard are missing. Today, every plant operator has a mostly internal set of guidelines, but although it has been the state of technology for years, it is not mapped in ISO 4126.
The accuracy and complexity of state-of-the-art methods and models for sizing each of the components of a pressure protection system have increased and are expected to grow in the future further. Hence, there is a strong need for appropriate sizing tools certified against the standard's requirements for single- and two-phase flow. For example, ProSaR is a web-based software application with high usability and is thoroughly adapted to ISO4126 (PROSAR, 2022).

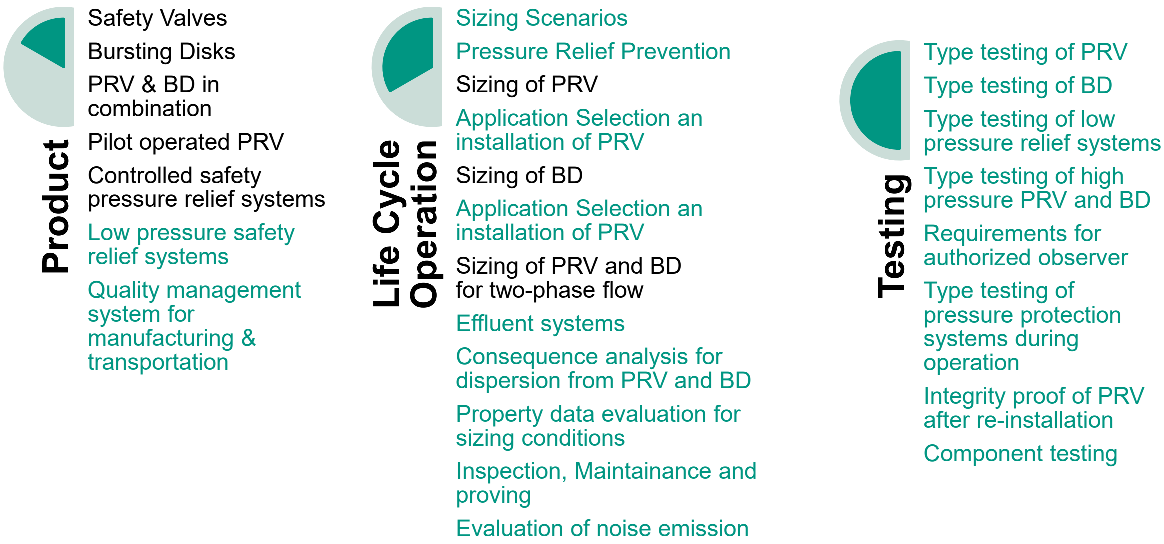

Figure 3: Proposal for future enlargement and standardization of ISO 4126 based on three main areas

In the **area of testing**, unfortunately, almost nothing has been standardized in ISO 4126. For many years, the operators of test facilities and the valve and rupture disk manufacturers have been developing a first standard part 11 for type tests according to ISO 4126. However, it has not yet been possible to reach an agreement. Figure 3 lists eight topics in the area of testing. Testing is becoming very important, especially in times of the shift towards hydrogen technologies. Type testing according to ISO 4126 was considered as a specific test to fulfill the requirements on a sole safety device under laboratory conditions. But it is no longer acceptable for pressure relief devices not to be tested at their typical operating conditions. High-pressure valves have been type tested at low set pressures and some without springs. This is not the state of technology, and plant operators should no longer accept such component tests. However, the tests themselves are not useful in some cases and need to be reconsidered. At high pressures - hydrogen typically in the 700 - 1200 bar range - type tests with air are not representative for pressure relief with hydrogen. The air cools below the dew point of oxygen and nitrogen due to the Joule-Thomson effect. The valves become extremely cold, freeze up, and behave differently than when hydrogen is blown off. It is time that this is considered in ISO 4126, and a standardization part for the tests at high pressures is created. The same applies to very low pressures, e.g., the breathing devices for low-pressure storage tanks. There are currently no standards, and measurement results from manufacturers worldwide differ significantly in quality and are often not comparable.
The proposed strategy 2030 of ISO 4126 corresponds to a change of perspective: life cycle operation of pressure protection systems from an "operator view" with its typical applications in industry. Only a comprehensive view of pressure protection systems in a large variety of industrial plants ensures safe operation. Tests must be carried out under typical operating conditions and not (only) seen as a stand-alone valve or bursting disk test. It is time to go forward. All interested parties are requested to participate constructively.
The old business plan for ISO 4126 from 2005 has been slightly reformulated to fit into the proposed strategy:
"The scope of ISO/TC 185 is the standardization of safety devices for protection against excessive pressure along a system life cycle. Safety devices include safety valves, bursting disk devices, pilot-operated safety

valves, controlled safety pressure protection systems (CSPRS), combination devices, and upstream and downstream protection equipment. Each device type is addressed in separate and distinct parts of the standard ISO/TC 4126. This standardization includes general design requirements, sizing demands, type testing for pressure-retaining integrity, and functional testing representative of typical field applications for operating and flow capacity performance. The main objectives are to enhance the standard to the current state of technology including emission reduction considerations."

According to the proposed strategy for 2030, the content of ISO 4126 should be primarily extended. Many new parts and topics are proposed, which can only hardly be developed if the current workflow under ISO and the review process of the standard are not drastically increased. Parallel to the standardization process of new parts, research and development in process and plant safety will proceed and bring up most probably other new methodologies and models to be integrated into ISO 4126. A vision for ongoing R&D activities in this field is outlined next.

4. Vision of future of pressure protection systems

During the last years, several new trends in process and plant safety were identified to simultaneously increase the safety and productivity of plants. Classical safety devices migrate into intelligent, process adaptable, and online-driven pressure protection systems. The main driver is even for new safety concepts, time to market, and modularization of processes and plants. The new generation of safety devices will be called SmOP (smart overpressure protection devices), see (Schmidt C., 2022). SmOP´s enable fully open a certain cross-section of a pressurized system for relief at a distinct pressure but open only up to an actual necessary lift. Set pressure and lift are continuously changed by the hazard potential within the pressurized system. This allows maximizing the production window while simultaneously suppressing level swell and two-phase discharge, avoiding unnecessary emissions, and optimizing flow rates for downstream flares or washers. And SmOP´s close immediately after a hazard is removed. Periodically partial stroke tests during installation may extend inspection intervals or alarm when systematic errors like encrustation are detected.

A SmOP consists of a typical actor who fasts and safely opens a relief cross-section connected to a safety-related high integrity programmable logic control system (HPLC), Figure 4.

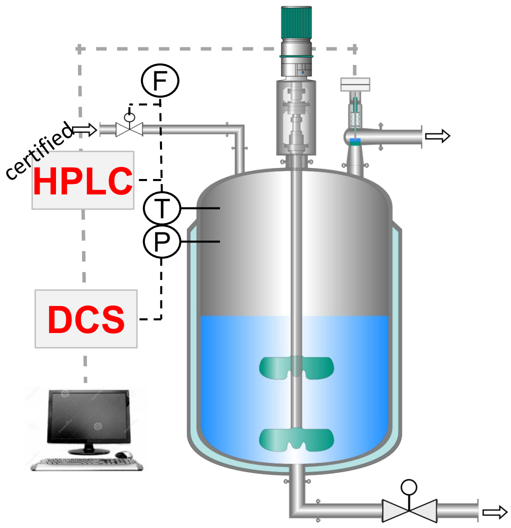

Figure 3: SmOP-Smart overpressure protection system developed at CSE Center of Safey Excellence

The HPLC is linked to specific sensors for online measurement, e.g., temperatures, pressures, feed, level, etc. A SmOP continuously estimates the actual hazard potential in a reactor or pressurized system and limits the control parameter to avoid discharge from the system (zero-emission mode). In case of high energy inputs into the pressurized system during abnormal conditions or for low design data of older equipment, the zero-emission mode is economically not feasible. Here, a SmOP optimizes the opening characteristic to prepare for emergency relief with low flow rates under abnormal plant operation (emission-control mode).

SmOPs will lead to a paradigm change in the future. They allow for a speedup of time-to-market because only very few sizes are necessary and directly connected to a particular reactor, vessel, or column. Currently, a safety device is sized when a reactor, vessel, or column is ordered, and all recipes for production are defined in

detail. A worst-case consideration leads to specific device size and necessary piping. As a result, hundreds of different device types, sizes, and accessories are stored at manufacturers and in plants. Whenever a recipe changes, the capacity is increased, or new products come into play, the sizing must be repeated, and installation must be modified. In contrast to the classical procedure, a SmOP belonging to specific equipment, i.e., reactor, vessel, or column, is ordered with this equipment and needs only to be adapted by parameter inputs into the HPLC before a production start. Sizing is done online and on-demand. Changes in recipes or capacity are just a matter of hours.
SmOPs are developed at the CSE Center of Safety Excellence (Schmidt C., 2022). Prototypes are under test. Due to their flexibility, they are ready for modularization of plants with production on demand.
But a vision is too limited if SmOP´s are the final pressure protection system. New challenges came up with climate discussion and the need to reduce emissions. More than a million safety devices are installed and operated to protect pressurized systems worldwide. In the future, it will most likely not be acceptable to discharge any hazardous substance into ambient – neither from reactors, vessels, columns, or storage tanks. This led to the long-term vision of the CSE Center of Safety Excellence outlined in three steps:

1. Smart pressure protection systems (**SmOP**), highly flexible and ready for modularization
2. Zero-Emission high integrity pressure protection systems (**SmartHIP**) without emergency relief
3. **Inherently Safe** systems based on operational measures to produce and protect simultaneously

Zero-Emission pressure protection systems represent the next generation of protection, completely based on intelligent, functional safety devices (Deerberg, 1995; Biernath et al., 2021). The safety integrity systems will be embedded in multiple operational systems of the regular production, allowing continuous functional checks of any running safety system. Softsensors will be added to increase the proof depth significantly. These are currently based on rigorous mathematical models (white-box modeling). Further development will open the variety of Softsensors based on stochastic models, artificial intelligence, and a combination of them (grey-box and black-box modeling). Production and safety will continuously merge until the quality of operational control is high enough, and the multi-sensorial checks allow for proof in a sufficient depth to reach an inherently safe mode of any pressurized system.

5. Conclusion

Pressure protection needs to be re-thought. ISO 4126 does not represent the state-of-technology of highly interdependent emergency relief systems, including devices, piping, and effluent systems typically encountered in Industry. Additionally, trends like faster time-to-market, modularization of production, zero-emission, etc., are not yet considered. Overall, a paradigm change is necessary, and ISO 4126 needs to be updated. A proposal is made for a strategy of the standard up to 2030. Eighteen new parts have been identified to include the state of technology in the areas of product, life-cycle operation, and testing. To keep the standard updated, new concepts of pressure protections, represented by SmOP´s, SmartHIP´s and inherently safety-safe systems, are outlined in a vision of the future for pressure protection.

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