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Status of a European Standard for the protection of helium cryostats against excessive pressure

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Abstract.
The overpressure protection of various types of cryogenic vessels is covered by a number of International Standards. Helium cryostats, however, include additional components such as superconducting magnets and cavities, electrical heaters and control valves with associated piping, which significantly influence the potential risk. At the European Committee for Standardization CEN, a new working group was hence founded as CEN/TC 268/WG6, dealing with 'Specific helium technology applications'. Its aim is to develop a European Standard for the protection of helium cryostats against excessive pressure that is harmonized with the European Pressure Equipment Directive. It will cover the typical conditions in accidental scenarios in order to harmonize the risk assessment as well as design practices for the pressure relieving systems. We report about the general concept of this new Standard, its structure and content, and the actual status of the project.

1. Introduction

Helium cryostats, other than cryogenic vessels used for storage of cryogenic liquids covered by ISO 21009 and EN 13458, include additional specific components such as superconducting magnets and cavities, electrical heaters, heat exchangers, bellows, circulation pumps and internal control valves. These components imply additional risks for excessive pressure increase, which are not covered by existing Standards and strongly influence the design of helium cryostats including their pressure relieving systems. A new working group was hence founded in July 2017 at the European Committee for Standardization CEN, dealing with 'Specific helium technology applications'. This working group, CEN/TC 268/WG6, is formed by experts from international and national research laboratories and from industry in Europe together with their related national standardization bodies. Its aim is to develop a European Standard for the protection of helium cryostats against excessive pressure that is harmonized with the European Pressure Equipment Directive (PED) [1].

In section 2 of this paper, we explain the overall scope and structure of the Standard, followed by a general description of the content regarding risk assessment in section 3, protection concepts in section 4 and dimensioning of pressure relief devices in section 5. Further design, operation and maintenance aspects are briefly discussed in section 6. A summary and outlook is given in section 7.

2. Scope and structure of the Standard

The new European Standard 'Helium cryostats – Protection against excessive pressure' will be applicable to superconducting magnet cryostats and cryostats for superconducting radio-frequency cavities, to coldboxes of helium refrigerators and liquefiers, to ultra-low temperature refrigerator systems using ^{3}He and ^{3}He/^{4}He mixtures as well as to helium distribution systems including valve boxes. Such cryostats are characterized by a variety of complex and individual design solutions, often exploiting small design margins for cutting-edge performance. Therefore, a common and specific technical solution for the protection against excessive pressure cannot be standardized. Rather, the *approach* of how to obtain a state-of-the-art protection is covered by this Standard, specifying the procedure and the minimum requirements for the various aspects in the main part of the Standard. Alternative and/or advanced methods, additional information, example solutions and exemplary measures are provided in an extensive Annex that mirrors the structure of the main part.

The new Standard is structured as follows:

- The technical part starts with a chapter on 'Risk assessment' whose content is described in section 3. It includes a pre-defined list of 'Sources of excessive pressure' as risk scenarios to be considered in the risk assessments '– before ordering' and '– in the design phase'. The 'Evaluation of risks by the equipment owner/employer' is also covered.
- Risk assessment is the prerequisite for the following chapter on 'Protection concepts' further explained in section 4. It distinguishes between single- and multi-stage protection concepts and defines particular requirements for 5 different types of systems.
- The 'Dimensioning of pressure relief devices' in the succeeding chapter is based on a pre-defined protection concept. The Standard allows two alternative methods, which is shown in section 5.
- Further chapters address requirements on 'Pressure relief devices', 'Substance release' and 'Operation of helium cryostats'. Their content is briefly summarized in section 6.

3. Risk assessment

Risk assessment is the basis of any preliminary and detailed design process of helium cryostats. The new Standard defines 15 risk scenarios as 'Sources of excessive pressure' (table 1), which shall be considered in the risk assessment process. For each of these risk scenarios, common data and examples are given in the Annex.

In a first step, the standard requires a qualitative risk assessment before procurement, typically accomplished by carrying out a Hazard and Operability Study (HAZOP) or an equivalent recognized method. This may typically include:

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Table 1. Sources of excessive pressure

Loss of insulating vacuum	Loss of beamline vacuum	Leak of cryogenic fluid
Quench of superconducting device	Thermal acoustic oscillation	Cryopumping
Entrapment of cryogenic fluid	Dielectric breakdown	Power failure
Pressure surge	Freezing	Backflow
Other sources of excessive pressure	Earthquake	Fire

- the process integration of the helium cryostat in the environment where it will be installed;
- the boundary conditions and the influence of associated installations, e.g. magnetic fields;
- the nominal operating conditions;
- the preliminary indication of a single- or a multi-stage protection concept;
- the discharge conditions and helium recovery systems.

In a second step, a quantitative risk assessment shall be issued in the design phase, including at least the evaluation and verification of the risks in table 1. This is accomplished by carrying out a Failure Mode and Effect Analysis (FMEA) or an equivalent recognized method.

In a final step, the equipment owner/employer shall perform a risk evaluation for the use of the equipment, in its foreseen environment, before commissioning and final acceptance in accordance with the national implementation of the provisions of the European Health and Safety at Work Directive [2].

4. Protection concepts

The new Standard defines a single-stage protection concept as the minimum requirement for pressure protection according to the PED.

In addition, multi-stage protection concepts may be applied in helium cryostats, where a primary pressure relief device (PRD) completely fulfills the pressure protection at the maximum allowable pressure p_{s} in compliance with the PED and based on the maximum credible incident (MCI) as defined by the risk assessment. With regard to the primary PRD, secondary PRD may be applied at either lower or higher relieving pressure p_0, either in series or in parallel. The secondary PRD shall not compromise the functionality of the primary PRD. However, secondary PRD may influence the definition of the maximum allowable pressure p_{s} in multi-stage protection concepts. The values of p_{s} and p_0 of the primary and the secondary PRD, respectively, shall be carefully defined, considering their tolerances and opening characteristics in order to prevent unintended activation or deactivation of the primary PRD.

The new Standard defines particular requirements for multi-stage protection concepts and provides example solutions for the following types of systems:

- high-pressure superconducting magnet cryostats;
- low-pressure helium cryostats, e.g. superconducting radio-frequency cavities;
- sub-atmospheric helium cryostats;
- cryostats for superfluid He-II;
- ultra-low temperature refrigerator systems.

5. Dimensioning of pressure relief devices

The dimensioning of PRD is based on mass-specific energy and momentum conservation as well as the continuity equation for one-dimensional, frictionless, compressible, steady-state and adiabatic fluid flow through short nozzles, where deviations from ideal fluid behavior are considered by correction factors. The following two methods are established to evaluate the thermo- and fluid dynamic relations, yielding similar results:

a) Homogeneous Equilibrium Model (HEM or G-model);
b) Case-specific model.

The HEM used in the main part of the new Standard does not require a pre-definition of the fluid state (i.e. liquid, two-phase or vapor) in the minimum discharge area (called the throat) of PRD, yielding a more compact algorithm.

The case-specific model presented in the Annex may be applied as alternative. In contrast to both ISO 4126-7:2013 and ISO 21013-3:2016, the algorithm uses SI-units without hidden scaling factors (the conversions are explained). This enables the use of one basic equation for the minimum discharge area, both for vapor flow, liquid flow and two-phase flow. Differences due to different fluid states are contained in the parameters of the basic equation.

In order to calculate the relieving mass flow rate following accidental scenarios, the new Standard only defines the maximum heat flux to cryogenic surfaces without multi-layer insulation (MLI), as a general algorithm for the variety of specific and advanced design solutions does not exist. For such cases, the determination of the heat load shall be based on either:

- experimental data given in the Annex or published elsewhere in literature for the respective conditions;
- unpublished experimental data obtained for the particular cryostat design including detailed documentation; or
- numerical modeling of the processes during the accidental scenario including detailed documentation.

6. Further aspects

In its present working state, the new Standard includes further chapters on

- Pressure relief devices;
- Substance release;
- Operation of helium cryostats.

The chapter on ‘Pressure relief devices’ gives reference to ISO 4126 as the relevant product Standard for pressure relief valves and bursting disks, emphasizing operating characteristics and tolerances that are particularly relevant for the combination of PRD in multi-stage protection concepts. It further contains requirements and examples of PRD for insulating vacuum vessels, support structures and materials.

The chapter on ‘Substance release’ deals with the requirements for discharge lines and helium recovery systems, as well as safety aspects for direct helium release to the environment.

The final chapter on ‘Operation of helium cryostats’ covers user requirements regarding the inspection before commissioning along with periodic inspections and maintenance of pressure relief devices.

7. Summary and outlook

The working group CEN/TC 268/WG6 was formed in July 2017 at the European Committee for Standardization CEN, dealing with ‘Specific helium technology applications’. Its aim is to develop a new European Standard on ‘Helium cryostats – Protection against excessive pressure’ that is harmonized with the European Pressure Equipment Directive. The Standard will be applicable to superconducting magnet cryostats and cryostats for superconducting radio-frequency cavities, to coldboxes of helium refrigerators and liquefiers, to ultra-low temperature

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refrigerator systems using ^{3}He and ^{3}He/^{4}He mixtures as well as to helium distribution systems including valve boxes.

The new Standard is planned to be published in 2019.

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References
[1] 2014 Pressure Equipment Directive (2014/68/EU) Directive European Union
[2] 2009 Health and Safety at Work Directive (2009/104/EC) Directive European Union