The PICARD Test Facility - KIT/CERN Collaboration on Cryogenic Pressure Relief Experiments

C. Heidt\textsuperscript{1,2}, A. Henriques\textsuperscript{3}, M. Stamm\textsuperscript{1}, C. Weber\textsuperscript{1,2}, S. Grohmann\textsuperscript{1,2}

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Outline

- State of the Art Helium Safety
- R&D Collaboration
- Design & Construction PICARD
- Exemplary Experimental Results
- Conclusion & Outlook
Dimensioning of cryogenic safety relief devices

Existing models and standards (e.g. DIN EN 13648) do not consider process dynamics \( \dot{q} = \text{const.} \).

- Lehmann/Zahn [1]: \( q_{\text{max}} = 3.8 \ W/cm^2 \)
- Cavallari et al. [2]: \( q_{\text{max}} = 4 \ W/cm^2 \)

R&D Collaboration

- On Cryogenic Pressure Relief Experiments between KIT and CERN from 12/2015 [3]

- Measurement of heat flux densities and relief flow rates in case of a breaking insulating vacuum
  - Without MLI [1,2]
  - With MLI [1]
  - With the relief point close to the critical point (EN 13648-3)

- Expansion in the two-phase area

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Purpose & Operating Range PICARD

- PICARD: Pressure Increase in Cryostats and Analysis of Relief Devices [4]
- Broad range of safety experiments in course of R&D Collaboration

<table>
<thead>
<tr>
<th>Variation of</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Venting diameter</td>
<td>Up to 40 mm</td>
</tr>
<tr>
<td>Liquid level</td>
<td>Up to 100 L LHe</td>
</tr>
<tr>
<td>Set relief pressure</td>
<td>Up to 12 bar(g)</td>
</tr>
<tr>
<td>Mass flow rates</td>
<td>Up to 4 kg/s</td>
</tr>
</tbody>
</table>

Safety Test Facility PICARD

- Quench gas line
- Vacuum pumps
- Exhaust gas line through water bath
- Venting orifice
- Cryostat
- Dewar
- Safety relief devices
- Assembly jig
- Filling line

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Settings of Exemplary Venting Experiments

- Vacuum insulation, radiation shield
- Venting with atm. air
- Most extreme conditions

<table>
<thead>
<tr>
<th></th>
<th>MP7</th>
<th>MP5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Venting diameter</td>
<td>30 mm</td>
<td>12.5 mm</td>
</tr>
<tr>
<td>Set relief pressure</td>
<td>6 bar(g)</td>
<td>2 bar(g)</td>
</tr>
<tr>
<td>Filling level</td>
<td>~60%</td>
<td>~80%</td>
</tr>
<tr>
<td>LHe volume</td>
<td>66 l</td>
<td>103 l</td>
</tr>
</tbody>
</table>
Temperature and Pressure Increase

Temperature in K

Pressure in bar(g)

Time in s

Closed

Open

- TI12
- TI13
- TI14
- TI15
- TI18

PI12, MP7
Temperature and Pressure Increase

- Staged protection
- Open system
- Humidity
- Only safety valve
- Plastic deformation
- Mechanical failure

Heat Flux Density and Relief Mass Flow

- $d_{\text{Vent}} = 30 \text{ mm, } p_0 = 6 \text{ bar(g)}$
- Conservative calculation of heat flux by desublimation/condensation with $T_V = T_A$
- Maximum heat flux literature
  - $q_{\text{max,Lehmann}} = 3.8 \text{ W/cm}^2 \ [1]$  
  - $q_{\text{max,Cavallari}} = 4.0 \text{ W/cm}^2 \ [2]$  
  - But: $q_{\text{max,Dhuley}} = 20 \text{ W/cm}^2 \ [5]$

> $\dot{q}_{\text{open}} < \dot{q}_{\text{max}}$

Heat Flux Density and Relief Mass Flow

- Usual dimensioning according to DIN EN 13648/ ISO 4126-7
  - with $q_{\text{max, Cavallari}} = 4.0 \text{ W/cm}^2$ [2]:
    - $m_{\text{Out, Cavallari}} = 1.6 \text{ kg/s}$
    - $d_{\text{SV, Cavallari}} = 22.2 \text{ mm}$
  - with $q_{\text{open, MP7}} = 1.75 \text{ W/cm}^2$:
    - $m_{\text{Out, MP7}} = 0.7 \text{ kg/s}$
    - $d_{\text{SV, MP7}} = 14.7 \text{ mm}$

- $\frac{A_{\text{SV, Cavallari}}}{A_{\text{SV, MP7}}} = 51\%$

- Oversizing!

Conclusions

- Neglecting process dynamics can lead to **over-sizing** of safety valves
- **Unstable operation** of safety valves (*chattering, pumping*)
- **Damage** to seat of safety valve
- **Overpressures**
  - Staged pressure protection: bursting of rupture disk, **open system**
  - No staged pressure protection: **Plastic deformation**/ mechanical failure of cryostat
Outlook

- Planned experiments in course of R&D collaboration with CERN:
  - With smaller safety valve
  - With MLI
  - Pressure close to critical point
  - Additional quench of sc. magnet

- Investigation of
  - Two-phase flow
  - Safety valve behavior at cryogenic temperatures

➢ See presentation “Investigation of Two-Phase Flow in Cryogenic Pressure Relief Devices” by Christina Weber
Thank you for your attention!