Safety for cryogenic equipment and Crab cryomodule: lessons learned with the prototype and future application in LHC

Luca Dassa on behalf of the engineering team

8th HL-LHC Collaboration Meeting – October, 15th -18th 2018 (CERN)
- SPS test stand
  - The SPS cryomodule
  - Documentation

- LHC installation
  - CERN rules
  - Cryomodule breakdown
  - PED key words / CERN rules specificity
  - Approach to grant compliance with CERN rules
  - Conclusions
- SPS test stand
The SPS cryomodule

- prototype approach
- in house manufacturing and assembly
- materials not considered in harmonised standards
- unconventional configuration (bolted vessel, edge-welded bellows…)
- proof test with high risk to impact on RF performances

Crab SPS prototype cryomodule

- According to PED Annex 2, the cryomodule belongs to risk category I
- equipment liable to have major Safety implications (GSI-M-4)
- exempted from EC-marking
- the equipment shall meet the Essential Safety Requirements (ESRs) stated PED 97/23/EC.
- EU harmonized standards used whenever possible
- If not possible, ASME Section VIII Div. 2 + compensatory measures in view of compliance with the ESRs of the PED.
- Hydrostatic proof test will be replaced by alternative methods

Valid only for SPS cryomodule
cryomodule components

And similar for other components...
LHC cryomodules
Overall context

RFD at P1

DQW at P5

Actors:
- CERN
  - internal
  - outsourcing
- Canada contribution
  - internal
  - outsourcing
- UK contribution
  - internal
  - outsourcing
- US-AUP contribution
  - internal
  - Outsourcing
  - ...

Compliance with CERN rules
Approach valid for every case
CERN rules for pressure/cryogenic equipment

SR-M Mechanical equipment

GSI-M-2 Standard pressure equipment

GSI-M-4 Cryogenic equipment

SSI-M-2-5 - Vacuum chambers and beam pipes

CE marking required, HSE could grant exception for “Cryogenic equipment liable to have major Safety implications:”

European law: Directive 2014/68/EU (PED)

Applicable harmonized standards

Compliance shall be granted

<table>
<thead>
<tr>
<th>Standard</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 764-5</td>
<td>Pressure equipment – Part 5: compliance and inspection documentation of materials</td>
</tr>
<tr>
<td>EN 764-7</td>
<td>Pressure equipment – Part 7: safety systems for unfired pressure vessels</td>
</tr>
<tr>
<td>EN 1251</td>
<td>Cryogenic vessels – Transportable vacuum insulated vessels of not more than 1000 litres volume</td>
</tr>
<tr>
<td>EN 1252</td>
<td>Cryogenic vessels – Materials</td>
</tr>
<tr>
<td>EN 1626</td>
<td>Cryogenic vessels – Valves for cryogenic service</td>
</tr>
<tr>
<td>EN 1797</td>
<td>Cryogenic vessels – Gas/material compatibility</td>
</tr>
<tr>
<td>EN 12213</td>
<td>Cryogenic vessels – Methods for performance evaluation of thermal insulation</td>
</tr>
<tr>
<td>EN 12300</td>
<td>Cryogenic vessels – Cleanliness for cryogenic service</td>
</tr>
<tr>
<td>EN 12434</td>
<td>Cryogenic vessels – Cryogenic flexible hoses</td>
</tr>
<tr>
<td>EN 13371</td>
<td>Cryogenic vessels – Couplings for cryogenic service</td>
</tr>
<tr>
<td>EN 13445</td>
<td>Unfired pressure vessels</td>
</tr>
<tr>
<td>EN 13458</td>
<td>Cryogenic vessels – Static vacuum insulated vessels</td>
</tr>
<tr>
<td>EN 13480</td>
<td>Metallic industrial piping</td>
</tr>
<tr>
<td>EN 13530</td>
<td>Cryogenic vessels – Large transportable vacuum insulated vessels</td>
</tr>
<tr>
<td>EN 13648</td>
<td>Cryogenic vessels – Safety devices for protection against excessive pressure</td>
</tr>
<tr>
<td>EN 14197</td>
<td>Cryogenic vessels – Static non-vacuum insulated vessels</td>
</tr>
<tr>
<td>EN 14398</td>
<td>Cryogenic vessels – Large transportable non-vacuum insulated vessels</td>
</tr>
<tr>
<td>EN 14917</td>
<td>Metal bellows expansion joints for pressure applications</td>
</tr>
<tr>
<td>EN ISO 4126</td>
<td>Safety devices for protection against excessive pressure</td>
</tr>
</tbody>
</table>
The basic unit: the cryomodule up to the jumper for connection with supply lines

CERN rules for standard pressure / cryogenic equipment!
PED key words

Directive 2014/68/EU

“manufacturer” means any natural or legal person who manufactures pressure equipment or an assembly or has such equipment or assembly designed or manufactured, and uses it for his own purposes;

Article 6
Obligations of manufacturers
1. When using (their pressure equipment or assemblies) for their own purposes, manufacturers shall ensure that they have been designed and manufactured in accordance with the essential safety requirements set out in Annex I.

CERN rules specificity

- materials not considered in harmonised standards Titanium / Nb / Nb-Ti
- unconventional configuration (bolted vessel, edge-welded bellows…)
- proof test with high risk to impact on RF performances

GSI-M-4 Cryogenic equipment

Cryogenic equipment liable to have major Safety implications

“… the approval of the HSE Unit is required for each stage in the life cycle of an item of cryogenic equipment liable to have major Safety implications.”

CERN is manufacturer of the cryomodule

The cryomodule shall be designed and manufactured in accordance with the essential safety requirements.

HSE has verbally agree on Crab cryomodule as “Cryogenic equipment liable to have major Safety implications” and on exemption from CE Marking
Finalization ongoing!
Approach to grant compliance with CERN rules

SSA System Safety Assessment

- list of applicable CERN rules and relevant European harmonized standard
- status “Cryogenic equipment liable to have major Safety implications” should be granted
- the equipment shall meet the Essential Safety Requirements (ESRs) stated PED 2014/68/EU
- No CE marking

Technical specification for cryomodule
Roadmap for compliance with CERN safety rules for cryomodule

Technical specification for dressed cavities
Roadmap for compliance with CERN safety rules for dressed cavities

Technical specification for cryogenic lines
Roadmap for compliance with CERN safety rules for cryogenic lines

Compliance with CERN rules is granted if the technical specification is fulfilled

Ad-hoc agreements / documentation can be discussed
Choice between European and US standards is sometimes allowed.
List of Essential safety requirements from PED
Few technical considerations

- Very low risk components: each component is treated independently

<table>
<thead>
<tr>
<th>Component</th>
<th>Pressure</th>
<th>Volume</th>
<th>Diameter</th>
<th>Fluid</th>
<th>PED risk category</th>
<th>Module for Conf. Asmtn.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dressed cavity (ACFDC)</td>
<td>1.8 [bara] 0.8 [barg] 80 [l] NA [mm]</td>
<td>Liquid He (1.9 K)</td>
<td>1</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOM (ACFHC)</td>
<td>1.8 [bara] 0.8 [barg] NA 28 mm</td>
<td>Liquid He (1.9 K)</td>
<td>SEP</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPC</td>
<td>TBD [bara] TBD [barg] NA TBD [mm]</td>
<td>Water (300 K)</td>
<td>TBD</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper cryogenic line (ACFQC)</td>
<td>1.8 [bara] 0.8 [barg] NA 103 mm</td>
<td>Liquid He (1.9 K)</td>
<td>SEP</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom cryogenic line (ACFQC)</td>
<td>1.8 [bara] 0.8 [barg] NA 28 mm</td>
<td>Liquid He (1.9 K)</td>
<td>SEP</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal shield line (ACFTS)</td>
<td>25 [bara] 24 [barg] NA 16 mm</td>
<td>Gas He (50 K)</td>
<td>SEP</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold-warm transition (ACFVW)</td>
<td>25 [bara] 24 [barg] NA 16 mm</td>
<td>Gas He (50 K)</td>
<td>SEP</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vacuum vessel (ACFVT)</td>
<td>1.5 [bara] 0.5 [barg] Not relevant NA</td>
<td>Insulation vacuum</td>
<td>Out of scope</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Assessment of the assembly according to PED (ANNEX 1: 2.3, 2.8, 2.9.)
- Notified body not required
# Status and tentative deadlines

<table>
<thead>
<tr>
<th>Status of the Tech Spec</th>
<th>Status of the Roadmap for Safety</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryomodule</td>
<td>Draft in work</td>
<td>Not started</td>
</tr>
<tr>
<td>Dressed cavities</td>
<td>Well advanced draft</td>
<td>Well advanced draft</td>
</tr>
<tr>
<td>Cryogenic lines</td>
<td>Well advanced draft</td>
<td>Well advanced draft</td>
</tr>
<tr>
<td>Thermal Shield</td>
<td>Waiting for decision about material</td>
<td>Not started</td>
</tr>
<tr>
<td>Vacuum vessel</td>
<td>Well advanced draft</td>
<td>Not started</td>
</tr>
<tr>
<td>Main coupler</td>
<td>Not started</td>
<td>Not started</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Status</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection device</td>
<td>Started (calculation on-going)</td>
</tr>
</tbody>
</table>
Conclusions

- CERN is manufacturer of the cryomodule
- Status of “cryogenic equipment liable to have major safety implications”
- Baseline approach “Technical specifications + Roadmap for compliance with CERN safety rules”
  - CERN is responsible for compliance with CERN rules of the cryomodule
  - Manufactures of components shall comply with technical specifications => **not blindly!**
- Choice between European and US standards is sometimes allowed
Thank you...
Back-up slides
CERN rules specificity

GSI-M-4 Cryogenic equipment

Cryogenic equipment liable to have major Safety implications:
cryogenic equipment:
- not compliant with the applicable European directives, or
- of a highly complex design, or
- using reduced safety factors, or
- requiring special conditions of use, or
- using unconventional materials or manufacturing technologies, or
- presenting a high-level hazard for people, the environment or other installations in the event of failure.
ANNEX 1

2.3. Provisions to ensure safe handling and operation

The method of operation specified for pressure equipment shall be such as to preclude any reasonably foreseeable risk in operation of the equipment. Particular attention shall be paid, where appropriate, to:

— closures and openings,
— dangerous discharge of pressure relief blow-off,
— devices to prevent physical access whilst pressure or a vacuum exists,
— surface temperature taking into consideration the intended use,
— decomposition of unstable fluids.

In particular, pressure equipment fitted with an access door shall be equipped with an automatic or manual device enabling the user easily to ascertain that the opening will not present any risk. Furthermore, where the opening can be operated quickly, the pressure equipment shall be fitted with a device to prevent it being opened whenever the pressure or temperature of the fluid presents a risk.

2.8. Assemblies

Assemblies shall be so designed that:

— the components to be assembled together are suitable and reliable for their duty,
— all the components are properly integrated and assembled in an appropriate manner.

2.9. Provisions for filling and discharge

Where appropriate, the pressure equipment shall be so designed and provided with accessories, or provision made for their fitting, as to ensure safe filling and discharge in particular with respect to risks such as:

(a) on filling:
— overfilling or overpressurisation having regard in particular to the filling ratio and to vapour pressure at the reference temperature,
— instability of the pressure equipment;

(b) on discharge: the uncontrolled release of the pressurised fluid;

(c) on filling or discharge: unsafe connection and disconnection.
LHC crab cavities (1)

EDMS 1698982, S. Baird, head of the HSE Unit: Conformity approach for Pressure Equipment for the High Luminosity LHC Project (June 10th, 2016)

- Approach by exception -> per equipment basis -> unique in-house technical competency -> no Notified Body (it would not add any risk mitigation) -> HSE-SEE will act as de facto Notified body
- Responsibility for design, manufacture, testing and quality insurance remains with HL-LHC Project team / technical justification shall be prepared by the equipment owner-work package leader
- Formal derogation not required if the HSE-SEE classes the equipment as being “liable to have major safety implications”
- Technical requirements
- Organizational and quality assurance requirements

Is the LHC crab cryomodule concerned???
4. Organisational and quality assurance aspects

In order to assure that the technical requirements described above are being met, this implies:

- HSE, Departments and HL-LHC Project team to collectively set and strictly respect prescriptions, milestones and deadlines for the equipment activities.
- Owner/work package leader to appoint a single point of contact within their team, with responsibility for quality assurance and preparation of the safety file and associated documentation, that HSE-SEE can regularly liaise with
  - Person should be sufficiently competent and conversant in the Essential Safety Requirements of the Pressure Equipment Directive.
- Owner/work package leader, their quality assurance person and HSE-SEE to jointly develop and agree to the Inspection and Test Plan.
- Agreement made between all relevant parties on dealing with non-conformities.
- Quality of engineering deliverables to be at an equivalent level as if the documents were being sent externally for formal approval by a Notified body, prior to requesting validation or endorsement.
- External partners (industry, other research institutes, in-kind contributions, etc.) shall supply on time the same technical documentation for design, manufacture, inspection and testing.
- Design to be validated by HSE-SEE prior to starting fabrication.
  - Including appropriate documentation of the ‘effective equivalence’ in all areas, e.g. materials selection, qualification of welders, NDT operator qualification, etc.
- Safety accessories – as standard products – shall fully comply, as applicable, with either:
  - GSI-M-2 Standard Pressure Equipment and SSI-M-2-3 Safety Accessories for Standard Pressure Equipment, or
  - GSI-M-4 Cryogenic Equipment.
- Safety accessories shall therefore be CE marked, including those used on equipment obtained as in-kind contributions from countries not subject to the European Pressure Equipment Directive.

3. Technical requirements for Pressure Equipment under the modified approach

The modified approach shall be based on the following requirements:

- Equipment shall fully meet the applicable Essential Safety Requirements (ESR) stated in Annex I of the European Pressure Equipment Directive.
  - Owner/work package leader shall demonstrate and document that they have achieved compliance to these Essential Safety Requirements.
  - Full traceability has to be assured, and auditable.
  - Equipment can be, however, exempted from CE marking.
- European harmonised standards shall be used whenever possible in the design, manufacture, inspection and testing of the equipment.
- When the use of harmonised standards is not fully achievable due to the specific features of the project (e.g. use of materials not covered by the harmonised European standards, in-kind contributions from non-EU countries, etc.) the use of ASME Section VIII Div. 2 can in general be applied, taking into account any necessary compensatory measures in view of compliance with the Essential Safety Requirements of the European Pressure Equipment Directive.