Certification of the XFEL cold linac and lessons learnt

Serena Barbanotti Hamburg, 15th March 2021





Agenda

Certification of the XFEL cold linac and lessons learnt

01 The EuXFEL

- The facility
- Cryogenic layout

02 The certification

- Why we certify a linac
- How does it work

03 Overview of the XFEL certification

- The linac
- The cryomodules
- The cavities

04 Other activities and conclusions

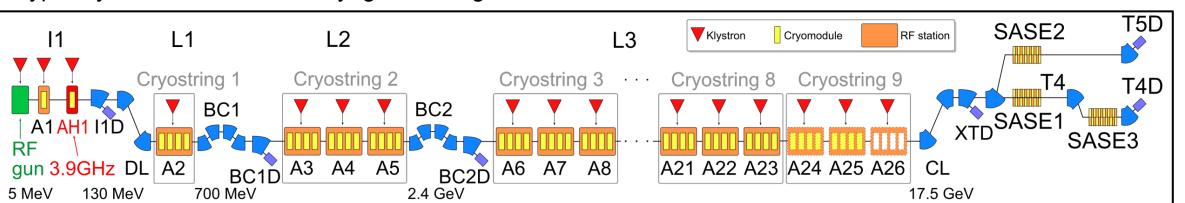
- What happened after EuXFEL cool down
- Lessons learnt

EuXFEL overview

The European X-ray Free Electron Laser (EuXFEL)

The complete facility

- Soft and hard X-ray light experiments .
- Design energy 17.5 GeV, typical SASE user runs at 14 -16.5 GeV .
- Pulsed operation at 10 Hz
- ~800 TESLA-type cavities •
- Resonance frequency 1.3 GHz
- 32 cavities per XTL RF station •
- Typically 3 RF stations for a cryogenic string



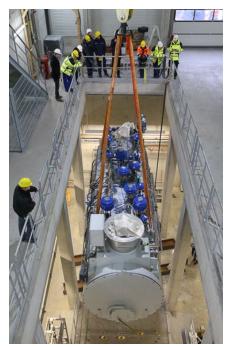


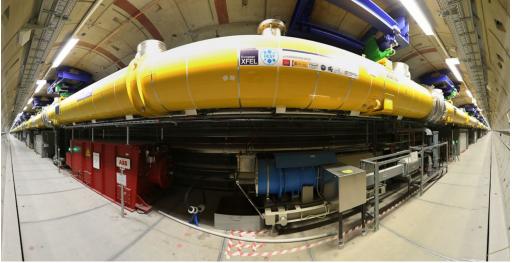


The EuXFEL cryogenic facility

"roughly one kilometer of cold linac"

- 2 cryoplants (2 refurbished of 3 former HERA plants)
- 1 coldbox with 4 stage cold compressors, 1 distribution system
- 14 cryogenic caps/boxes for cryomodule connections
- 98 cryomodules



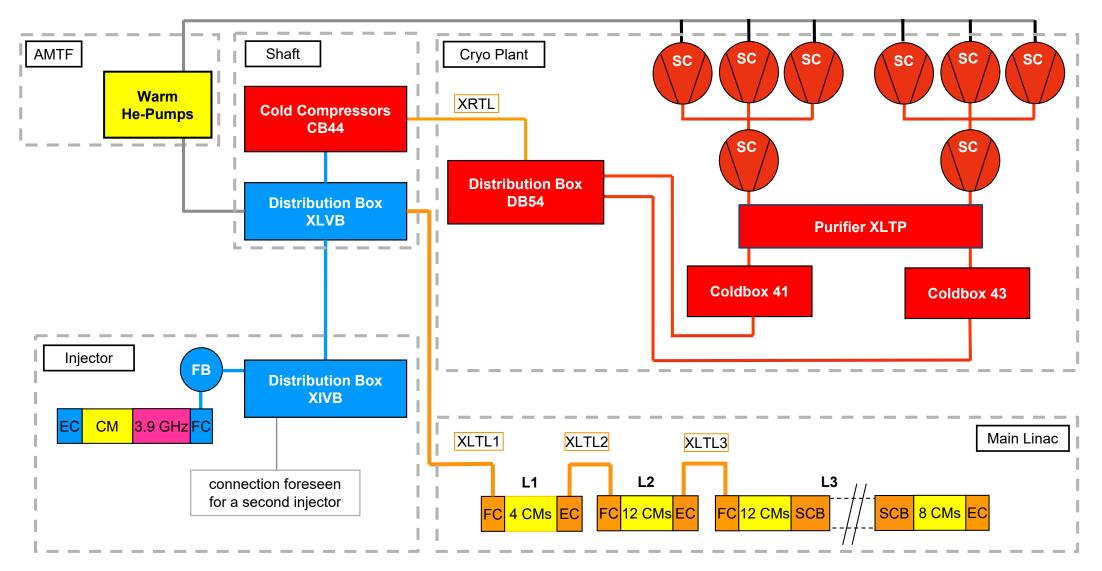






The EuXFEL cryogenic system

At 2K since December 2016

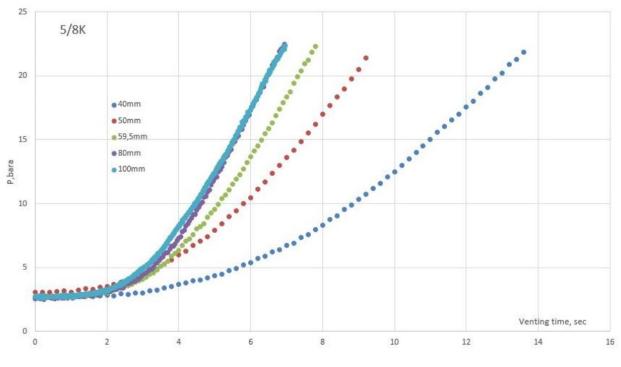


Why a certification?

How dangerous are pressure and cold?

Impressions from a crash test

- Crash test of **ONE** XFEL-like 1.3 GHz cryomodule
- Simulated accidents: venting of a DN50 DN100 pipe to air
- Pressure rises from 2.5 to 20 bar in a few seconds (6s for a DN80 pipe)



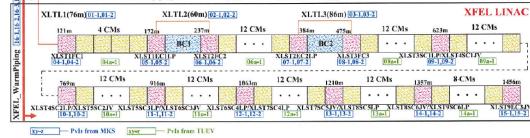




What do we need to operate the XFEL cold linac?

From the pressure equipment point of view

- The XFEL cold linac is a facility requiring monitoring, i.e. the XFEL linac has to fulfill the requirements of the German implementation of the directive 2009/104/EC "use of work equipment" ("Betriebsicherheitsverordung")
 - Should be verified also during design/construction
- The directive stipulates for facilities requiring monitoring which tests has to be performed by an approved inspection body (the ZÜS, Zugelassene-Überwachungs-Stelle), in our case the TÜV Nord
- The TÜV Nord collects all the documentation and makes a "testing before commissioning" (in German "PvI"); with a successful PvI, the linac gets the authorization to operate





Steps to a Pvl

- The XFEL cold linac is classified as a pressure equipment (P>0.5 bar) and is built in Europe:
 - The design, manufacturing and inspection has to follow the Pressure Equipment Directive (PED)
- The PED is not a "manual how to build", but includes the **minimal requirements** that you have to fulfill; for example, it doesn't define which materials are allowed, but it requires that materials used for pressure equipment fulfill one of the following three formal requirements:
 - comply with a material harmonized standard
 - OR are covered by a European Approval of Material (EAM)
 - OR have a Particular Material Appraisal (PMA)
- The technical rules for the design, fabrication and inspection are specified in the European standards:
 - EN 13445 Unfired Pressure Vessels
 - EN 13480 European metallic industrial piping code
 - Others: AD 2000-Regelwerk, ...
 - (The ASME Boiler and Pressure Vessel Code in NOT accepted as standard)

EUROPÄISCHE NORM EUROPEAN STANDARD	EN 13445-1
NORME EUROPÉENNE	Juli 2009
ICS 23.020.30	Ersatz für EN 13445-1:2002
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Unfired pressure vessels — Part 1: General	Récipients sous pression non soumis à la flamme — Partie 1: généralités
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dieser Europäischen Norm ohne jede Änderung der Status ein	affsordnung zu erfüllen, in der die Bedingungen festgelegt sind, unter denen ner nationalen Norm zu geben ist. Auf dem letzten Stand befindliche Listen n sind beim Management-Zentrum des CEN oder bei jedem CEN-Mitglied auf
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Griechenland, Irland, Island, Italien, Lettland, Litauen, Luxemb	igien, Bulgarien, Dänemarik, Deutschland, Estland, Finnland, Frankreich, Jurg, Maita, den Niederlanden, Norwegen, Österreich, Polen, Portugal, , Spanien, der Tschechlischen Republik, Ungarn, dem Vereinigten Königreich

EuXFEL certification

Steps to a Pvl

Applied to the XFEL linac

- DESY chose to build the XFEL linac following :
 - The AD2000 for boxes and transfer lines
 - The EN13445, EN13480 standards for the cryomodules
- The notified body that followed the whole process was the TÜV Nord
- The XFEL linac was divided in 3 sub-components: accelerator, injector, cryo plant
- DESY was the manufacturer of the components; this means
 - DESY has to be certified as manufacturer
 - The procedures have to be qualified
 - The DESY personnel (welders and testing personnel) has to be certified



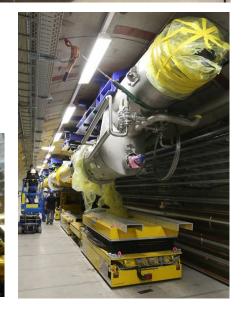
The cold linac

1.3 km long pressure equipment

- The cold XFEL linac is an assembly:
 - 100 CE stamped cryomodules
 - ~ 100 sets of bellows for the cryomodule connections (parts of pressure equipment)
 - CE stamped string connection boxes and end/feed caps with relief valves
 - Transfer lines between linac sections and to the distribution box
- All these components have either:
 - A CE stamp
 - A declaration of conformity from the manufacturer (DESY or a certified company)









The XFEL cryomodule

An assembly in the assembly

- The XFEL cryomodule is an assembly, made of the following "PED relevant" sub-components:
 - 8 cavities
 - 1 quadrupole
 - 7 titanium bellows
- cavity string
- 1 end connection
- 1 quadrupole pipe
- 1 cold mass, also an assembly of all the cooling pipes
- Each of this components is independently certified as a "pressure equipment" or "part of a pressure equipment" by the TÜV or by DESY
- The assembly took place at CEA Saclay and was supervised by DESY as manufacturer and by the TÜV Nord as notified body
- The cryomodule is CE stamped (0045) and approved by the TÜV Nord and a declaration of conformity from DESY



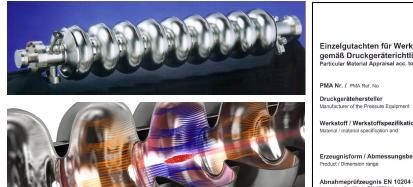


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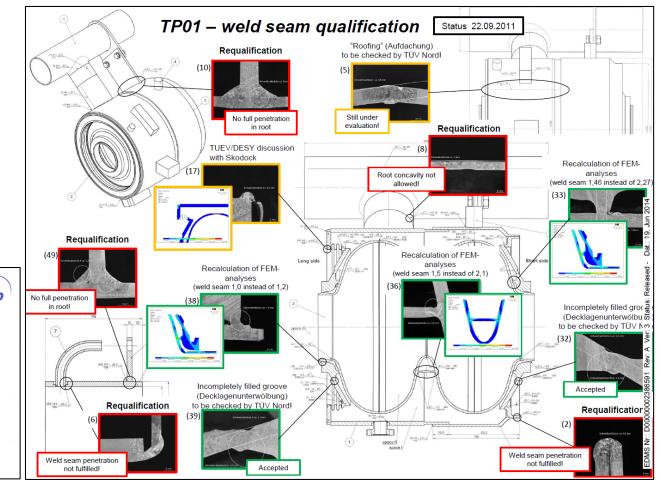
The XFEL cavity

Our "special child"

- **Critical issue**: the materials Niobium and NbTi are not approved materials for pressure equipment
- Solution: Particular Material Appraisal
 - This means additional documentation and tests on the material
- Additional issue: historically not designed as pressure vessel -> welds needed to be qualified
- Solution: additional test piece



	TIV NORD
Einzelgutachten für Werkstoffe gemäß Druckgeräterichtlinie (9 Particular Material Appraisal acc. to Pressu	
PMA Nr. / PMA Ref. No	: 1326W172790-W01
Druckgerätehersteller Manufacturer of the Pressure Equipment	: Deutsches Elektronen Synchrotron (DESY) 22607 Hamburg, Deutschland
Werkstoff / Werkstoffspezifikation, Material / material specification and	: Nb 300 RRR, Nb 40 RRR / DESY SPECIFICATION XFEL/003, XFEL/007, ASTM B 391 – 03, ASTM B 393 – 05, ASTM B 394 – 03
Erzeugnisform / Abmessungsbereich Product / Dimension range	: Rod, Plate, Ring, Tube – annealed / acc. to design XFEL/004
Abnahmeprüfzeugnis EN 10204 (Art) Inspection Certificate EN 10204 (type)	: - 3.1 ¹⁾
Anwendungsbereich / Druckgerät Application range / Pressure Equipment	: Pressure Vessel, Cavity for XFEL - DESY

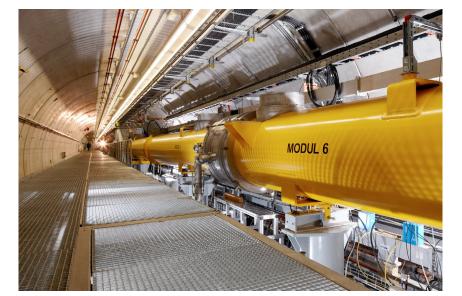


After 2016

Further activities since 2016:

Maintaining the certification

- DESY shall maintain its certification for EuXFEL:
 - Repair activities (4 modules repaired in the last 4 years)
 - Revision of components (safety valves, warm piping ...)
 - Recurring inspections as prescribed
 - R&D activities for CW cryomodules
- The following projects also involve pressure equipment:
 - ALPS II (reuse 24 HERA magnets in search of new particles, WISPs)
 - FLASH2020 (refurbishment of 2 cryomodules and a few boxes)
 - Testing of superconducting undulators
 - Cryo-platform



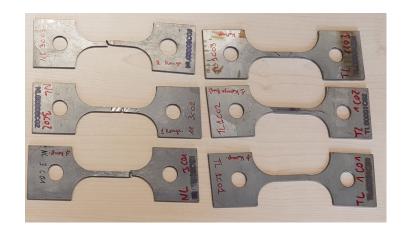


Further activities since 2016:

Large Grain Niobium

- Large grain Niobium might be an option for future CW operation:
 - Higher Q0 than fine grain
 - High gradient for pulsed operation still possible
- Large grain Niobium:
 - Like fine grain Nb becomes brittle at low temperatures
 - Has a lower yield strength than fine grain (too close to the limit)
 - The yield strength depends on the material and grain orientation

 \rightarrow Special material investigation needed



- Collaboration ongoing with the TÜV Nord to qualify this material for pressure equipment:
 - Additional FEA
 - Additional cold traction tests of specimens and welded components



Conclusions: our lessons learnt

In the last 10 years

- Invest a bit time and money at the beginning to avoid show stoppers:
 - Build your own expertise, the authority can help you on regulations, but you know your facility at best
- Define as soon as possible (in the design phase) how you will deal with the safety and health regulations
 - Choose your normative frame (ASME, EN or AD)...
 - Get a standardize process with clearly defined roles
 - If you need a certification from an authority, work with them since the beginning and keep a close contact all the time
- Consider each pressurized component as a part of the whole system
- Clarify in advance the required documentation, including quality control documents, test reports, ...
 - Do not work "on the fly"; it's more efficient and cheaper
 - Advantage for everybody, once the work is ongoing \rightarrow clear path to follow, no discussions, ...
- Fix your "revision plan" in advance:
 - Include doubling components in the design if needed
 - Fix in advance the amount and frequency of inspections (at cold and warm) and plan the required shutdowns (very important for large user facilities)

Thank you

Contact

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www.desy.de