PED REQUIREMENTS APPLIED TO THE CAVITY AND HELIUM TANK MANUFACTURING

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Abstract

For the European XFEL more than 800 Cavities are manufactured by industrial partners. Each cavity is housed in an individual cryo vessel, the so called helium tank. All vessels are made from titanium and manufactured by industry as well. The cavity, welded into its helium tank, is a pressure loaded part and has to follow the pressure equipment directive - PED (97/23/EC). Setting up a series production of cavities and helium tanks by different vendors according given standards, was the task of the XFEL WPG-1 LINAC-WP04. In cooperation with the TUEV-Nord as the notified body, DESY is responsible for the qualification of design, material in use and reasonable tests to get a certificate for pressure bearing parts.

INTRODUCTION

The max pressure of the cryogenic system of the XFEL Linac is fixed to 4 bar absolute. The smallest isolatable volume is the accelerator module, consisting of eight superconducting (s.c.) resonators, a beam position monitor and a super conducting quadrupol magnet.

To avoid pressure tests of complete modules as a part of the pressure bearing vessel tests, the s.c. cavities were assigned by DESY to follow the tests of category IV of PED annex II regulations [1].

REQUIRED TESTS FOR A PED QUALIFIED CAVITY

The certification of industrial manufactured resonators made from fine grain Niobium is done according to the conformity evaluation procedures modules B1 (EC design-examination), B (EC type-examination) and F (product verification) see also table 1. For testing the applicability of large grain niobium [2] in s.c. accelerators eight resonator made of large grain niobium will be installed to the XFEL Linac as well. Due to the special material properties, they are tested according to Module G (EC unit verification).

Table 1: Conformity Evaluation Procedures

Conformity evaluations according to PED annex III	
Module B1 EC design examination	Review of cavity and helium tank design
	Review of drawings
	Tests on materials
Module B EC type examination	Company qualification
	Destructive and non-destructive tests of test piece
Module F EC product verification	Non-destructive tests for series production
Module G EC unit verification on large grain cavity	Additional material tests
	Additional burst test

Design and Drawing Approval

In accordance with module B1, EC design examination, all fabrication drawings are checked in detail by a notified body. Each joint assembly, weld symbol, dimension of remaining wall thicknesses and named materials have been approved according to DIN EN 13445 – unfired pressure vessels.

A finite element analysis (FEM) is performed to locate the position of the highest stress in the structure Result of the calculation is that the maximum stress, which is close to the maximum allowed stress of niobium respectively titanium is located at the connections of stiffening ring to half-cell and bellow unit to tank tube. Special care is taken on these regions by controlling the correct weld penetration and process stability.

To avoid crossing longitudinal welds at the interconnection of tank tube, sliding collar and reduction ring the welds are marked and their positions fixes in the drawings.

Material Approval

Due to its high forming degree the bellows is made from Ti grade 1. Ensuring the highest reliability of this component the Ti1 has to full fill the requirements of the DIN standards. For Ti2, in use for the parts with lower stress factors like the helium tank tube, the less strict regulations of the ASTM code can be applied.

The post weld heat treatment for welded Ti tubes was investigated and has shown that the temperature treatment according to DIN 17869 will have no influences to the material characteristics.

All material parameters for niobium RRR40 and RRR300 and for the niobium-titanium alloy are fixed in the DESY specifications XFEL/007 respectively XFEL/008. The specifications are reviewed and approved for cavity application for the XFEL Project by the TÜV-Nord.

Material suppliers for pressure bearing parts have to be qualified according to PED annex I, paragraph 4.3. All materials in use have to be confirmed by a 3.1 or 3.2 inspection certificate according to EN 10204. Particular material appraisals (PMA) for titanium grade 1 and 2, niobium RRR40 and RRR300 and the niobium-titanium alloy were handed out to DESY for the XFEL project.

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Company Qualification

Two companies E. Zanon S.p.A. in Schio Italy (EZ) and Research Instruments in Bergisch Gladbach Germany (RI) are contracted for the fabrication of XFEL cavities. One step in the cavity production line is the completion of the cavity with the helium tank. EZ is contracted to manufacture the helium tanks for their own cavity production themself. The helium tanks, needed for the production at RI, are provided by DESY. DESY subcontracted these helium tanks at E. Zanon S.p.A and C.S.C S.p.A.in Schio, Italy [4].

An audit/assessment by the notified body, TUEV-Nord of these companies took place. A quality control plan is set up to determine necessary witness and hold points of the production for controls by the notified body. The companies personal for welding and testing, is verified by valid qualifications and certifications as well.

Due to their individual techniques in forming, heating, welding procedures and personnel a so called test piece according to ISO 15613 is produced to qualify the specific processes at each company. The manufacturing was witnessed by the notified body. For a stable production more than one welder or e.g. EB machine needed to be qualified by a second test piece.

All welding and production of not pressure loaded parts is done under responsibility of DESY.

Tests on Test Piece

The test piece is designed as a two cell cavity with shortened helium tank and without end tubes (Fig.: 1). All pressure loaded parts, all welding joints and manufacturing characters applied at the companies for the XFEL cavities had to be demonstrated by the test piece. The test piece is examined by destructive and non-destructive tests in accordance with the ISO 15613.

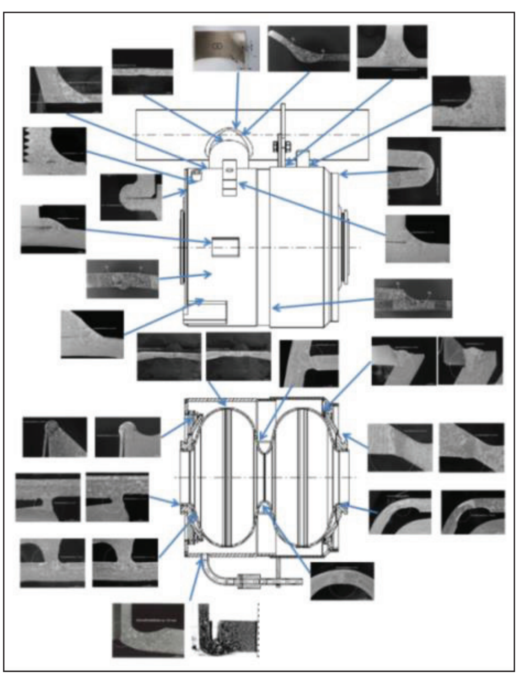

Figure 1: Overview on micrographs of the test piece.

Visual tests, dye penetrant tests, micrographs, hardness measurements and measurement of the remaining wall thickness are performed on each weld of the test piece.

All tests on the test piece are performed by the TUEV-Nord in Hamburg.

Non-Destructive Tests for Series Production

For the tests according to module F, product verification, it was agreed that no more destructive tests are required for the series production; only non-destructive tests should be performed (table 2).

Table 2: Non-Destructive Tests for series Production

Tests on each…	
Cavity without helium tank	Visual test on all welds
	Vacuum leakage test cavity
Helium tank	Radiographic test on longitudinal welds
	Color penetrant test on all welds **or** Visual test on all welds
	Vacuum leakage test on bellow unit and helium tank
Cavity equipped with helium tank	Visual test on all welds
	Pressure test

Studies of the Impact to the Cavity during Pressurization

Performing a pressure test of each individual cavity was an inescapable request from the TUEV-Nord. Appling a pressure test to a cavity in helium tank can influence the frequency and field profiles distribution change during pressurizing. Therefor DESY investigates the effect to the frequency and displacement of the cavity during and after pressurisation.

The maximum difference pressure of the XFEL LINAC is set to 4bar [5]. The offset for pressure tests according to PED annex I, paragraph 7.4 is 1,43. For the pressure test the differential pressure is 5,72bar. Taking into account 1 bar atmosphere during the pressure test, the absolute pressure is 6,72bar for XFEL cavities.

$$4bar_{\ P\ difference}\ x\ 1{,}43 + 1bar_{atmosphere} = 6{,}72bar_{P\ absolute}$$

In total 9 large grain and 2 fine grain cavities have undergone a pressure test at DESY (Fig.: 2). Water have been used for the pressure test. The frequency change and mechanical displacement have been measured during pressurization. It is found, that the frequency shifts up to 350 KHz during pressurizing with 6,72bar absolute. The short beam tube, fixed to the helium tank, is displaced up to 0,2mm elastically. The long beam tube, connected to the bellow, is blocked by bellow clamps. Even with enforced bellow clamps the beam tube moved up to 0,5mm during pressurization. The movement during pressurization is almost elastically and no significant and permanent change of spectrum or field profile is observed after relaxing.

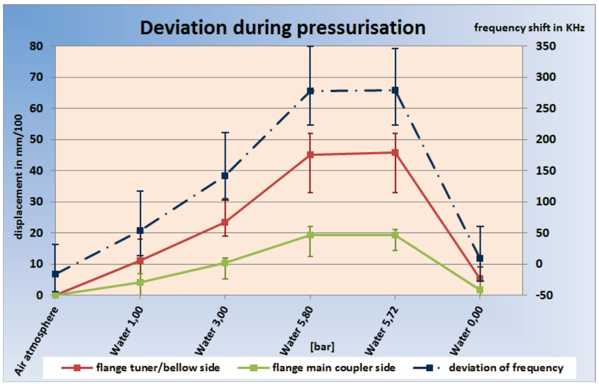

Figure 2: Summarizing graphic of 9 large grain and 2 fine grain cavities.

Additional test for the qualification of large grain cavities

Tensile tests at 4K and room temperature of the large grain niobium (LG) showed that it has lower elasticity than fine grain niobium. Taking into account the mechanical strength properties of large grain material the FEM was recalculated. The FEM calculation predicted a stress overload at the connection half-cell and stiffening ring even at lower pressure than the requested pressure of 6,72bar for the pressure test. In contradiction an overload of stress was not seen during the standard pressure test already performed. Only a burst test on a LG cavity could approve the sufficient stability of the construction with LG niobium. According to EN13445 the structure has to withstand fife times the design pressure.

$$5 \text{ x } 4 \text{ Bar}_{P \text{ operation}} = 20 \text{ Bar}_{P \text{ min. burst}}$$

Up to 12bar the frequency measurement and dial gauges showed linear displacement. At 18bar the bellow began to deform plastically. At 20 bar the RF equipment and dial gauges were removed to have a look into the cavity. At 22 bar water blast into the cavity and the pressure dropped down to 0bar immediately. After cutting the tank it showed up that lots of dents independent of grain boundaries are distributed all over the cavity. The largest dent is present at cell six (Fig.: 3). A crack resulting from the wide forming degree of the dent in the cell at the connection to the stiffening ring at the sixth iris is clearly visible (Fig.: 4).

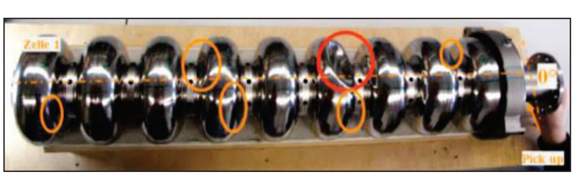

Figure 3: Large grain cavity (AC153) after pressure test with 22bar. Dents are marked with circles.

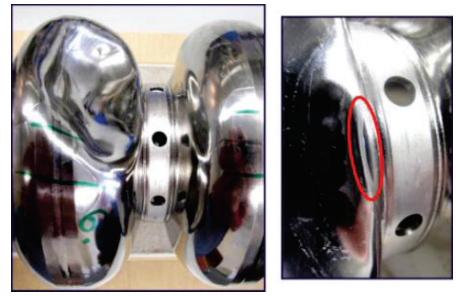

Figure 4: Deformation and breakage at stiffening ring of cell six.

For comparison a fine grain cavity was tested with a burst test additionally (Fig.: 5).

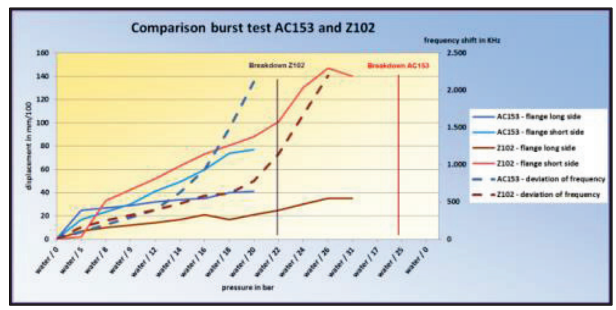

Figure 5: Mechanical and frequency measurement during burst test.

At the test of a fine grain cavity the bellow began deforming plastically at 17bar. At 31bar the pressure discharged to 17bar. The RF equipment and dial gauges were removed here as well for inspecting the inner side of the cavity. During the following pressurisation and looking inside the cavity, material of cell 3 was swelling into the cavity. At 25bar near the region of cell 3, water blast into the inner side of the cavity.

After cutting the tank a totally deformation of cell 3 is visible. The stiffening ring peels of and a crack at the iris was found (Fig.: 6 and 7).

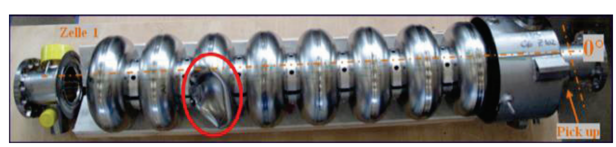

Figure 6: Fine grain cavity after pressure test with 31bar with dent in cell three.

Figure 7: Deformation and breakage at iris of cell three.

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In comparison with the LG material the fine grain cavity has only one big dent; all other cells were not affected. In both tests the bellow is always deformed extremely but did not break.

SUMMARY

The requirements of the European Pressure Equipment Directive (97/23/EC) are fulfilled for the XFEL cavities.

TUEV Nord and DESY made a detailed analysis of material in use, design reviews and PED related applicable tests for the production. Failed tests were repeated with optimized parameter. The procedures of non-destructive tests for series production are fixed. Finally the approval for series production was given by the TUEV Nord.

The contracted companies manufacture the XFEL cavity according to PED and a certificate of a final assessment report for pressure equipment is handed out.

Also the performed burst test showed that LG niobium is applicable for a XFEL cavity.

REFERENCES

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