QUALITY CONTROL OF THE VESSEL AND COLD MASS PRODUCTION FOR THE 1.3 GHZ XFEL CRYOMODULES

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Abstract

The industrial production of one hundred and three cold masses and vacuum vessels for the 1.3 GHz XFEL cryomodules is now fully in operation. Quality checks at the companies and controls at DESY assure the quality level required for the cryomodule assembly. Verifications of the main production steps, non-destructive tests and dimensional controls are performed by DESY personnel before accepting the components. This paper resumes the quality control strategy and the results for the first components produced by the companies.

INTRODUCTION

Two of the main components, the vacuum vessel and the cold mass, of the one hundred and three cryomodules that will form the XFEL linear accelerator [1] are now under series-production at two different facilities: E. Zanon Company in Schio, Italy and IHEP-Beijing subcontracted to CX company in Wuxi, China.

The quality of these components is a key factor for the quality of the whole accelerator and is an integral part of the PED qualification process of the whole machine as a pressurised component. A well-defined procedure need to be followed, before, during and after the production to guarantee the adherence to the PED specifications and ensure the final approval from the PED certification authority (TÜV Nord for the XFEL linac).

This procedure, for example, requires the approval of the material list and the welding book before the beginning of the production; allows the use of a restricted list of materials, tested and approved for cold operation, lists the Non-Destructive-Test (NDT) to be performed during the production and defines which norms need to be followed to perform the main activities, like welding and performing the NDT.

These steps are all necessary for the operation of the components, since they are considered as pressurised elements. But the functionality of a final assembled cryomodule includes aspects that are not guaranteed by the PED certification and need therefore to be verified separately [2].

First, a cryomodule provides the mechanical support for the accelerating components (cavities). Through a low friction pad system the cavities hang from the vacuum vessel via the support posts, a shrink-fit assembly of a thin G10 pipe and a series of metallic disk-ring couples. Three of these components need to support the total weight of the cold mass with cavity string (a few tons) and are therefore tested individually.

Furthermore, the cryomodule is essential for the cavity string alignment. The cavity support system has to guarantee an alignment of the cavity string with a precision better than 0.5 mm. Therefore, dimensional controls with laser tracker of the pre-assembled cold masses and vacuum vessels are performed during and after the production.

Finally, a leak test is performed on all the components that foresee vacuum or helium operation.

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QUALITY CONTROL BEFORE THE BEGINNING OF THE PRODUCTION

The following documentation has been reviewed and approved by the DESY personnel before the beginning of the production:

- Material list and material certificates. All the materials used for the cold mass have to be approved for use at cold temperatures up to 77 K, while the ones used for the vacuum vessel need to be approved for temperatures up to 223 K. The stainless steel used for cold operation (up to 2 K) has to pass a V-Charpy impact test at 77 K at energy > 27 J.
- Manufacturing drawings. All the drawings issued by the companies for the fabrication of the parts have to be reviewed and approved.
- Complete welding book: welding maps/plan, WPS (Welding Procedure Specifications), WPAR (Welding Procedure Approval Certificates), welding material certificates, certification of welders.
- Test procedures: all the NDT (performed by certified personnel) leak test, pressure test, penetrant liquids test, radiography test and other special test: traction test.
- Other special procedures and materials (i.e. painting of the vacuum vessel, MLI installation …).

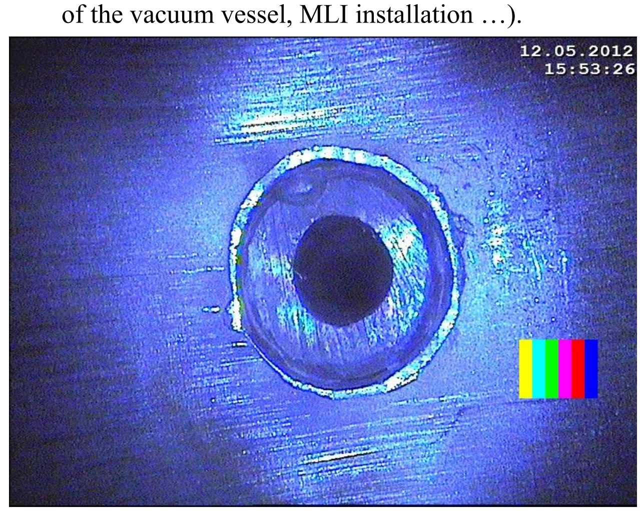

Figure 1: View with the endoscope of the capillary weld inside the warm up pipe.

VERIFICATION OF WELDS

After approval of the welding book, the welds undergo a series of tests before the component can be accepted for the final assembly:

Radiography Examination

The welds on the pipes and on the vacuum vessel are radiography tested for about 10% of their extension.

Penetrant Liquid Examination

The welds that are not radiography tested undergo a liquid penetrant test for 100% of their extension.

Visual Examination

Critical welds are also randomly checked with the use of an endoscope (Figure 1) or doing some destructive tests to verify, for example, the fusion level inside the material (Figure 2).

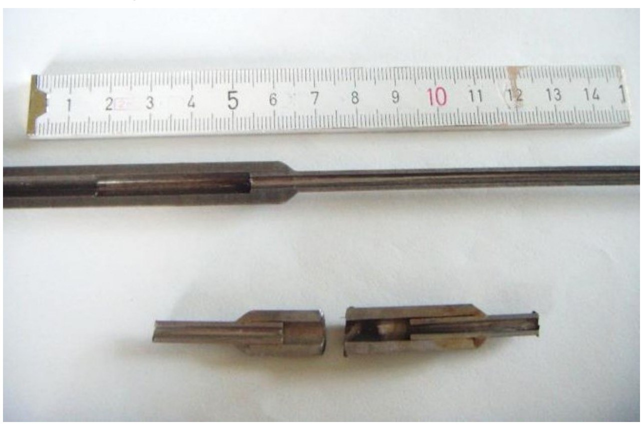

Figure 2: Section of a capillary weld.

PRESSURE TEST

The following table summarizes the test parameters of each pipe than need to be pressure tested (Figure 3) during the production.

Table 1: Summary of Pressure Test Parameters.

Pipe name (material)	Diameter (mm)	Max pressure (abs bar)
Gas Return Pipe (SS)	312	5.8
2.2 K Forward (SS)	48.3	29.0
Warm Up (SS)	42.4	29.0
5 K Forward (SS)	60.3	29.0
8 K Return (Al)	75	29.0
70 K Forward (SS)	76.1	29.0
80 K Return (Al)	75	29.0
Vacuum Vessel	965.2	P<0.5 bar no test needed

Figure 3: Pressure test of a process pipe.

TRACTION TEST

Each support post, the component that sustains the cold mass inside the vacuum vessel, undergoes a traction test (Figure 4) before being installed inside a cold mass.

Each post is loaded with a maximum of 5 tons and the total height is measured before and after each test; the permitted difference between the measurements before and after the test is ± 0.2 mm. If the post doesn't pass the test, it cannot be used for the installation.

Up to now (September 2013) about 150 posts have been assembled and tested and none has been rejected.

Figure 4: Traction test of a support post.

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DIMENSIONAL CONTROL

Dimensional controls of the single parts and of the final sub-assemblies are performed with a laser tracker at the production sites at the end of the machining operations. A verification test is also performed after receiving the final products at DESY or CEA-Saclay.

This activity is a fundamental part of the component acceptance tests. Some cold masses of both companies needed to be reworked at the company site after the dimensional control in DESY showed some non-conformities (not flat cavity supports, .banana shape of the 12 m long GRP…). More details about this activity can be found in the dedicated paper [3], also presented in this conference.

HELIUM LEAK TEST

A helium leak test is performed on all the process pipes, the Gas Return Pipe and the Vacuum Vessel.

The helium leak test is performed following the procedure defined by the EU norm EN 1779, EN 1330-8.

Special caps are installed at the end of the GRP and VV to perform this test. Depending on the solution adopted by the company, either vacuum is pumped inside the pipe and helium spayed on the outside of the welds, or the pipe is installed inside a vacuum chamber and helium is sprayed inside the pipe itself, while monitoring the helium level in the gas pumped from the chamber.

An integral helium leak test should be performed on all the process lines at ~295 K with pressure in the test vessel $< 10^{-5}$ mbar and a maximum measured leak rate $< 10^{-9}$ mbar*l/s. For the vacuum vessel the pressure in the test vessel should be $< 10^{-4}$ mbar and the maximum leak measured $< 10^{-9}$ mbar*l/s.

Up to now (September 2013) about 20 sets of pipes have been tested in each production facility and the average leak rate was below 10^{-9} mbar*l/s. All these components have been therefore accepted for installation.

INCOMING CONTROL AT DESY

The Vacuum Vessel and Cold Mass pre-assemblies undergo some additional tests once the parts are delivered to DESY. After a visual incoming check, to verify that no damages occurred during transportation, the following controls are performed:

- Verification of the longitudinal and vertical position of the main process pipes (figure 5).
- Visual inspection of the GRP and VV bellows.
- Visual test of critical welding seams (end-ring, bellows and brackets on the GRP, 8 K and 80 K transitions on the Al pipes, capillary connection on the warm up pipe).
- Verification of critical subcomponents with gauges (thermal shields, needle support assemblies…).
- Control of the position and orientation of the vacuum vessel hanging supports, critical for the tunnel installation.
- Leak test of CX pipes after welding the pipe extensions. The pipe ends are cut before shipment to DESY to fit the cold mass in a standard container and significantly simplify the shipping procedure.
- CM and VV dimensional control with laser tracker.

These controls highlighted a few critical points in the production and handling of the first components (especially at the CX Company, which had limited experience in the production of cold masses and vacuum vessels, since they produced only one prototype module) that have now been addressed, thanks to the effective and intense collaboration with the colleagues at IHEP, CX and Zanon. The incoming control reports of the last modules arrived in DESY show a very high quality standard for both companies.

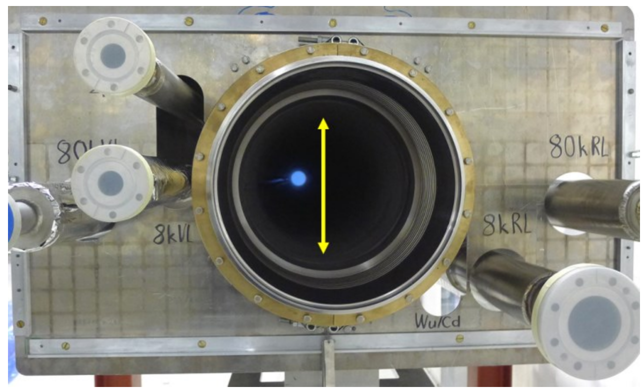

Figure 5: Verification of pipe position.

CONCLUSIONS

About 40 cold masses and vacuum vessels have been so far produced at the two facilities in China and Italy. A set of tests and verifications have been performed on these components and, after an initial period of adjustment, the components show now a very high quality.

Some of the tests here presented are not only needed to guarantee the overall quality of the products, but also an integral part of the PED certification needed to operate the XFEL accelerator.

ACKNOWLEDGMENT

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