CLEAN ROOM INTEGRATION OF THE EUROPEAN XFEL CAVITY STRINGS

S. Berry, C. Cloué, C. Madec, O. Napoly, T. Trublet, B.Visentin, CEA, Saclay, France
F. Chastel, A. Clippet, M. Mbeleg, P. Pluvy, ALSYOM, Tarbes, France

Abstract

The 101 cryomodules of the XFEL cold linac will be integrated at Saclay under the CEA responsability by the industrial operator ALSYOM, at the production rate of cryomodule per week. Each cryomodule includes a string of 8 Niobium superconducting cavities and a BPM-quadrupole unit (downstream end). To avoid particle contamination of the RF cavities, the strings are assembled in an ISO4 cleanroom by following strict cleaning and high-vacuum procedures. The major technical challenge of the string integration thus lies in the capacity to realize 25 connections in two weeks while protecting the cavity and coupler RF surfaces and to check their leak-tightness up to 10^{-10} hPa.l/s. The partial demonstration was made by the CEA team with the first pre-series module XM-3 which achieves a total accelerating voltage of 232 MV preserving the individual performances of cavities. In this paper the status and challenges of the production line is presented, including the quality management, equipment and operator training aspects. The optimisation process toward a faster assembly while preserving or actually decreasing the cavity exposure to contamination sources is also described.

ISO4 CLEAN ROOM AND TOOLS

Infrastructures Specificities

The 112 m^2 ISO4 room is part of 200 m^2 cleanrooms set. The qualification of all rooms is performed regularly according to 14644-3. The “ISO4 room” has been measured ISO1 down to 0.1 µm particles sizes in January 2013 [1]. The contamination checks down particles size of 0.3 µm shows frequently that the ISO5 and ISO4 rooms are both of the ISO4 class.

Two railing systems located under the technical floor are used every other week. A sliding target over 46 m at the working height (beam tube) stayed within a precision of ±1.5 mm (measured with Optical level Wild NA3and theodolite Zeiss Elta S10).

An industrial washer (Belimed PH860.2L) allows critical components to enter directly into ISO4 handled on washing racks designed for precision cleaning of the parts and tools.

Back filling sliding doors from inside clean room have been created in front of the rails for a possible direct entry into ISO4 of the bottom plates of the cavity posts.

Alignment System

The alignment tools used for prototype and pre-series modules was based on FERMI Lab concept. The procedure have been simplified since module XM1, reducing the time duration of this stage.

One question addressed at the beginning of the pre-series concern the flow of the cavity posts: they can either go back and forth on the rail or been dismounted outside/washed through the washer/remounted inside ISO4? The time’s compromise is between alignment of the cavities and posts cleaning. The choice was to back and forth. The time consuming with cleaning will soon decrease thanks to tissues wrapped over the posts before going out the ISO5 room. Nevertheless the risk of production cessation in ISO4 still remains in case a problem occurs on downward flow, except if we use the back filling sliding doors.

XFEL Vacuum Specifications

In order to avoid particles displacement during venting and pumping, the rate of these stages has to be monitored at 3 l/min of filtered and dry nitrogen [2]. The tight specifications on residual gas analysis (RGA: total pressure below 10^{-7} mbar the sum of the partial pressures of masses above mass 45 is less than 10^{-3} of the total pressure) or leak test (The integral leak rate has to be $\leq 1 \cdot 10^{-10}$ mbar l sec^{-1}) are qualified by a mass spectrometer [3].

DESY Vacuum Pumping Units

The prototype modules assemblies have been possible thanks to early delivery form MVS (DESY). The DESY expert’s support is much appreciated. The architecture of this system needs the network availability and a well-trained vacuum expert. The time slot for RGA analysis is narrow due to efficient pumping of the water masses out of the recipient for long time. These pumping units are around the cleanroom with pipes going through the wall. Thus they are used for the so called “cold coupler” workstation (hereafter CC) and for the string assembly final qualification.

Nitrogen Flushing Lines

DESY pumping unit have been completed to flush nitrogen through the part during the assembly at a rate of 10 L/min. Manual ultra-high purity gas valves (Aptech spring less series AZ3652) and ceramic filters with removal rating > 99.9999999 % at 0.003 µm (SCF3-VR4-P30), have been selected during the setting up of CEA pumping units. These components went through qualification according to particles counting and leak tightness with the goal to implement a quicker assembly scheme (see below solution 3).

CEA Vacuum Pumping System

The CEA pumping systems are distributed with turbo molecular pump closest to the cavity and the scroll pump and leak detector in the cellar. As the cleanroom is a closed environment we highly recommend using aluminum gaskets only, for pipes under the technical floor. The system is able to leak check, vent slowly and flush nitrogen through the assembled parts. Simplified screens have been developed for non-vacuum experts. These pumping units are in the cleanroom with flexible pipes. Thus they are used for the so called "string assembly" workstation (hereafter SA) in order to vent cavities or QP package.

Vacuum Pumping Lines Qualification

After any change in the piping configuration and after cleanroom maintenance, the vacuum pumping lines including nitrogen flushing are qualified by a leak check and a RGA [2], particles counting [4]

Helium Detection Shells

During the leak check, the outer surface of the cavity string to be tested has to be located in some kind of a tent in which the helium concentration will be raised to 100% helium. Now we operate with taped plastic foil around new connections (bellows and coupler). We plan to use solid plastic shells now under design.

PARTS AND ASSEMBLY PROCEDURES

Challenges

The main constituents of the XFEL accelerator module are eight superconducting cavities supplied by one RF power coupler each, a superconducting quadrupole package which includes correction coils (steerer) and a beam position monitor (BPM), cold vacuum components like bellows and valves. The Institute's contributions and work packages procurement responsibilities are describe elsewhere [5, 6]. The challenge is to assemble 103 accelerator cryomodules by an industrial contractor ALSYOM under CEA supervision. The foreseen goal is a nominal rate of 1 cryomodule per week and a production cycle is 7 weeks.

As Received Parts

Fully equipped cavity in helium tanks are sent to CEA (Saclay) under vacuum after cold RF test in vertical cryostat by four. Their two high order mode couplers and their electron pick-up are assembled.
The coupler cold parts are sent under vacuum by pair on their test wave guide after the high power RF test.
The ending gate valve and copper coated bellows are sent cleaned and double bagged under ISO5 environment.

Gaskets and Fastening

For the clean activities, CEA is in charge of the procurement of beam vacuum fastening and gaskets for cavity to coupler or cavity to bellow connection. Hardness of the procured material has been check for the first series of procurement. The initial strategy to order already cleaned studs and screws was not possible at the DESY specification level [7] due to container contamination during transport.

Now material certificates (type 3.1) are delivered and controlled. The cleaning recipe and tools to control of the parts have been developed in house.

Work Flow

The actual work flow starts at the warehouse with reception of components. The first week of assembly continue with the cold coupler parts to the 8 cavities on the so called "cold coupler" workstation. The cavities with cold part of the coupler are then parked under vacuum in the clean room. The next week the cavities with coupler and quadrupole package are assembled in a string on so called "string assembly" workstation.
Each assembly stages produce "Assembly report" and before almost non reversible decision to continue the regular process have to pass through a hold point carried out by CEA quality representative and technical experts with Alsyom quality representative.

ANOMALY DETECTION AND NON-CONFORMITY MANAGEMENT

In addition to tools developed with IT DESY groups to manage the configuration and store assembly history on the EDMS data management system (see [8,9]), CEA and its industrial partner established a scheme and developed a tool for the operator to detect anomalies and if needed declare it as a non-conformity. Some statistics are now available on these anomalies and NCR's.

RESULTS

Prototype Cryomodules

The goal of the prototyping phase was to validate the factory and CEA trained experts [8].

Training of the ALSYOM People

The pre-series module XM-3, XM-2 and XM1 have been used to transfer continuously the knowhow to Alsyom.

On XM-3 CEA operators showed to Alsyom the tasks.
The cavities are not from XFEL production but large grains one. The average individual cavity gradient is 32 MV/m .Three cavities reach gradients above 38 MV/m Only cavity 1 is degraded from 31 down to 23 MV/m useable gradient. The module develops 232MV with lower cryogenics loss than specified.

SPEED-UP THE PRODUCTION

Continuous improvements are done to reduce the assembly time as shown on figure 1, on last string assembly the time was 15 days instead of 10 days foreseen.

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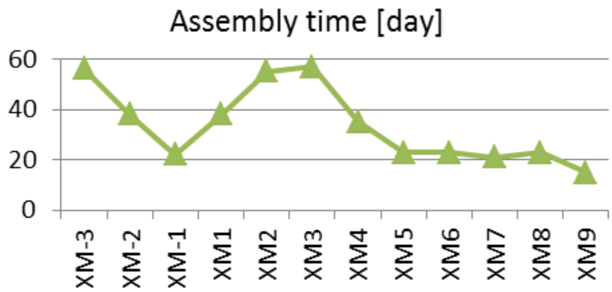

Figure 1: Number of days between starting to end a cavity string. The foreseen initial goal is 10 days. On last string assembly the time was 15 days.

The long time spent qualifying pumping lines was a chance to quantify that opening of a valve DN40CF is creating particles. Then we thought about several solutions to decrease the number of venting of the cavity to avoid degradation of the cavity string performance. Several schemes have been described, the proof of feasibility with preliminary tests have been performed for solution 3. Solutions brief description:

1 cavity+coupler in CC then two half strings in SA
2 cavity+ coupler in CC then string in SA
3 as n°2 but venting the cavity+coupler in CC
4a bellows, coupler and gate valve assembled in SA
4b gate valve in CC then bellows, coupler assembled in SA
5 venting in CC then bellows, coupler and gate valve assembled in SA

The solution 1 was contracted with Alsyom and is able to be parallelized with manpower. The solution 2 is the actual one. Some vacuum tests have been performed in order to check if the solution 3 is consistent with production time. The solution 3 consists in exchanging filter and valve closing nitrogen on the flushing line. Solution 4a is concentrated on high valued tasks for the requested goal. Solution 4b restores partially the advantage to have work distributed on two workstations. Solution 5 is a compromise to take advantage of distributed on two workstations using solution 3 technical proposal without adding to many tasks compare to the 4a optimum.

Table 1 shows the number of risky tasks for each solution. There is room for reducing the time keeping the quality of the cavities if we consider that the high valued tasks (not shown in table 1) are only the eight connections coupler to cavity and the 17 beam tube connections.

The estimated vacuum process time can be reduced from 178h with actual solution to 25h with solution 4a.

Table 1: Solutions toward a Faster Assembly with Evidence of Margins for Improvement

SOLUTION	1	2	3	4a	4b	5
venting per cavity	2	2	1	1	1	1
cavity handling	24	24	24	8	9	16
valve to pipe connection	22	22	14	14	14	14
DN40CF opening	22	21	13	13	13	13
nitrogen flushing after an opening	18	17	9	9	9	9
leak checks	41	40	32	23	24	23
residual gas analysis RGA	9	9	9	1	1	1

CONCLUSION

Four cryomodules have been tested successfully by DESY [10]. Cavity performances are conforming to the XFEL specifications and have very few cases of field emission.

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