IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: V Anashin *et al* 2015 *IOP Conf. Ser.: Mater. Sci. Eng.* **101** 012139

IOP Conf. Series: Materials Science and Engineering **101** (2015) 012139 doi:10.1088/1757-899X/101/1/012139

Experience with cryogenic operation of Accelerator Module Test Facility during testing of one third of XFEL cryomodules

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In order to produce pulsed electron beam with the energy of 17.5 GeV, the XFEL linear accelerator is under construction. After the assembly but before being installed in the accelerator tunnel, 100 accelerator modules have to be tested in Accelerator Module Test Facility (AMTF). Two vertical cryostats and three horizontal test benches are devoted to the testing of cavities and cryomodules as well as two other cold boxes and liquid helium (LHe) storage tank are installed to enable their operation. This paper describes our experience with cryogenic operation of AMTF after two years of operation.

1. Introduction

The European X-ray Free Electron Laser (XFEL), which will serve as research facility for multiple users, is currently under construction at DESY, Hamburg. The accelerator will consist of 100 cryomodules with 8 cavities and one superconducting magnet package in each module. The cryomodule of about 12 m length has cold mass, 5-8K and 40-80K shields. The cavity and magnet package are mounted on the 300 mm tube, which serves as a backbone for the whole cold mass at 2K temperature level. More details on cryomodule development history and present cryomodule could be found in references [1-3].

In order to test XFEL cryomodules, Accelerator Module Test Facility was built, see Figure 1 for schematic overview and reference [4] for details of construction.

The present paper gives more performance details on the cryogenic infrastructure operation over the last two years. In the first part, a short overview of cryomodule and cavity testing rate is given. Comparison to design values of testing rates is also considered here. In the second part, experience based on two year's operation and lessons learned are mentioned.

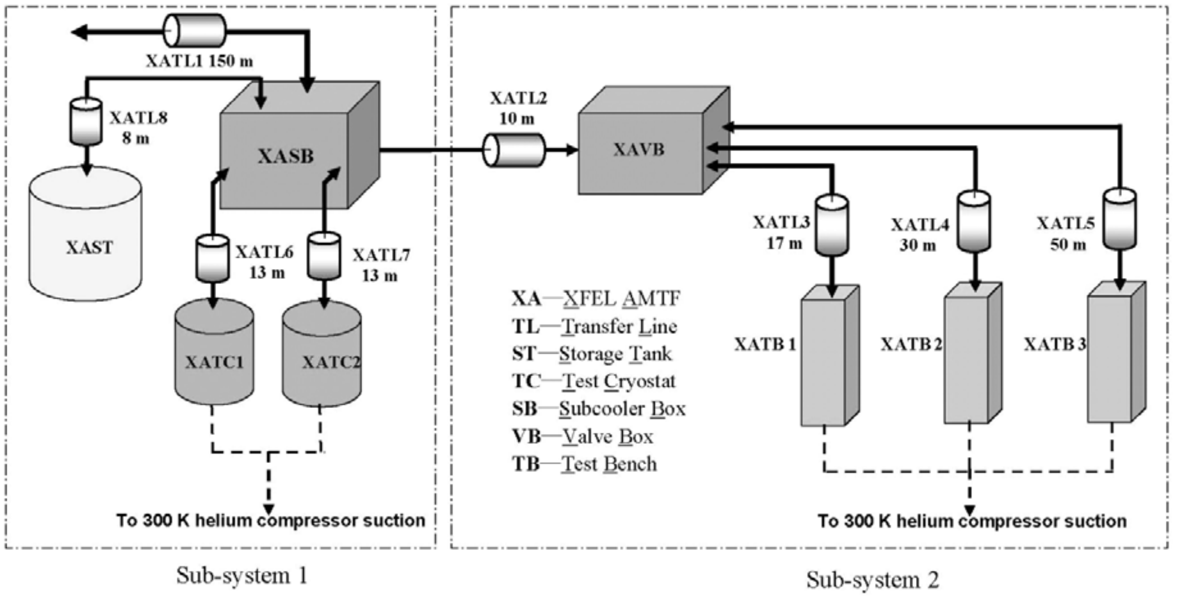

Figure 1. Schematic view of AMTF cryogenic infrastructure

2. Cavities and Cryomodule Testing Rate

Figure 2 shows the testing rate of cryomodule over past two years at three test benches (XATB). All tested cryomodules including prototype, pre-series and re-testing of XM3 are counted. Modules, which were cooled down but not tested for some reasons, e.g. due to cold leaks, are not included in the list.

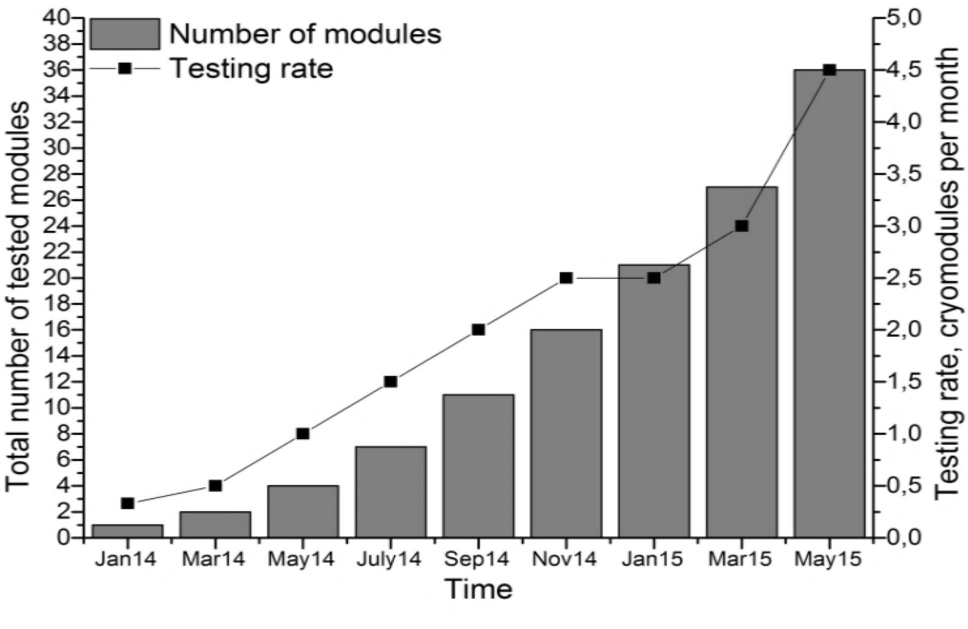

Figure 2. Total number of XFEL cryomodule tested at AMTF.

2014 year was considered as period needed for the ramping-up of cryomodule testing rate. A bit slower testing rate at this initial time period was caused by several issues, which are typical for such facilities:

- Commissioning of two XATB (XATB3 was commissioned in 2013, but XATBs 2 and 1 in 2014).
- Some extra time needed for the testing of first cryomodules delived from CEA/Saclay due to some minor changing in assembling procedures, and in components, e.g. couplers, cavities, etc.
- Optimisation of the testing procedures at AMTF, e.g. heat load measurements, or Low Level RF measurements, etc.
- Due to a bit slower cryomodule delivery time in the first half of 2014, i.e. around one cryomodule per two weeks, it was possible to spend a bit more time to other activities, which were mainly related to the more detailed testing of cryomodules and some additional testing of AMTF hardware and software.

In January-February 2015, the cryomodule testing rate was a bit below one per week (one cryomodule per week is the design value,) which was related to two reasons: i) XATB1 was occupied for some time by some activities devoted to the cavity testing for 3.9 GHz cryomodule, and ii) some unforeseen (in many cases unavoidable) technical challenges occurred, which were mainly caused by leaks from process pipes and beam line into insulation vacuum as well as from coupler vacuum to the ambient air.

Cryogenic testing of cavities at vertical cryostats XATC1 and 2 went smoothly without any challenges. If cryogenic activities at XATB are low, it was possible to use the free cooling capacities for XATC and testing rate could reach ca. 9, sometimes up to 10 cavities per week, which significantly larger than the design value of 6 cavities per week. After optimization of the testing procedures, it was decided to keep the testing rate of 8 cavities per week, and increase for the case if free cryogenic capacities as well as operating personal from Institute of Nuclear Physics of Polish Academy of Science (INP-PAS) team are available.

3. Discussion

Cryogenic operation of XATC1 and 2 is performed as expected and no deviation from standard procedures was observed. The typical whole testing cycle has the following steps: i) pump and purge, ii) cool-down to 100K, iii) LHe transfer to cryostat from storage vessel, iv) pump down to 2K, v) measurements at 2K, vi) pressure rise to 1 bar and LHe transfer from cryostat to the LHe storage tank, vii) warm-up to 300K. All steps, except pump down to 2K, are completely automated, so operators have only to supervise the system.

Two issues were particularly advantageous for the simplification of operation and reducing the time for cool-down/warm-up:

- No limitation on the temperature gradients inside the cryostat between different components as well as no limitation on the cool-down/warm-up rates (though some limitations due to cavities cool-down/warm-up are present, these limitations are not so stringent in comparison to ones of cryomodules at XATB). This significantly simplified automation of the cool-down/warm-up procedures, because it was possible to operate the valves for mixing of 4K and 300K GHe flows at convenient range, i.e. above 10% opening. For the time being, some additional tests related to automation of XATC and particular XATB are being performed.
- Usage of LHe storage vessel allowed transfer of large amount of LHe toward the cryostat and vice versa. This substantially shorted cool-down/warm-up time for 4-80K temperature range as well as liquefaction/evaporation time. It was also possible to directly transfer LHe from one cryostat to another in order to avoid usage of LHe storage vessel.

Performance of XATB1, 2 and 3 was also within our expectation. The whole testing cycle has the following steps: i) pump and purge, ii) cool-down to 70K, iii) cool-down to 4K and LHe liquefaction, iv) pump down to 2K, v) measurements at 2K, vi) pressure rise to 1 bar and LHe evaporation, vii) warm-up to 300K. At present time, the warm-up automatic procedure near for all temperature range is applied, while the cool-down one is still under development, and therefore, several steps are still performed manually either by INP-PAS cryooperator during normal working time or DESY ones over nights and week-ends.

At the time being, the cool-down and warm-up are performed in 2-2.5 days, typically over the week-ends, and are also within the design values. Cryomodule testing at low temperature occurs over 5 working days.

During the commissioning, some challenges were related to the minor design modification in comparison to CryoModule Test Bench (CMTB), i.e. only one connection from 2-phase tube to the 300mm one was done at AMTF (see Figure 3), while at CMTB connections at both ends are made. At one hand it allowed to speed up the cool-down/warm-up rate, because all GHe flows through the 300mm tube, while at CMTB, half of the GHe flow bypasses 300mm tube. On the other hand during normal operation the flash gas after expansion at JT-valve had to flow through all 2-phase tube, which led to limitation on the maximal achievable LHe level.

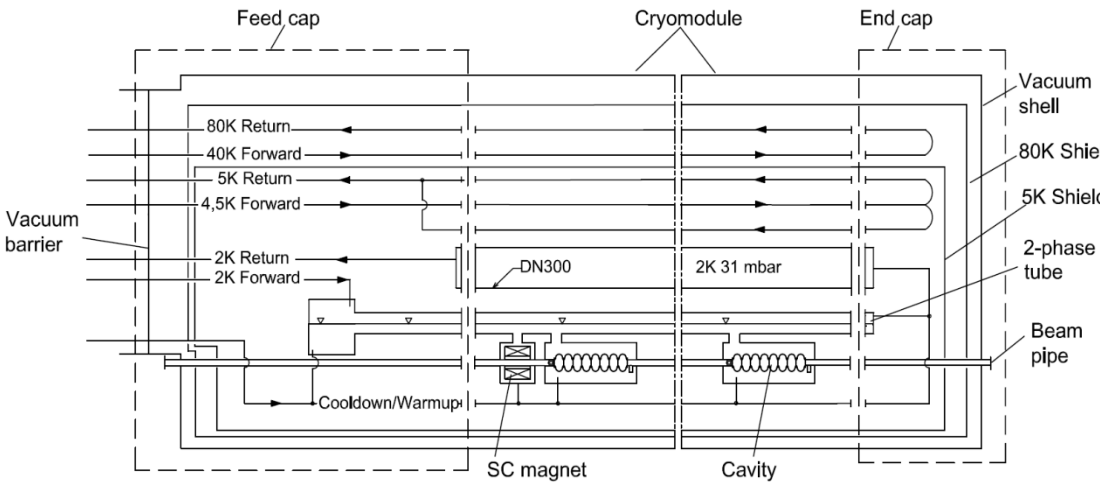

Figure 3. AMTF simplified scheme of Feed cap, End cap and Cryomodule.

Another challenge was in the abnormal operation of JT-valve at one of the test benches. Due to damage of seat and cone, large leakages are present, e.g. at 5% opening valve had maximum design value of the GHe flow, and during normal operation this valve had to be opened below 2-2.5%. Valve cone and spindle were changed several times but no improvement was observed. To change the seat it would be necessary to remove the valve, though this will be performed when time is available (these activities need 3-4 weeks). At the present time, the valve is kept fixed at some value of around 2%, and LHe is regulated by electrical heaters.

There were some other minor problems, which are typical for cryogenic commissioning and operation, e.g.:

- Helium vacuum compressors for 2K operation mode have relative limited time between maintenance, ca. 5000 h. During maintenances all bearings were replaced. However, no impact for AMTF operation was observed due to very reliable service & support from manufacturer.
- LHe level meter: i) measurements were somehow affected by operation of electrical heater, and ii) to have more stable signal, operation current was increased.
- Misalignment of process tube flanges: adaptors were designed.

- At the beginning of cool-down or warm-up, mixing of warm (300K) and cold (4K) helium flows needed careful operation over several hours.
- To improve pressure and LHe regulation, valve positioners were changed.

Lessons learned could be summarized as following:

- Mixing of serial testing with commissioning activities should be avoided if possible. Though it is well-known from experience from other cryogenic facilities, for large projects it is quite difficult to avoid due to possible (and in many cases unavoidable) time delays. For our case, e.g. we could change malfunctioning JT-valve.
- Though the cryogenic experience with similar facilities, e.g. vertical cryostat at Hall 3, as well as CMTB, is gained, cryogenic commissioning time and efforts were underestimated, particular for XATB.
- For the successful testing of cryomodules and cavities, it is important to have very good teamwork between DESY groups as well as with external group, which is responsible for the cavity and cryomodule testing. This experience is similar to the one gained at CERN [5-7].

4. Summary and Present Status

At the time being, all cryogenic facilities operate at the designed conditions.

Up to now, approximately half of XFEL cryomodules are successfully tested. The test of all XFEL cryomodules will be completed in about one year.

5. Acknowledgment

The authors are also thankful for all colleagues working in the MKS group for their contribution over the whole project. Particular thanks for the colleagues from the INP-PAS (Poland), for their continuous work on the preparation, conduction and presenting results on serial testing of XFEL modules, WUT (Poland), KrioSystem (Poland), BINP (Russia) and DeMaCo (Netherlands) for manufacturing of cryogenic components as well as Linde/Cofely for operation of XFEL refrigerator and AMTF infrastructure overnight and week-end shifts.

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