IMPROVEMENTS OF THE MECHANICAL, VACUUM AND CRYOGENIC PROCEDURES FOR EUROPEAN XFEL CRYOMODULE TESTING

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Abstract

The European X-ray Free Electron Laser is under construction at DESY, Hamburg. The linear accelerator part of the laser consists of 100 SRF cryomodules. Before installation in the tunnel the cryomodules undergo a series of performance tests at the AMTF Hall. Testing procedures have been implemented based on TTF (Tesla Test Facility) experience. However, the rate of testing and number of test benches is greater than in the TTF infrastructure. To maintain the goal testing rate of one module per week, improvement to the existing procedures were implemented at AMTF. Around 50 % of the testing time is taken by connection of the cryomodule to the test bench, performing all necessary checks and cool down. Most of the preparation procedures have been optimized to decrease mounting time. This paper describes improvements made to the mechanical connections, vacuum checks and cryogenics operation.

INTRODUCTION

During the planning phase of the XFEL [1] project it was presumed that one Cryomodule should leave AMTF (Accelerator Module Test Facility) Hall per week. The AMTF Hall consists of three separated Cryomodule test benches. This means that presumed time for single Cryomodule test was estimated for around 3 weeks. During this time following operation have to be performed on Cryomodule:

- Installation of the cryomodule on the test bench
- Connection of the Beam Line
- Connection of the cryogenic process pipes
- Integral leak check
- Leak check of the Cryomodule
- Interconnection isolation with MLI (Multi - Layer Isolation)
- Warm coupler conditioning
- Cool - down
- Measurements at 2K (this paper does not cover this part of the testing procedure, see [2])
- Warm - up
- Disconnection of the Cryomodule from the test bench

In the old testing procedure all mentioned steps were split in three weeks. During first week connection of the Cryomodule to test bench and cool - down process was done. Second week was foreseen for measurements at 2K. Third week was foreseen for warm - up and disconnection of the Cryomodule. However, the old procedure has one general problem. It did not cover the problem which could occur during the test procedure. Moreover, there were no time foreseen for any mistakes or Cryomodules reparation inside the test stand. This means that each problem during the test (like leaks on the Cryomodules) causes delay in the general schedule. There was a necessity to improve the procedure to get some extra time needed for some special testing cases, reparation, exchanging of the Cryomodule parts etc.

MECHANICAL PROCEDURES IMPROVEMENTS

Shifting of the Possible Mounting Operations from Test Bench to Preparation Time (eg. GRP Adapters)

After reception of the cryomodule special preparation time is scheduled within incoming inspection checks and preparation of the cryomodule to installation into test bench are performed [3]. After that, the cryomodule can be mounted into test bench and all connections can be performed. One of the task which realization has been shifted from inside to outside of the test bench is mounting of the GRP adapter. GRP complex reductor is used to connect a cryomodule to the test bench. During installation of the cryomodule into test bench all process pipes are connected.

Figure 1: GRP adapter.

One of them is 300 mm of diameter gas return pipe. The test bench gas return pipe has 150 mm of diameter. Therefore to connect a cryomodule to test bench a special reductor (See Fig.1) as well as special indium seal have been designed. The installation of the GRP adapter to the cryomodule has to be performed very attentively according to the special

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procedure, otherwise it could fail and reinstall of the GRP adapter will be necessary. Due to construction of the cryomodule as well as test bench the reduction from 300 mm to 150 mm is realized by the eccentricity. Mounting time for such adapter is around 2h but waiting time until indium seal is ready for further action after it had been used is around 12h. During this period of time tightening of the indium seal connection has to be performed at least two times. Special procedure which was developed during testing of cryomodules at AMTF hall gives possibilities to mount of the GRP adapter outside of the test bench with success (See Fig 2).

Figure 2: GRP adapter already installed on the cryomodule.

Applying of Thicker Indium Seal

Due to several cold leaks appeared during cool down of the cryomodules or during the measurement at 2K conditions, it was very important to find what the reason of such leaks. One of the suspicions was directed toward the indium seal. At the beginning the seal had 2 mm of diameter which in perfect case should be enough. Taking into account inaccuracies of the manufactured pipes as well as number of different aspects it was decided to use thicker indium seal (see Fig. 3)

Currently 3.5 mm of diameter indium seal is used and cold leaks stopped to occur. Gained experience also shows that better is to perform the tightening of the connection three times instead of two in order to avoid the effect of plastic flow of the seal.

Optimization Procedure of Mounting GRP Adapters

Installation of the GRP adapters outside of the test stand and use thicker indium seal required modification of mounting procedures. It was also necessary to produce more adapters due to two facts. First as a result of larger number of GRP adapters installed onto cryomodules in the same time. Second, need of more adapters with different diameters due to irregular shape of 300 mm of diameter gas return pipe. The tightening up to nominal value of the connection between adapters and cryomodules has been increased from

Figure 3: 3.5 mm diameter indium seal.

two times to three times due to fact used thicker indium seal. All of these improvements save time and what is more important gives a big chance to avoid unforeseen leaks during further part of the cryomodule test.

Dismounting of Waveguides during Final Stage of Warm up Process

One of the steps during deinstallation of the cryomodule from the test bench after the test is dismounting of the waveguides. Developing of the test procedures and several safety aspects gave a chance to find a possibility to dismount the waveguides during final stage of warm up process. Therefore dismounting time of the cryomodule from the test bench became shorter of around 5h what also has influence on the testing rate.

VACUUM PROCEDURES IMPROVEMENTS

Additional Pump Stations

The most time consuming vacuum process is pumping down of the cryomodule insulation vacuum (ISO-VAC). Due to the fact that this process is realized twice it is very important to reduce the time need for it as much as possible. At the beginning of cryomodule tests performed at the AMTF hall ISO-VAC was pumped down by 2 pumping sets consists of rotation pump (D65) and turbo pump (HERA type) connected to cryomodule at Feed-cap and End-Cap side. Two and a half days was needed in order to reach pressure about 1e-3 mbar by those pump stations. Adding one additional pump station to each test stand (eg. Pfeiffer HRH 700) allowed reducing pumping time of about 12 hours.

Optimization of Leak Check Procedures

Pumping down of ISO-VAC with additional pump station is still very long process. To reduce results of potential mounting mistakes and occurrence of the leaks the preliminary integral leak check as well as leak check of the cry-

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omodule was introduced. In this case the vacuum conditions for the check did not meet the acceptance criteria but allows eliminate failures on the earlier stage of pumping down. The reaped benefit on time scale is significant. Moreover after preliminary leak check finished with success the leak has never been found during final leak test performing according to acceptance criteria. Based on this experience after consultations with DESY vacuum experts it was decided to allow performing final leak check of the cryomodule and final integral leak check under one decade higher pressure (1e-2 mbar) than before (1e-3 mbar). According to new acceptance criteria it was possible to start final leak check procedure in time bellow 1 day of pumping instead of 2.

Dismounting VMS before Installation of the Module into Test – Stand

Before connection of the cryomodule beamline to test stand it is necessary to dismount Vacuum Monitoring System (VMS) and angle valve (AV).Both components are installed in Saclay and required to monitor beamline vacuum during shipment time from Saclay to DESY in Hamburg. This operation has to be performed in clean room conditions (see Fig. 4). In addition both mentioned volumes have to be vented before dismounting by particle free gas. Because of this the whole procedure takes at least 8 hours. To reduce a time when the cryomodule occupies the test stand the VMS and the AV are dismounting outside of the test bench. Therefore dismounting procedures have been adapted to new conditions as well as new clean room and vacuum pump station have been introduced. This solution has helped to reduce a time spent by the cryomodule inside the test bench.

Figure 4: Dismounting of VMS outside of the test bench.

Combine of the Leak Check of 2K Circuit with the Integral Leak Check of Process Pipes

From the set of all interconnections needed to connect cryomodule to the test stand the most sensitive connection is between GRP adapter and 300 mm of diameter gas return pipe, this is due to use nonstandard seal (Indium seal). To reduce the risk of leak at this place it was decided to perform additional leak check of 2K circuit. This procedure was applied for first set of modules tested at AMTF. In order to perform leak check it is needed to connect additional pump station and pump down the 2K circuit. This method is very time-consuming and in addition it is not as sensitive method as integral leak check. Moreover the leak check of the 2K circuit is a part of Integral leak check. After analysis it became clear that time of fixation of potential leak discovered during integral leak check is shorter than complete previous method of 2K circuit leak check. In consequence combine of the leak check of 2K circuit with the integral leak check of process pipes allowed to safe at least 16 hours.

Integral Leak Check on All of the Circuits in Parallel

The procedure of integral leak check has been also modified. In previous version each circuit was checked separately. At present, all circuits are checked in the same time and with dedicated pressure for each of them according to theirs operating conditions. It allowed reducing time of this activity by factor 2.

CRYOGENIC PROCEDURES IMPROVEMENTS

Venting Insulation Vacuum during Final Stage of Warm – Up Process

During warm-up process temperature of the gas flowing through the cryogenic pipes is gradually increased. The gas is heating internal elements of the module. However, not all module's elements have equal thermal contact with cryogenic pipes. Some parts are thermally connected in such way that heat conductivity does not permit temperature of some spots to follow the temperatures of the rest of elements; this problem can be seen on Figure 5.

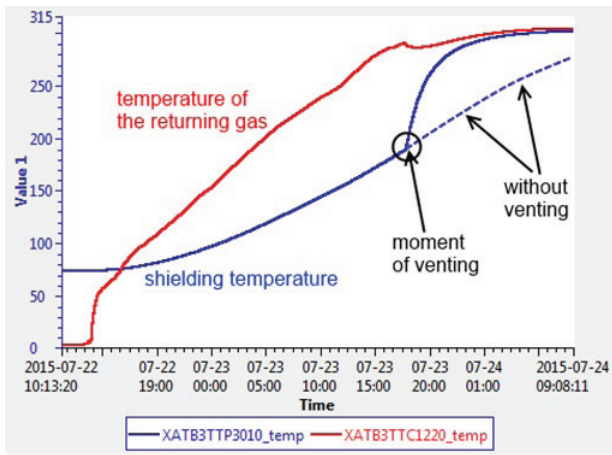

Figure 5: Impact of the insulation vacuum venting to warm - up procedure.

Even when the temperature of the returning gas reaches desired threshold of 280K some elements can be at much lower temperatures. In this case venting insulation vacuum improves heat transfer and speeds up arriving at required temperature. The earliest venting moment has been set to the time when gas in the return line of 2K circuit reaches 260K. Early venting of the ISOVAC can save several hours of warm-up time.

Reduction of Waiting Time for Start of Cool down Process by Using Additional Leak Detectors

In order to start cool-down process it is required to monitor the leak rate in the insulation vacuum volumes inside the module. HERA leak detectors require inlet pressure lower than 1e-4 mbar to operate. With current capacity of pumps dedicated for the module test stands obtaining such a vacuum could take more than 1 day and significantly postpone the cool-down start. To address this problem, another leak detector was introduced to operate while the vacuum is not yet good enough for the HERA detectors. Thanks to that the cool-down can be started much earlier (often after 12h) while pumping down continues. Once the pressure drops below 1e-4 mbar the HERA detectors can take over the measurement.

Optimization of 5/8K and 40/80K Shielding Heat Loads Measurements

After testing of 40 cryo-modules, a new way of cryo loses test was introduced. Old procedure consisted of several independent, long duration tests for determining static heat load values, dynamic heat load from RF power and dynamic heat load from magnets. Each of the tests was taking approximately 12h. It was observed that thermal stabilization after applying RF power is reached relatively fast and it does not require 12 hours of operation. Moreover, heat load contribution from magnets was below the measured signal noise. In the new way of measurement 12h dynamic tests are skipped. Static measurements are taken from night periods and only one static heat load value for 40/80K line is measured. Dynamic RF heat load measurements of the shieldings are merged with slightly extended 2K line measurement. On this improvement 36 hour of test was saved.

Using of Automatic Software for Cool down and Warm – Up Processes

The time of warm up process in manual way may vary from 42 to more than 50 hours depending on cryo operator experience and actual cryo plant efficiency. Thanks to automation of process, cryo operation time become independent on operator experience and vary from 40 to 45 hours. In similar way automation of cool down can save up to 12 hours.

CONCLUSION

The testing rate of the cryomodules during last half a year increased significantly (see Fig 6). The time needed for test of one cryomodule was reduced not only to 21 days but even to 14 days. This gives an opportunities to have some time buffer in case of unexpected problems.

This is an effect of constant work on procedures as well as gained experience during performing test of the cryomodules.

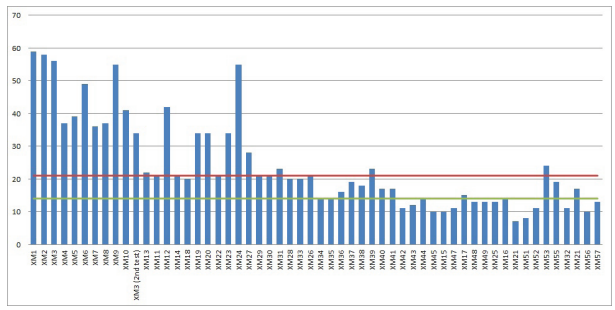

Figure 6: Number of days inside the test bench for each tested cryomodule. Red line is 21 days. Green line is 14 days.

ACKNOWLEDGMENT

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