XFEL: PLANS FOR 101 CRYOMODULES

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Abstract

The XFEL project [1,2] will use 101 accelerator modules in its superconducting electron linac. A review of the design is being given as well as the most recent test results at the module test stand and at the FLASH [3] accelerator. The fabrication and preparation of the superconducting cavities will be done in industry. The current plans for the acceptance testing of the cavities and the final test of the completed modules will be discussed.

INTRODUCTION

The XFEL main accelerator consists of 101 accelerator modules with 8 superconducting accelerating structures (also called cavities) and a superconducting magnet package for focussing and steering. The design is based on the development of accelerator modules for the TESLA linear collider design [4]. A similar layout is also being pursued for the International linear Collider (ILC) [5].

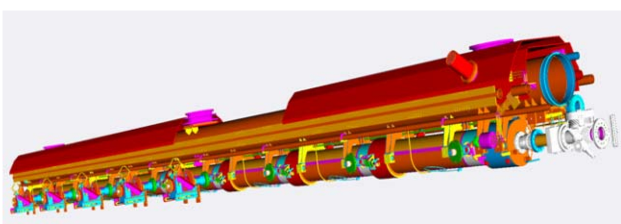

Figure 1: Layout of the superconducting accelerator modules for the XFEL.

MODULE LAYOUT

The design is shown in figures 1 and 2. The overall design was driven by the idea to have a long string of modules connected while building a very compact helium distribution system. By minimising the number of cold-warm transitions and the integration of the helium gas return pipe into the accelerator module itself, significant cost savings could be realised.

The module design itself has undergone several iterations, which have been tested at the TESLA Test Facility and the FLASH accelerator at DESY. The most important design improvements introduced where the usage of a standard pipe diameter and an improved longitudinal positioning system for the cavities and the magnet package. The latter consists of an invar rod to which the cavities and the magnet are attached to. The cavities and the magnet are suspended on low friction sliding supports from the gas return pipe, thus allowing shrinkage of this tube whilst keeping the longitudinal position [6].

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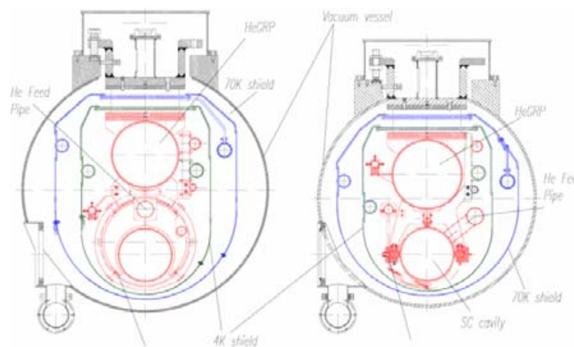

Figure 2: Cross-section of the superconducting accelerator modules at FLASH (Old design – left, new design – right). The cavities and the magnet package are suspended from the large 2 K helium gas return line.

Figure 3: Picture of the cryomodule test bench (CMTB) at DESY.

TEST RESULTS ON ACCELRATOR MODULES

To date 10 accelerator modules have been built. These include prototypes and a special module for a different kind of accelerating structure called superstructure.

Several tests have been performed, both in the FLASH linac and on the cryomodule test bench (CMTB). The latter is a separated test stand where accelerator modules can be tested at full power but without beam (Figure 3).

The CMTB is an essential tool as it allows linac independent tests e.g. repeated thermal cycling which is more difficult in the FLASH linac as it is partially dedicated to user operation.

Overall Module performance

On a recent test an accelerator module was thermally cycled 11 times. During these tests it could be verified that the alignment of the cavities and the magnet package is behaving reproducibly between warm and cold position. In addition, no leaks have occurred which indicates that the current design of flanges and seals can be used for the XFEL as well.

In addition the static and dynamic losses where measured and are acceptable within XFEL performance.

RF Performance

A significant time of testing was used to study the RF performance of the accelerator modules. The accelerating gradient specified for the XFEL is 23.8 MV/m for the superconducting cavities. Several accelerator modules have achieved this performance (Figure 4)[7].

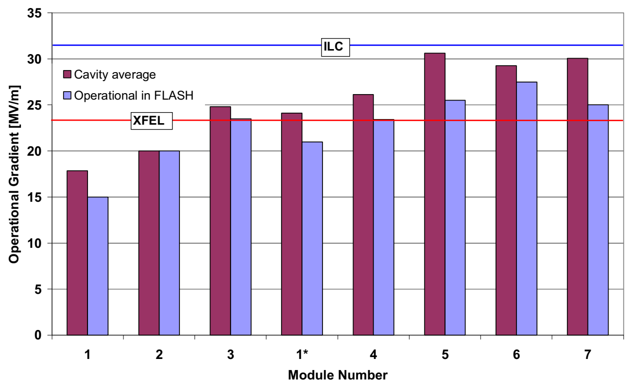

Figure 4: Accelerating gradients of cryomodules built at DESY. The figure shows the operational gradient which is accessible with equal RF power distributed to all cavities and the average gradient of the cavities which can be used with more sophisticated RF distributions.

In Figure 4 two data points are shown for each module: The operational gradient assumes a simple power distribution where each cavity is supplied with the same RF power. This is the baseline power distribution scheme for the XFEL and the ILC. Both projects are developing more advanced distribution schemes where each cavity can be supplied with an individual power level suited best for its performance. Thus the average gradient (second data set in figure 4) of the cavities would become the operating gradient. One clearly sees that the XFEL specification has been safely demonstrated. Also the ILC specification is within reach and average accelerating gradients of 30 MV/m have been demonstrated. The ILC specification is 31.5 MV/m operational gradient for the cryomodules.

Cavity Auxiliary Performance

The CMTB allows also investigations in much better detail on cavity auxiliary components i.e. the high power input couplers and the cavity frequency tuners. In figure 5, the RF conditioning times for the modules tested on CMTB are shown. Conditioning was always done for 4 couplers at a time, so that each module shows two entries. Only during the first operation of CMTB extended times of more than 100 hours for conditioning were needed. This was caused by extremely tight thresholds on the coupler vacuum interlock. After proper setting of this interlock value (comparable to levels used in other test stands at DESY) conditioning times are down to an acceptable level of 20 hours. One should note that the conditioning is done to levels of 1 MW for pulse length up to 400 us and 600 kW up to 1.3 ms which would satisfy even ILC requirements [8].

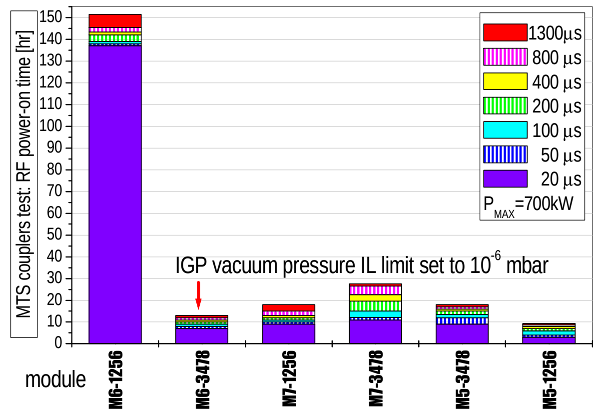

Figure 5: RF conditioning times for the high power couplers on CMTB. Couplers were conditioned four at a time (Courtesy D. Kostin – DESY).

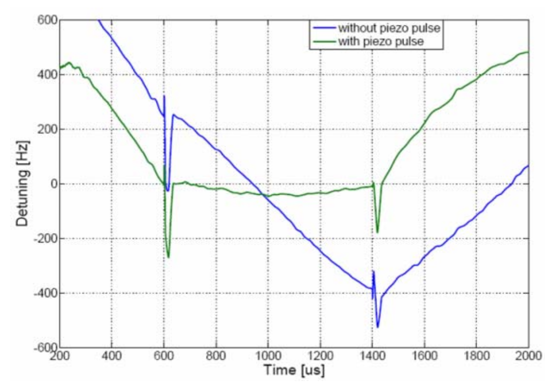

Figure 6: Detuning of a cavity within on RF pulse with (green) and without (blue) piezo compensation.

The frequency tuners in the XFEL modules are equipped with a slow and a fast tuning system. The slow system uses a stepping motor with zero holding current and is mainly used to compensate slow drifts of helium pressure. The fast system uses piezoelectric actuators which should counteract the detuning which occurs during one RF pulse due to Lorentz forces. This is needed to limit the RF overhead power for cavity amplitude and phase control to an acceptable level. Several tests have shown that this concept can be used [9]. An example is shown in figure 6, where the detuning of a cavity operated at a gradient of 35 MV/m with and without piezo compensation is shown. Again, the measured performance is fully satisfying even for the more stringent ILC requirements.

FUTURE TEST STANDS FOR THE XFEL

For the testing of the large series of modules needed for the XFEL and for the validation of the tunnel layout concept two new test stands are under construction or under design, respectively. The first test stand is the tunnel mock-up, where a string of accelerator modules can be installed into a tunnel segment on the surface with the dimensions of the real XFEL tunnel to be constructed later. This will confirm that the suspension of the modules from the ceiling is feasible as initial results have indicated. In addition, the overall tunnel installation and transport concept can be tested. In figure 7 a picture during the construction of the mock-up is shown. The construction has been finished by now.

Figure 7: Picture of the tunnel mock-up at DESY. The final XFEL tunnel layout is included as a computer simulation.

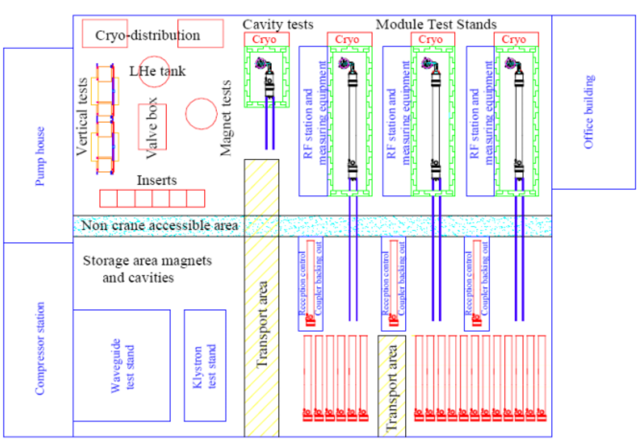

Figure 8: TDR version of the Accelerator Modules Test Facility. The final version to be built until 2009 will be available soon.

The second test stand to be constructed is the Accelerator Module Test Facility (AMTF). As for the XFEL all accelerator modules will be tested for their performance, the test capacity of the CMTB will not be sufficient. The rate of cryomodule production will be roughly one per week. Given that the duration of a test is roughly 2 weeks at least 2 test stands are needed to match the production rate. Testing will include RF performance and the cavity auxiliaries as well as the cryogenic performance.

In the AMTF also vertical cryostats for the low-power acceptance tests of individual cavities are constructed. Currently it is planned to test each of the 808 cavities for their RF performance after delivery from industry before being installed into the accelerator module. Four cavities will be tested in one cooldown.

SUMMARY

The preparation for the XFEL is well advanced. Several accelerator modules have been built and meet the XFEL performance. Gradients in those modules are already close to what would be needed for the ILC thus demonstrating the beneficial synergy between these projects. The CMTB has been proven to be an essential tool for the testing of cryogenic accelerator modules. The new test stands (tunnel mock-up and AMTF) will demonstrate the feasibility of the tunnel layout and serve as an important quality control for a series production of accelerator modules.

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