IMPROVED HEAT CONDUCTION FEEDTHROUGHS FOR HOM COUPLERS AT DESY*

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Abstract

Vertical acceptance test of 808 cavities of the XFEL superconducting linac will be conducted for cavities equipped with HOM antennae, mainly to reduce the production and preparation cost. This new procedure is different from that we applied to all superconducting cavities tested in last two decades at DESY. In addition, cw and long pulse operations can be envisioned as complementary modes to the nominal short pulse operation of the XFEL facility. The new vertical test conditions and the new possible operation modes will require better cooling of the HOM couplers. In this contribution we discuss new heating conditions of the HOM antennae and present new feedthrough we ordered for the XFEL cavities.

INTRODUCTION

The XFEL cavity and its auxiliaries were designed in early 90's for short pulse operation of the superconducting linear collider TESLA. Details of the TESLA cavity have been summarized in the Tesla Technical Design Report [1], which was published in 2001. The proposed duty factor (DF) for the TESLA collider, and presently for XFEL, is ca. 1%. This allows location of the HOM couplers outside liquid helium vessel, as shown in Figure 1. Such a design significantly reduces cost of the cavity and was an unavoidable step for 22 000 cavities of the TESLA main accelerator. Many years of operation of the FLASH linac, at present made of 56 cavities, proved that the TESLA cavity design is well suited for the nominal duty factor of XFEL. Nonetheless, the remarkable continuous improvement in performance of the TESLA cavities, both in gradients and intrinsic quality factors, raises a question, already since several years, whether or not one can increase the DF for XFEL and gain additional flexibility in time structure of the electron and photon beams [2]. As production of the XFEL cavities will begin in 2012, it is still possible to make minor changes in quality of auxiliaries to keep open the possibility of other operation modes with higher DF.

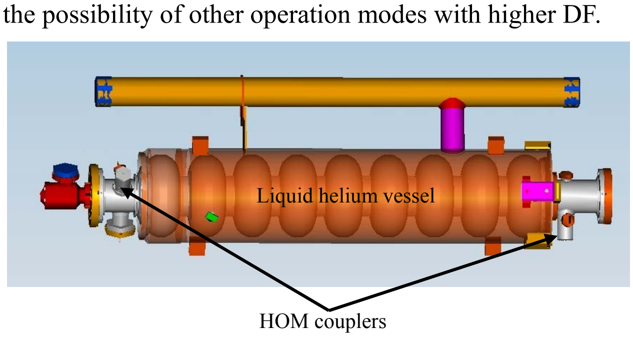

Figure 1: 9-cell TESLA cavity in liquid helium vessel.

VERTICAL ACCEPTANCE TEST

Vertical acceptance test for all 808 XFEL cavities will take place at DESY. The cavities will have attached HOM antennae (feedthroughs) at factories before the test, mainly to lower the production and preparation cost. This new procedure is different from that we applied to all superconducting cavities tested in last two decades at DESY. The standard cw vertical acceptance test, at the specified gradient of 23.4 MV/m, would cause 100 times higher heat load for the antennae than the nominal operation with 1% DF. Unfortunately, unlike the cavity wall, removing that heat from antenna is indirect, and depends on the heat conduction of isolating window and on material it is brazed to. Two measures have been undertaken for the acceptance test to mitigate the excessive overheating.

At first, we decided to test cavities in a pulse mode with DF of ca. 10%. In that way overheating of HOM antennae will be 10 times smaller than in the standard cw vertical test. Secondly, we will replace present HOM feedthroughs with ones having higher heat conduction, because it is expected that heating of HOM antennae could be also a limitation in the linac performance for new operation modes. Design of the new feedthrough will be discuss later, but in general it follows modifications proposed first at TJNAF for cavities developed for the 12 GeV upgrade of CEBAF.

NEW OPERATION MODES OF XFEL LINAC

Two new operation modes of XFEL are at present under discussion; the cw mode and long pulse (lp) mode. In the latter one, the linac will operate with ~100 ms long pulses, which repetition rate is 1 Hz. The intended maximum gradient for the lp mode is close to the present nominal one of 23.4 MV/m. For the cw operation, the cavities will run at 7.5 MV/m at most. Accordingly to our estimation, either of new operations will cause heating of the HOM antenna comparable to that in the pulse acceptance test.

The new modes require new RF-amplifiers with capability to run both in the cw and in long pulse mode. In addition, overall efficiency of the RF-system is an important criterion for choice of the amplifier, especially in case of the lp operation, when at the highest gradient the DF will be ~10%, and thus for 90% of time there will be no beam in the linac. We consider two candidates for the RF-source, either does not take or takes very little energy from the grid when it does not generate RF power. The first is an IOT (Inductive Output Tube), which is a

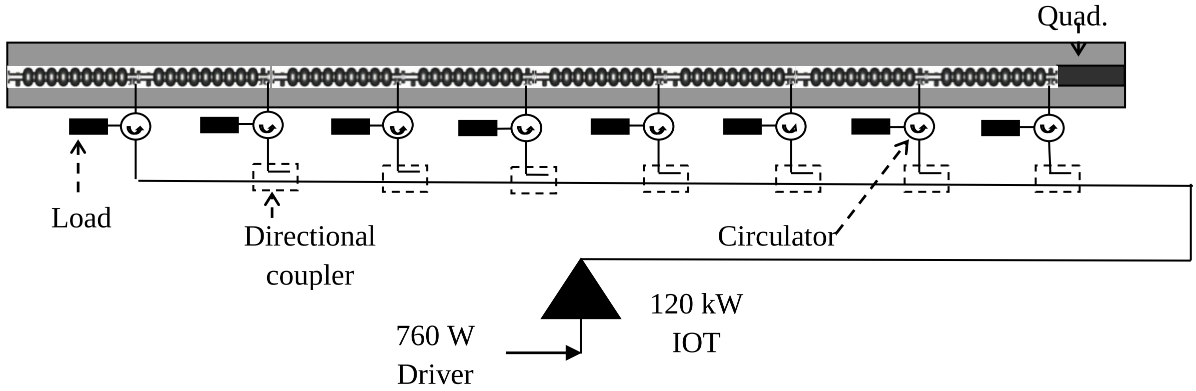

Figure 2: RF-power distribution system for a 8-cavity cryomodule with 120 kW IOT amplifier.

tetrode. The second is a solid-state amplifier. Our former studies showed that ca. 120 kW RF power per eight-cavity cryomodule will be sufficient to accelerate of up to 0.25 mA beam at the nominal XFEL gradient, keeping a safety margin of the power to compensate for microphonics. For the size and cost reason an IOT seems at present to be a better choice; however we will follow the progress in the solid-state amplifier offer. The schematic configuration of the XFEL cryomodule and an IOT amplifier is shown in Figure 2.

RESULTS OF EXPERIMENTS

Pulse Acceptance Test

Since March 2010 we test 9-cell cavities, when they are equipped with feedthroughs, in the pulse mode. The time structure of pulse sequence is shown in Figure 3. The DF factor for the test is set to 10 % and the pulse duration of ~5 s is sufficient to reach the charging plateau for intrinsic quality factors ~2E10 (loaded Q ~1E10). Many cavities, equipped either with old "fashion" or with new prototypes of feedthroughs, have been tested and with an exception of few they performed very well. Some of these few cavities were limited by heating of the HOM couplers. That happened usually when couplers had not been well cleaned or had scratches on the surface (for example made by the electrode of EP setup). Not carefully cleaned HOM couplers showed often multipacting, which in some cases could be conditioned.

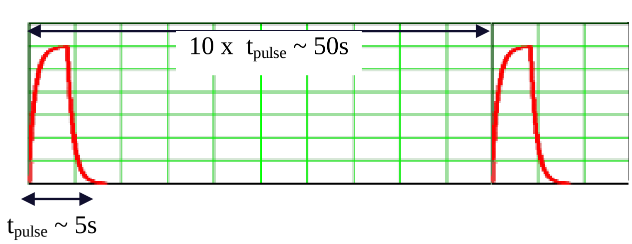

Figure 3: RF-pulses for the vertical acceptance test with DF ca. 10% and the pulse length for intrinsic quality factors ~ 2 E10.

Operation of an 8-cavity Cryomodule with IOT

In July 2011, we have conducted the very first test of the cw and lp operations. For that test we used 85 kW IOT built by CPI in the frame of the EuroFEL program. The tested cryomodule had all eight cavities equipped with low conduction "old fashion" feedthroughs, which per purpose were not thermally connected to the 2K-tube. In that way we could test the worst case scenario for cooling conditions of the end groups.

In the test:

- 6 cavities had loaded Q = 1.6E7, one 8E6 (limit in E_{acc}) and one 4E6 (blocked FM coupler).
- Achieved gradients were: in cw up to 5.5 MV/m and in lp mode 11 MV/m (t_p=300 ms).
- Voltage vector sum stabilization was: 1E-3 (rms) with no "dedicated" LLRF system.

The result is encouraging and we will perform second test in January/February 2012 with new LLRF, dedicated to cw/lp modes, and better thermal conditions for the HOM couplers. For that test, we will have cryomodule in which 5 cavities will be equipped with high conduction- and only 3 with low conduction feedthroughs. All will be thermally connected to the 2K-tube.

HIGH THERMAL CONDUCTION FEEDTHROUGH

As already mentioned, all high conduction feedthroughs, offered by several industrial vendors, are based on the design developed at TJNAF for the cw operation of 1.5 GHz upgrade cavities. In that design, standard alumina ceramic Al_2O_3 has been replaced with a sapphire crystal. In addition, the feedthroughs which we will use for the XFEL cavities will have sapphire window brazed directly to a copper fixture, allowing good heat transfer from the antenna. The antenna will be made of high purity niobium. Flange of the feedthrough will be made of titanium, which has better heat conductivity at 2K than commonly used stainless steel. The proposed feedthrough is shown in Figure 4.

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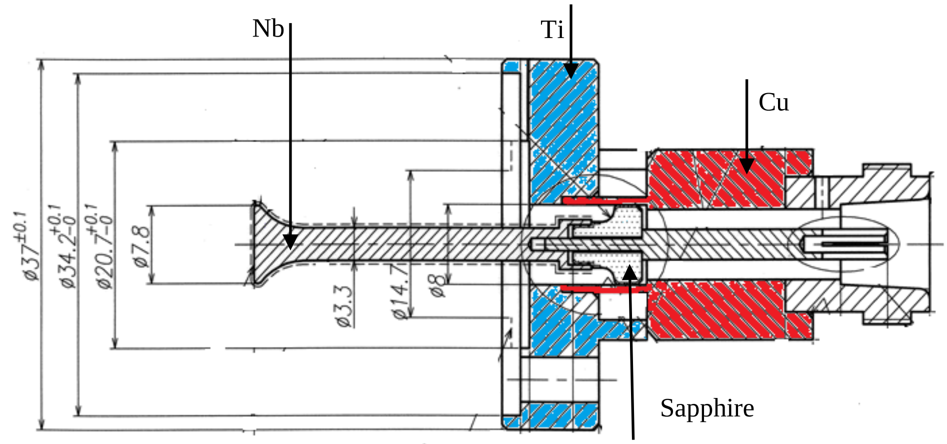

Figure 4: High conduction feedthrough with the sapphire window.

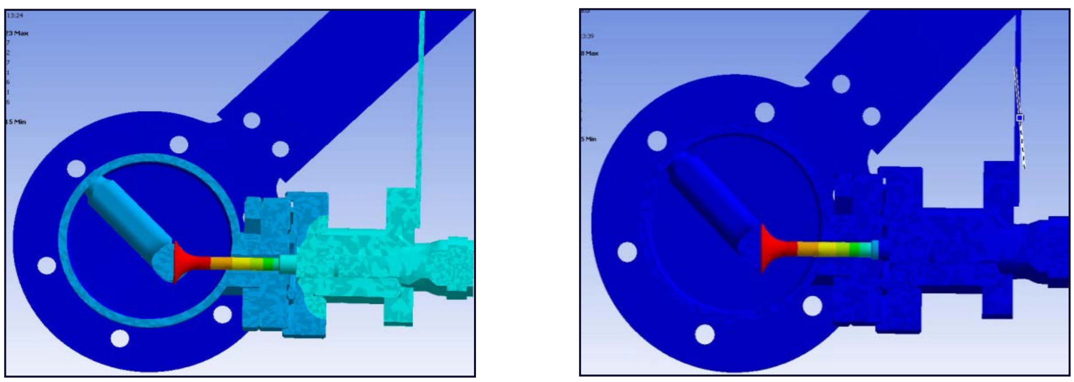

Figure 5: Calculated with ANSYS temperature profile for the HOM coupler immersed in superfluid helium (right) and when a cavity is in cryomodule (left). Dark blue color marks 2K.

We have conducted computer modeling of the antenna heating for thermal conditions in the acceptance test, when a cavity is immersed in superfluid helium and then when it is installed in a cryomodule and hence the end groups are in vacuum. For the modeling, the high conduction feedthrough was chosen. The results, T profile and T vs. dissipated heat, are shown in Figure 5 and in the Table 1 respectively. The temperatures are very similar for either condition. When the mean dissipated power on the antenna stays below 20 mW, the antenna should remain in the superconducting state. This will allow to minimize heat load for the new types of operation.

Table 1: Highest Temperature on the Antenna

Heat [mW]	T in vacuum [K]	T in superfluid He [K]
20	7.0	6.8
5	4.6	4.5
4	4.2	4.2
3	4.0	3.9
2	3.6	3.5
1	3.1	3.0

REFERENCES

[1] R. Brinkmann et al. (editors), TESLA TDR, DESY-Report-2001-23 (2001).

[2] J. Sekutowicz, "Parameter set for cw and near-cw operation of a XFEL driving superconducting linac", EUROFEL-Report-2005-DS5-003, http://www.eurofel.org/e693/e1009/

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