CW AND LP OPERATION TEST OF XFEL-LIKE CRYOMODULE

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Abstract

A continuous improvement in the performance of superconducting TESLA cavities should make possible, from the cryogenic point of view, operation of the XFEL linac in continuous wave (cw) mode at gradients up to 7.5 MV/m and in long pulse (lp) mode up to the XFEL nominal gradient of 23.4 MV/m [1]. Each of these new operation modes will offer an additional flexibility in time structure of the photon beam, and therefore will allow for more experiments and in some cases less demanding and less expensive equipment. In this contribution we discuss results of the first RF test of these new types of operation with a XFEL-like cryomodule, which was conducted in summer 2011.

INTRODUCTION

The XFEL cryomodules are based on TESLA cryomodules [2] and thus they still have many features of that original design from early 90's. The TESLA cryomodules have been compromised to keep their price possibly low. In the 8-cavity TESLA cryomodule, unlike for example the 2-cavity HERA cryomodule, only cells are immersed in superfluid helium. So called end-groups, which consist of beam tubes with attached HOM couplers and ports for input couplers, are cooled by the heat conduction of pure niobium they are made of. The design has proven to run very successfully in the XFEL nominal short pulsed mode when the duty factor (DF) does not exceed 1.3 %, RF-pulses are ca. 1.3 ms long and the repetition rate is 10 Hz. This operation is demonstrated at FLASH since many years.

A continuous improvement in the performance of superconducting 9-cell TESLA cavities and minor cooling improvements for the end-groups should make possible, from the cryogenic point of view, operation of the XFEL cryomodules in continuous wave (cw) mode at gradients up to ~7.5 MV/m and in long pulse (lp) mode up to the XFEL nominal gradient of 23.4 MV/m.

PREPARATION OF THE TEST

IOT and High Voltage Power Supply

We have equipped CMTB (Cryo-Module Test Bench) at DESY with the first prototype of high power Inductive Output Tube (IOT) amplifier to investigate these new type of operation modes. The 1.3 GHz IOT amplifier was designed and built at CPI in USA. The tube was previously tested in cw mode up 85 kW. The measured parameters are listed in Table 1. A fifteen-year-old 0.6 MW high voltage power supply, we used for this experiment, had been designed for the cw operation and pulsing of the IOT caused voltage oscillation in the range of 1%. An example of the current and voltage of the power supply is shown in Figure 1.

Table 1: IOT parameters

Parameter	Unit	Value
Max. Pout	[kW]	85
Max. Gain	[dB]	22.3
Efficiency	[%]	54
High Voltage	[kV]	46-48

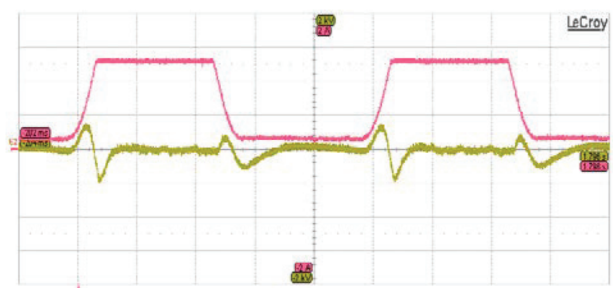

Figure 1: (Colour) Voltage (green) and current (pink) of the HV supply. Vertical scale is 0.5A/div and 500V/div. Horizontal scale is 200 ms/div.

Cryomodule PXFEL2_1

Layout of the installation in CMTB is shown schematically in Figure 2. For this first test we took prototype PXFEL2_1 cryomodule, which had no additional cooling features for the end-groups, and which 7 cavities were equipped with the standard low heat conduction HOM feedthroughs and only one cavity had

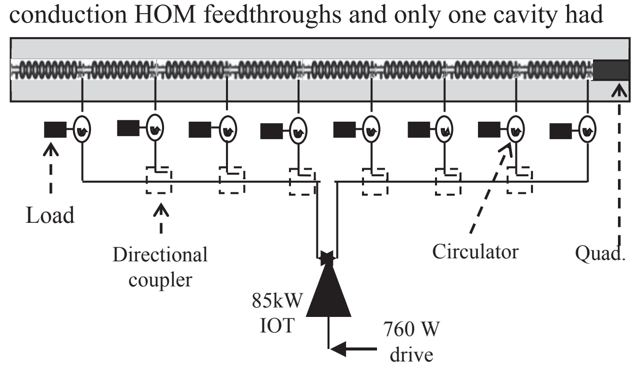

Figure 2: The 8-cavity XFEL like cryomodule with RF-power distribution for IOT amplifier in CMTB.

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newer generation feedthroughs with better heat conduction. Having in the next tested cryomodule copper-braid connections of the end-groups to 2K tube for better cooling and implementing high conduction feedthroughs, especially designed for XFEL, we will be able to estimate improvement in the cryogenic performance due to these modifications. To monitor warming of the end-groups, temperature sensors have been attached to the HOM couplers. We will install the temperature sensors also in the next tested cryomodule. Preceding the cw/lp test, PXFEL2_1 cryomodule was extensively tested with 10MW klystron, in the nominal short pulse mode. For the cw/lp test input couplers of six cavities were readjusted for higher Q_{ext} of $1.6 \cdot 10^7$ (see Table 2). Two cavities were left with lower Q_{ext}. Cavity no. 3 was poorly performing during the short pulse test, therefore its Q_{ext} was adjusted to lower value. Coupler of cavity no. 8 was improperly assembled and its inner conductor could not be retracted to lower the coupling and Q_{ext} of that cavity had to remain as it was adjusted for the nominal short pulse test.

Table 2: Q_{ext} and BW after adjustment

Cavity	Q_{ext} [10^7]	BW [Hz]	Comment
1	1.6	81	
2	1.6	81	
3	0.8	162	Poor performance
4	1.6	81	
5	1.6	81	
6	1.6	81	
7	1.6	81	
8	0.4	324	Coupler failure

HEAT LOAD IN CW MODE

Heat Load for Operation at 2K

We have measured dynamic heat load of cavities operating cw at mean accelerating gradient of 5.3 MV/m. The static heat load for the cryomodule was measured prior to this test and it amounts to 6.2 W. The total heat load was estimated with superfluid helium mass flow for RF-on and off. The measurement is shown in Figure 3.

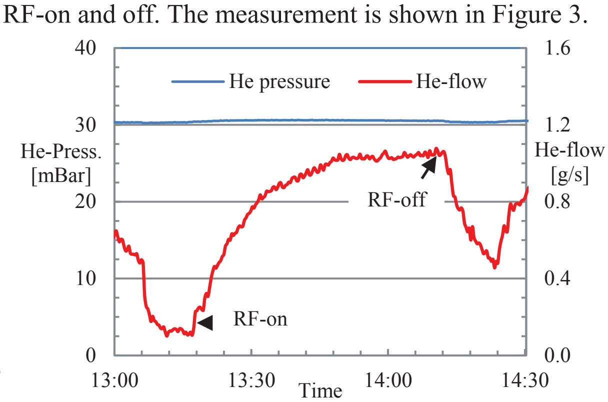

Figure 3: (Colour) Helium pressure and mass flow during the heat load measurement at 5.3 MV/m.

The measured total and dynamic heat loads are listed in Table 3. Estimated dynamic heat, for assumed intrinsic quality factor Q_o of $1.5 \cdot 10^{10}$ is shown in column 4.

Table 3: Measured heat load in cw mode at 2K

E_{acc}	Total Heat	Dynamic Heat	Estimated Dynamic Heat	Difference
[MV/m]	[W]	[W]	[W]	[W]
5.3	27	20.8	16.0	4.8

The difference of 4.8 W between the estimated and measured loads can be attributed to enhanced cryogenic losses in the end-groups due to their higher temperature. The sensors attached to the HOM couplers feedthrough flanges showed that both for the nominal short pulse- and for the cw operation their temperature raised, however this did not cause quenching. The temperature of the HOM couplers cans increased much less and stayed, with one exception of cavity 2, below the critical temperature for Nb. The measured temperatures and locations of sensors are shown in Figures 4a (flanges) and 4b (cans).

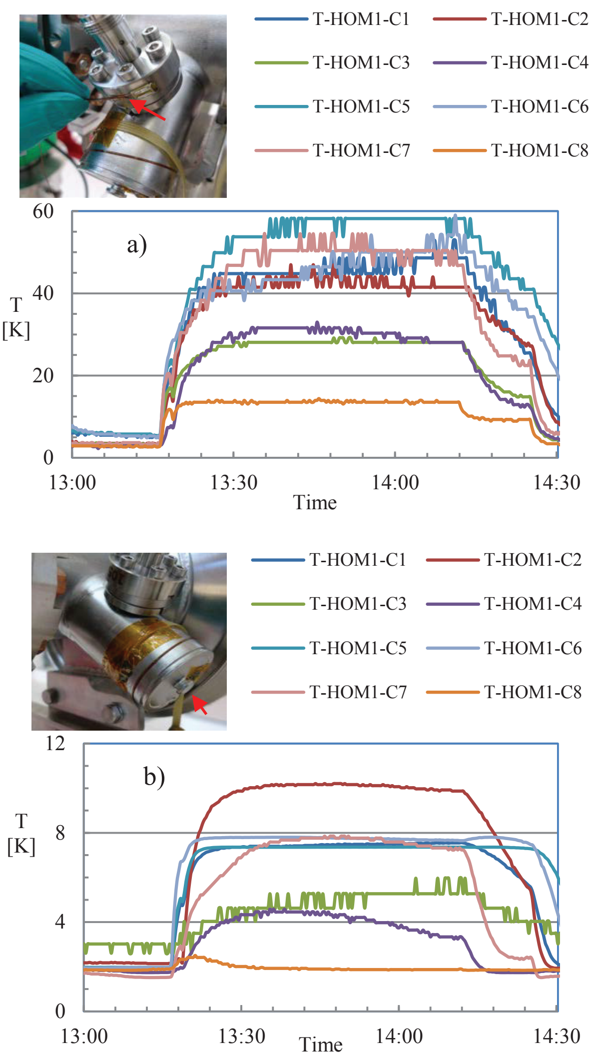

Figure 4: (Colour) Temperatures measured on the HOM flanges (a) and cans (b) for cw operation at 5.3 MV/m.

Heat Load for Operation at 1.8 K

The heat load measurement was repeated at 1.8 K for mean gradient of 3.3 MV/m. This time, the estimated heat load was larger than the measured, even though we assumed high intrinsic Qo of $3.5 \cdot 10^{10}$. We think that the reason for the discrepancy is that the measurement for low mass flow is inaccurate. The test result is displayed in Table 4. The temperatures of HOM couplers (Figure 5) were lower, but they did not scale from those measured at 2 K by factor $(3.3/5.3)^2$=0.39. This points out that operation at 1.8 K reduces mostly dissipation in cells of cavities but not the losses in end-groups, which are outside helium vessels.

Table 4: Measured heat load in cw mode at 1.8 K

E_{acc}	Total Heat	Dynamic Heat	Estimated Dynamic Heat	Difference
[MV/m]	[W]	[W]	[W]	[W]
3.3	9.3	2.6	3.1	-0.5

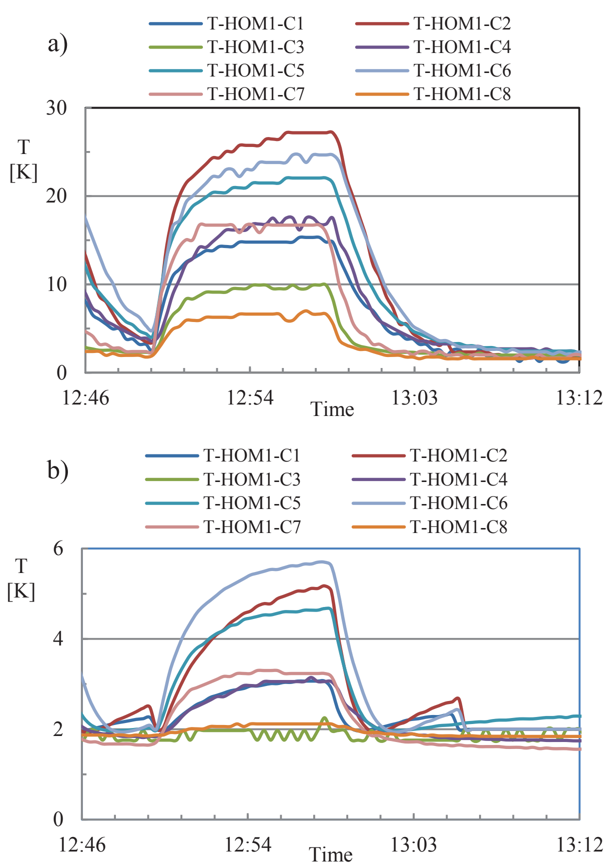

Figure 5: (Colour) Temperatures measured on the HOM flanges (a) and cans (b) for cw operation at 3.3 MV/m.

PULSE OPERATION AT 2K

For the lp operation, with rise time of 100 ms, flat top 200 ms and repetition rate of 1 Hz, six high Q_{ext} cavities could run at gradients up to 10.8 MV/m. The pulse operation at highest gradient continued for ca. 20 min. but the cryogenic plant, used in parallel for other experiments, was not stable enough for the measurement of dynamic heat load. Nonetheless, no quenching was observed at that gradient, even though the DF was 20 times larger than the nominal one.

LLRF

For the reported experiment we used LLRF based on the VME electronics. Both for the cw and lp operation the RF-feedback was able to stabilize the vector sum of the E_{acc} amplitude to 10^{-3} peak-to-peak. Stabilization of the phase was worse, only 0.5° peak-to-peak. The signals were strongly perturbed by 47-50 Hz oscillation, which origin was not known to us at the time. Later, when we began to prepare the second test in 2012, it was found out that vacuum pumps at the middle part of the cryomodule were causing that mechanical vibration. Additionally, in either operation we did first attempt to use piezo-actuators integrated in cold tuners. The piezos have two-fold functionality. The bias of the piezo actuator allows for very precise frequency adjustment. The piezo feedback should compensate for microphonics. In the 2011 experiment we used only the bias, which confirmed to be very useful for the fine frequency adjustment and moreover suppressed partially mechanical vibrations. The piezo feedback test was planned for the 2012 experiment.

FINAL REMARKS

The first experiment in 2011 to investigate limits for the cw and lp operations of XFEL cryomodules confirmed that either type of operation mode is possible. Further experiments are planned to prove whether or not we can operate cryomodules having better cooling up to 7.5 MV/m and 23.5 MV/m in the cw and lp mode respectively, fulfilling the XFEL spec of 1E-4 and 0.01° standard deviation stability in amplitude and phase of the vector sum.

Very recently we have conducted first part of the cw/lp experiment scheduled for 2012. We are still analysing the data, but with additional cooling features in the cryomodule (PXFEL3_1) we could operate it very stable at 8.1 MV/m with up to 650 ms long pulses for many hours. Furthermore a new LLRF based on µTCA, the piezo bias and feedback performed very reliable in that attempt. These new and promising results will be reported when the second run in summer 2012 will be finished.

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REFERENCES

[1] J. Sekutowicz et al., "Test results of components for cw and near-cw operation of a superconducting linac", Linac10, Tsukuba, Japan, September 12-17, 2010.
[2] R. Brinkmann et al. (editors), TESLA TDR, DESY-Report-2001-23, 2001.

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