COMPONENTS FOR CW AND LP OPERATION OF THE XFEL LINAC

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Abstract

The European XFEL will be driven by superconducting linac based on the TESLA technology [1]. The linac will be operated with ca. 1 ms RF pulses which repetition rate will be 10 Hz. This nominal short pulse (sp) operation mode has been "inherited" from the TESLA collider project. In this contribution, we discuss progress made over last two years in the R&D program for future upgrade of the European XFEL linac to operation in the continuous wave (cw) and long pulse (lp) mode, each allowing for more flexibility in the electron and photon beam time structure and thus enabling wider spectrum of experiments. Many of presented here results have been achieved in collaboration between DESY and TJNAF, BNL (USA), WUT, TUL, NCNR (Poland) and HZB (Germany).

INTRODUCTION

Our motivation, technical limitations of the linac and results of cw/lp tests were reported in [2] and [3, 4] in 2010 and 2012 respectively. Since then, we built more prototypes of components needed for the cw and lp operation modes.

In brief, the goal of the R&D program is feasibility of the XFEL cw operation at gradients up to Eacc of 7 MV/m. For Eacc higher than 7 MV/m, we would like to operate linac in the lp mode, with duty factors (DF) scaled proportional to ~ $(7/\mathrm{Eacc})^2$.

One of technical constrains is the allowed heat load (HL) for present type of cryomodule, which in total (static plus dynamic) should not exceed 20 W. The limit results from diameter of the 2-phase tube and 12-cryomodule long cryogenic strings. To keep high quality of electron bunches, as it will be for the present linac configuration and nominal operation, we will need to replace first 17 cryomodules (136 cavities) with new, modified for the cw operation at gradients between 11 MV/m and 16 MV/m. Twelve of these cryomodules can be re-installed at the end of the XFEL linac. In this scenario, the XFEL linac will consist of 113 cryomodules (904 cavities). Table 1 lists spec for the current and upgraded cryogenic plants and the total HL at 2K and 1.8K for the sp and cw/lp operations respectively. One should note that required capacity of the cryogenic plant is similar to that of the CEBAF cryogenic refrigerator at TJNAF.

Table 1: Cryoplant Capacity and HL for two Operations

SP OPERATION (2K)		CW/LP OPERATION (1.8K)	
Cap. [W]	HL [W]	Cap. [W]	HL [W]
2450	1175	4980	3320

Figure 1 displays result of one of tests we performed in 2012. In that test, 7 cavities were in operation at average gradient of 8.8 MV/m. One cavity had detuned HOM coupler and could operate at Eacc < 4 MV/m. The RF-pulse length was ca. 165 ms and their repetition rate was 0.7 Hz. Figure 1 shows dynamic heat load (DHL) at the beginning, for 7 cavities, and reference value measured when all cavities were off resonance. Then, we detuned cavity by cavity off resonance to estimate with what fraction each cavity contributed to the total DHL. The conclusion was that as long as there was no nonlinear heating effect, the measured DHL of each cavity agreed very well with its DHL measured in vertical cryostat. The estimated DHL for 7 cavities was 3.9 W and measured one 3.7 W.

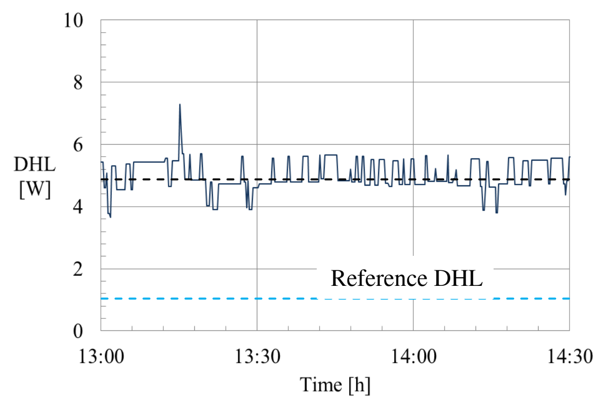

Figure 1: Measured DHL of 7 cavities at 8.8 MV/m (black line) and its mean value (black dash line), reference DHL ca. 1 W (blue dash line).

CAVITIES FOR CW AND SP OPERATION

Originally TESLA cavity and its auxiliaries were design for DF of 1%. The cw operating cavity will require modified HOM couplers, which output antennae will be less exposed to residual magnetic flux of the fundamental mode. We followed in our first approach the HOM coupler modification at TJNAF [5]. Figure 2 shows modified HOM coupler with additional inductance allowing placing of the antenna in the output tube. We expect much less heating of the antenna. Currently thermal modeling of this technical solution takes place. The Nb prototype of single-cell cavity should be ready for vertical test by the end of this year.

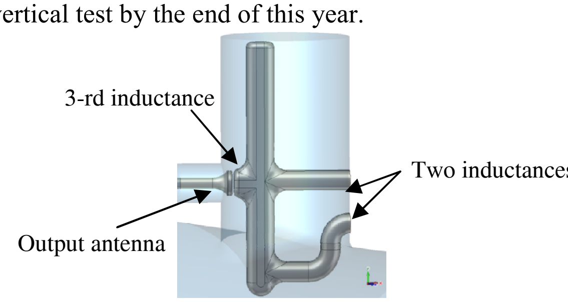

Figure 2: New HOM coupler with additional inductance and pulled back output antenna, *(Courtesy D. Kostin).*

Feedthroughs and Thermal Connections for Standart TESLA Cavities

Figure 3 shows picture of new HOM feedthroughs, developed for the cw/lp operations. The feedthroughs are made of high conductivity materials, pure niobium, molybdenum and sapphire. The Nb antenna is brazed to the molybdenum pin, which is fixed in the sapphire window. This ensures better heat removal from the antenna, which is exposed to residual magnetic flux of the fundamental mode. We received already feedthroughs for all 808 cavities. The quality control process is in progress.

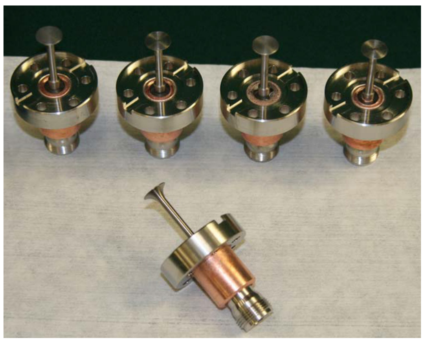

Figure 3: New feedthroughs for XFEL cavities.

All feedthroughs of HOM couplers will be connected thermally to the 2-phase tube with cooper braids for better heat transfer to the 2 K environment (Figure 4). Production of 1616 sets is in progress and it will be finished by the end of this year.

Figure 4: Prototype of the thermal braids for standard TESLA cavities (*courtesy NCNR*).

BEAM LINE ABSORBER

Total deposited HOM power by the nominal XFEL beam will be 3.81 W per cryomodule, if no synchronous excitation will take place. Most of this power, ca. 85%, will be dissipated in the beam line absorbers (BLA). The absorbers will be integrated into interconnections between cryomodules. The absorption of microwaves takes place in the ceramic ring with brazed copper stub. The stub, via thermal connection, transfers the dissipated energy to the 70K cryostat shield. In the absorber design we took into account operations in the cw/lp modes, in which beam deposited power can be as high as 100 W. The first prototype of BLA is installed in FLASH since 2007 and was tested in 2008 and 2009 [2]. Figure 5 shows two prototypes of the BLA, which were built by industry to demonstrate the capability of the company, which later was awarded with the contract for 108 pieces.

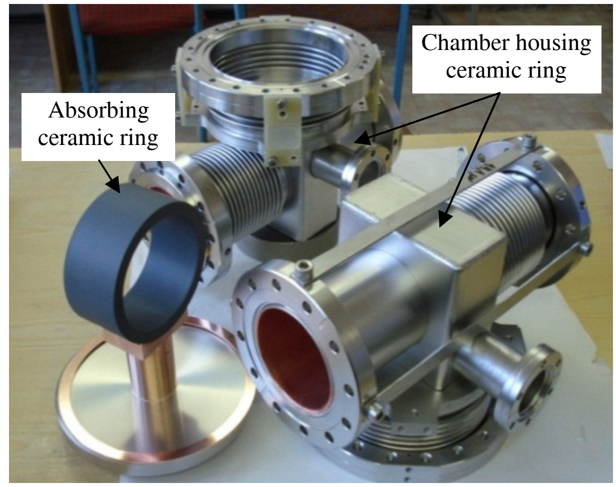

Figure 5: Parts of recently built prototypes of the BLA, (*Courtesy NCNR and Lamina*).

SRF ELECTRON SOURCE

The new XFEL operation modes will require a new electron source operating in cw mode. One of the possible options is an all superconducting Nb/Pb gun. The concept of such injector with a sc lead cathode was first discussed in 2005. In February 2012 we reconsidered plug version of the SRF gun as it had been proposed and reported by P. Kneisel et al. in [6]. The gun was built as no-plug version and then modified to the plug cavity at TJNAF. The plug option simplifies coating of the cathode and makes much easier cleaning of the cavity. The disadvantage of that option, in the previous version proposed in 2005, was insufficient cooling of the cathode surface. This was solved in 2012. We have removed more material from the back side of the plug and put more Indium on the sealing surface to improve heat transfer between the plug and cavity wall. The results we obtained with the uncoated plug (baseline test) and with the plug Pb-coated at NCNR, is shown in Figure 7. The baseline result showed that intrinsic quality factor Qo $>10^{10}$ can be obtained for the peak field on the cathode, Ecathode, up to 50 MV/m.

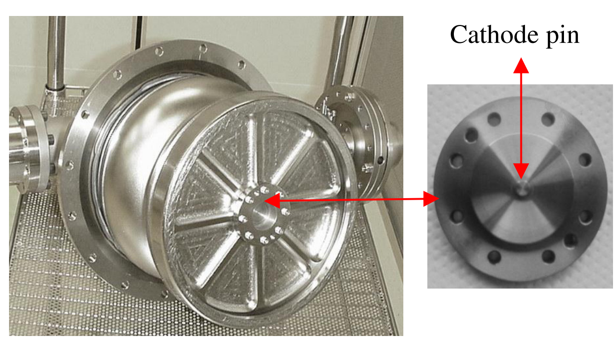

Figure 6: SRF-injector cavity with attached cathode plug (left), cathode plug (right, not to scale), (*courtesy TJNAF*).

ISBN 978-3-95450-122-9

At the maximum field of 54 MV/m, Qo was still $5\cdot10^9$. With the Pb-coated plug, we observed worse performance, but up to ~35 MV/m, intrinsic quality factor was higher than $5\cdot10^9$. Because the Pb cathode had small, 5 mm, diameter and it was located in very low magnetic flux B < 0.6 mT, we think that the worse performance was due to improper assembly of the plug.

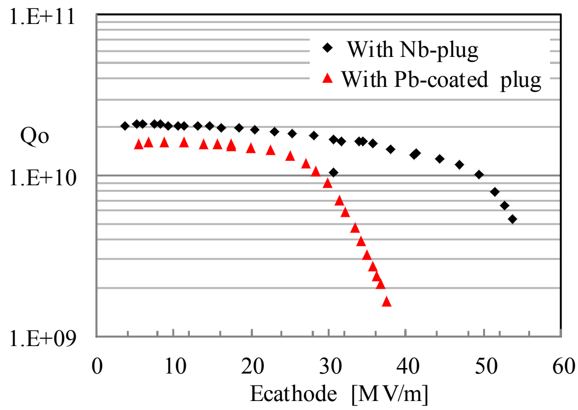

Figure 7: Tests results of the 1.6-cell Nb cavity with uncoated Nb-plug and with Pb-coated plug.

Finally, cavity was equipped with the TESLA-type input coupler and a valve for installation in the test cryostat at HZB. After shipment from TJNAF to HZB, cavity with coated plug was tested, but both the SRF performance and quantum efficiency were worse than expected. The cavity is disassembled at DESY for inspection of the plug and for chemical treatment. We plan to conduct next test of the cavity with Pb-coated plug by the end of June 2013.

RF-POWER SOURCE

New RF-power sources will be needed for the long-pulse and cw operations. To lower both investment and operation costs of a new RF-system, a high power Inductive Output Tube (IOT) was developed at CPI Company in frame of the EUROFEL program. The first prototype was delivered to DESY in 2009 and is routinely used for the cw/lp cryomodule tests. The second prototype was ordered in 2012. Specification for the second prototype is listed in Table 2. The tube should be delivered to DESY after acceptance test in July 2013.

Table 2: Parameters of the Second IOT Prototype

	Unit	Spec
f	[MHz]	1300
Pout	[kW]	> 100
Gain	[db]	> 22
η	[%]	> 60
V_{beam}	[kV]	47-49

The second prototype will replace the first one in the Cryomodule Test Bed. The first prototype will be sent to CPI for maintenance and then it will be used at DESY for development of a new IOT power supply and protection system.

LOW LEVEL RF

In April 2012, we have used for the cw/lp cryomodule tests new low level RF system, based on the µTCA architecture, for the phase and amplitude control of the accelerating field. For experiments in 2012, Qext of all FM couplers were adjusted to $1.5\cdot10^7$. Figure 8 shows amplitude stabilization of the vector sum (VS) for 1s time range. The standard deviation in the shown time interval was 0.0065 and mean value 102.7, which results in $6\cdot10^{-5}$ stabilization of the VS amplitude. The phase was stabilized with 0.01°. Both results fulfill spec for XFEL. In the next test we plan integration of the RF- and piezo feedbacks, which was not possible in the performed tests.

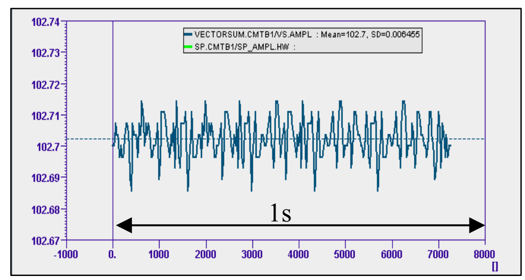

Figure 8: The VS amplitude stabilization with µTCA.

FINAL REMARKS

The components discussed here are still in a R&D or/and test stage. All of them are essential for the future possible upgrade of the XFEL facility; they can also be very useful for smaller FEL facilities operating with high DF or/and cw at lower gradients.

ACKNOWLEDGMENTS

The author would like to thank all colleagues at TJNAF, NCNR, WUT, TUL, HZB, BNL and DESY for their scientific, engineering and technical support in the R&D programs presented here.

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