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COMMISSIONING OF S-BAND CAVITY TEST FACILITY AT ELETTRA FOR CONDITIONING OF HIGH GRADIENT STRUCTURES FOR THE FERMI LINAC UPGRADE

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Abstract

FERMI is the seeded Free Electron Laser (FEL) user facility at Elettra laboratory in Trieste, operating in the VUV to soft X-rays spectral range. In order to extend the FEL spectral range to shorter wavelengths, a feasibility study for increasing the Linac energy from 1.5 GeV to 1.8 GeV is actually going on. A short prototype of a new High Gradient (HG) S-band accelerating structure has been built in collaboration with Paul Scherrer Institute (PSI). The new structures are intended to replace the present Backward Travelling Wave (BTW) sections and tailored to be operated at a gradient of 30 MV/m. For RF conditioning and high power testing of prototype, a Cavity Test Facility (CTF) is commissioned at FERMI. The test facility is equipped with RF pulse compressor system and a dedicated diagnostic for breakdown rate (BDR) measurements and events localization. In this paper we present in detail cavity test facility of FERMI and high power testing of the first prototype.

INTRODUCTION

FERMI has achieved its nominal performance goals by the production of photon energies above 300 eV. However, there is a great demand from scientific community to cover the whole water window by reaching both the nitrogen and oxygen K-edges. This will require the extension of the photon energy up to 600 eV. FEL simulations show that this goal can be achieved by increasing the electron beam energy from the present value of 1.5 GeV up to 1.8 GeV, while the beam peak current should be pushed up to 1 kA. This is not possible in the current configuration due to some limitations with the seven, 6.4 m long, BTW structures which are limited presently to maximum gradient of 24 MV/m. To solve this issue and to have reliable accelerating gradient of 30 MV/m, an upgrade of FERMI Linac is currently under study. In the upgrade scenario each BTW structure would be replaced by two, 3.0 m long, structures fed by the same power source. An agreement was signed with PSI in April 2017 to develop a short prototype of new high gradient structure. The prototype was installed at cavity test facility in April 2018. The structure achieved the nominal operating parameters, reaching the goal gradient of 30MV/m fast without problems.

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RF DESIGN

An extensive comparison between magnetic-coupled (MC) and electric-coupled (EC) RF couplers is made in [1]. A customized version of dual-fed-EC coupler is chosen for the new, high gradient, structures, due to significantly lower surface fields. The complete design of new accelerating structures is reported in [2]. All the geometrical parameters of an accelerating cell are summarized in Table 1. To achieve 1.8 GeV the new structure has to work at 30 MV/m gradient which is considerably high for typical S-band accelerators. So, to lower the peak electric field in the cell, an elliptical rounding is introduced and optimized using HFSS.

Table 1: RF Parameters of Accelerating Structure

Parameter	Value
f_0 [MHz]	2998.01
Mode	$2\pi/3$
$L_{structure}$ [mm]	2998.3
L_{cell} [mm]	33.332
N_{cell}	84
t (disk thickness) [mm]	2.5
or (bending radius) [mm]	13
R_{sh} [MΩ/m]	72.07 → 80.83
Q_0	≈ 15850
t_f [ns]	645
τ [Neper]	0.38

PROTOTYPE FABRICATION AND COLD MEASUREMENTS

To prove the reliability and the feasibility of upgrade proposal at an accelerating gradient of 30 MV/m, a short prototype shown in Fig. 1 has been built in collaboration with PSI, Switzerland using the same structure technology as developed for the SwissFEL C-band structres [4]. For more details about the fabrication process refer to [5].

CAVITY TEST FACILITY

At FERMI the RF station designated as hot spare for first two Linac stations, is also used as RF source for S-band RF Cavity Test Facility (CTF). This RF station is equipped with same FERMI LLRF hardware installed on all other RF sta-

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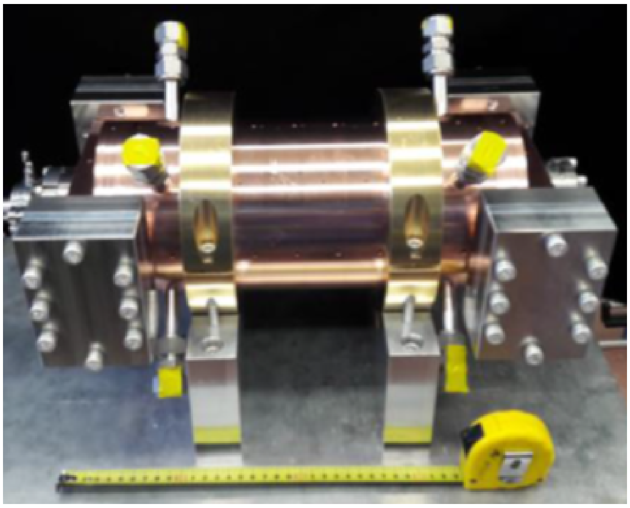

Figure 1: Short prototype.

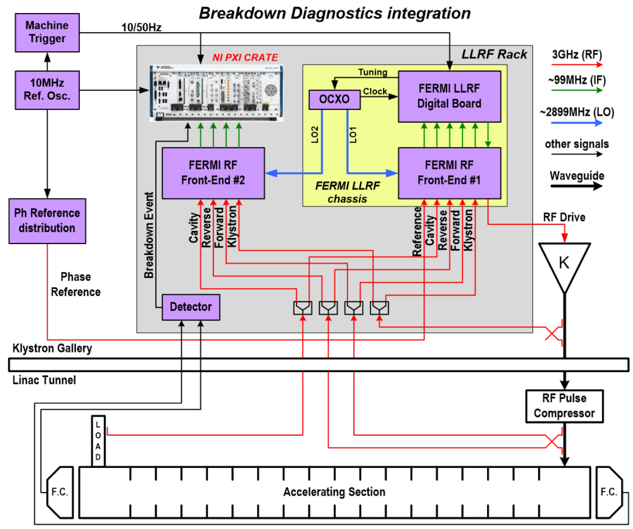

Figure 2: Layout of LLRF system for cavity test facility.

tions and is fully integrated with the other machine systems, i.e. control system, synchronization, machine and personal security. CTF is equipped with BOC type pulse compressor to increase the RF peak power available from Klystron. Being a test facility, additional diagnostic is required. In the framework of a collaboration between CERN and Elettra, CERN like breakdown diagnostic oriented hardware and software, based on National Instruments (NI) products, is integrated with LLRF system of FERMI. Unlike CERN, where NI hardware is in-charge of whole control of the station, in CTF, a selected subset of its tasks is merged into the actual systems. The scheme of this integration is shown in Fig. 2. For every klystron shot, the added diagnostic acquires distinct RF signals along RF path and calculates their amplitude and phase keeping them in its internal memory. While performing this task, it saves a complete set of RF pulses information every minute and, in case of breakdown inside the structure, besides the breakdown flag, it stores the information of the last three consecutive pulses for later analysis.

Integration of NI System into FERMI LLRF

Amplitude and phase of the RF pulses come from the digital acquisition of low frequency (IF) signals acquired by means of RF down-conversion, which requires a precise and phase-locked LO signal. At CERN, LO frequency is chosen to have the IF frequency exactly one fourth of the NI board sampling rate so that I/Q demodulation can be performed. In CTF, the frequencies involved in the LLRF system are not rounded, therefore a specific frequency phase locked LO signal was extremely difficult to generate. So, a different strategy has been chosen for CTF. The FERMI LLRF system generates two identical LO signals, one of which is used, together with an additional FERMI front-end RF board, to generate enough signals at FERMI IF frequency. This FERMI IF is very close to four times the sampling rate of another NI acquisition board, so a new code for this NI FPGA digitizer has been developed. This code converts the acquired samples from this NI digitizer in the equivalent ones as they would have been acquired at exactly four times the FERMI IF frequency. Complete NI hardware is frequency locked to the rest of the machine by means of the FERMI 10 MHz Rubidium Reference Oscillator. This integration allows LLRF and the NI diagnostics to acquire the identical information from the same RF pulses as shown in Fig. 3, along with the actual hardware, the RF amplitudes to the structure acquired with the two systems.

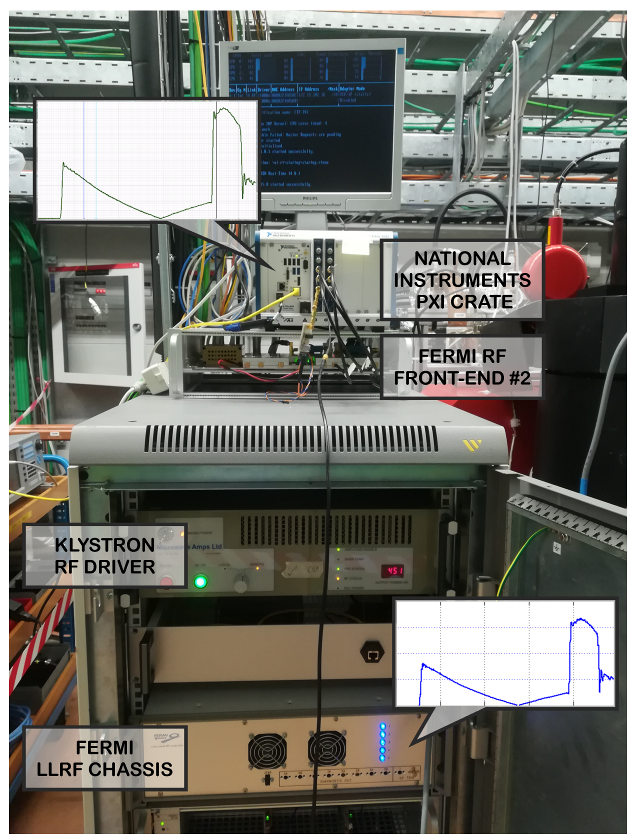

Figure 3: LLRF system for cavity test facility at FERMI.

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Faraday Cup Interface as Arc Detector

Detecting only the breakdowns taking place in the structure is crucial to collect proper data. For this purpose CTF has been equipped with a couple of Faraday cups, installed at both sides of the prototype so that the accelerated current produced by any arc inside the structure, can be detected and used to trigger the breakdown event within the NI diagnostic. A dedicated electronic interface has been designed to individually process the two signals and combine them to be acquired by one of the NI FPGA digitizer.

Data Processing Tool

The advantage of having the logged data in the CERN-like format is that part of the Matlab code developed at CERN can be adapted and used for CTF. This Matlab code can locate the spatial position of the breakdown along the structure using the amplitude and phase information coming from the forward and reflected RF signals of the structure [6, 7]. Unlike the phase, the amplitude needs more effort because a calibration is necessary. Starting from the waveguide directional couplers, all the RF measurement hardware chain (cables, filters, splitters, attenuators) is calibrated. Special mention needs the front-end RF because, involving a frequency conversion stage, it needs a specific calibration procedure performed with a vector analyser. Lastly, also the 2 NI FPGA digitizers have been calibrated. For this purpose a separate measurement set-up has been designed, involving the FERMI LLRF hardware, the FERMI front-end RF and a dedicated NI developed code. With this code we can get the NI FPGA digitizers amplitude response for their complete amplitude range having a more accurate measurement. Being the NI code interfaced with the FERMI Tango control system, it can also be used to perform a FERMI LLRF semi-automatic calibration.

CONDITIONING OF PROTOTYPE

Beginning of April 2018, the prototype has been installed in the cavity test facility (CTF) at FERMI for high power testing. Prototype is successfully conditioned at cavity test facility of FERMI for a reliable operation of 30 MV/m accelerating gradient. The conditioning history is summarized in Fig. 4.

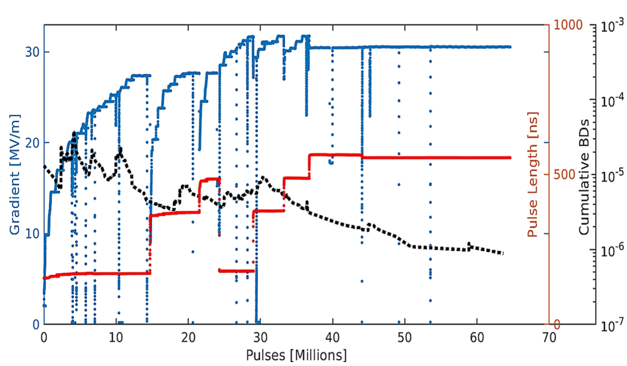

Figure 4: History plot of conditioning of prototype.

CONCLUSION

Prototype is successfully conditioned at cavity test facility of FERMI for reliable operation at accelerating gradient of 30 MV/m. An agreement is signed with PSI for the production of full HG module. By the start of 2020 new HG module would be installed at CTF for conditioning and high power testing. By the start of 2021 first HG module would be installed in place of BTW structure in FERMI tunnel as shown in Fig. 5.

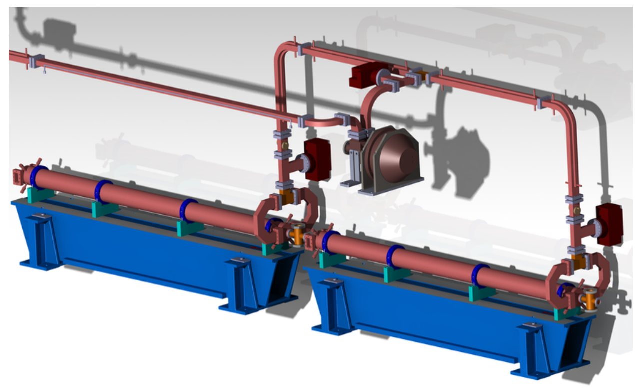

Figure 5: Layout of full HG module in FERMI tunnel.

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