FIRST LLRF TESTS OF bERLinPro GUN CAVITY PROTOTYPE

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Abstract

The goal of Berlin Energy Recovery Linac Project (BERLinPro) is the generation of a 50 MeV, 100-mA low emittance (below 1 mm mrad) CW electron beam at 2 ps rms bunch duration or below. Three different types of 1.3 GHz SRF modules will be employed: the electron gun, the booster and the main linac. Precise RF amplitude and phase control are needed due to the beam recovery process. In this paper we describe the first tests of the Low Level RF control of the first injector prototype at the HoBiCaT facility, implemented in the digital VME-based LLRF controller developed by Cornell University. Tuner movement control by an mTCA.4 system, together with further plans of using this technology will be also presented.

INTRODUCTION

The bERLinPro Energy Recovery Linac is a single pass, high average current and all superconducting CW driven ERL currently in construction by Helmholtz Zentrum Berlin (HZB). Its purpose is to serve as a prototype to demonstrate low normalized beam emittance of 1 mm·mrad at 100 mA and short pulses of about 2 ps [1]. bERLinPro will be formed by three 1.3 GHz modules with different characteristics and parameters [2]. The first module is a 1.4-cell gun cavity using a high quantum efficiency (QE) normal conducting multi-alkali cathode, which will deliver 2.3 MeV. The gun module is then followed by the booster module formed by three high power 2-cell booster cavities of Cornell type, where two of them deliver 2.1 MeV each and the third one is operated in zero crossing for bunch compression. The beam is merged into the main linac module consisting in three 7-cell cavities where it is accelerated to 50 MeV in a first pass and decelerated again to 6.5 MeV in a second pass. The beam is finally dumped in a 650 KW beam dump.

The gun is one of the most critical components and in order to mitigate risk, it is being developed in several stages. The first one, the so-called Gun0, was a fully superconducting system with a super conducting lead deposited on the back. It allowed beam studies without a complex insert of a high QE normal conducting cathode in a SC environment, [3]. The prototype presented here, called Gun1.0, is a medium power version of the final high power structure and utilizes CW modified TTF-III couplers. It is a beam dynamic optimized design with high QE cathode insert system allowing the generation of a beam up to 4 mA, [4]. It will be used to study bERLinPro bunch parameters and the usage of high QE NC cathode within a SC environment. The last step in the gun development is the Gun2.0, which will feature two modified KEK c-ERL high power couplers [5] to allow 100 mA average current operation.

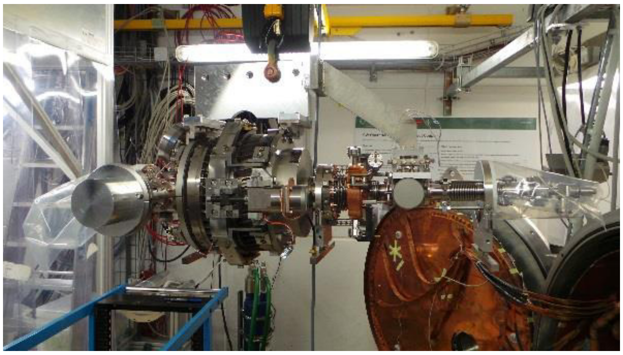

Figure 1: Gun1.0 cavity's cold mass with fundamental power couplers (left), blade tuner and cathode insert (right).

GUN1.0 CAVITY

After several vertical and horizontal tests at JLab and HZB where the Q_0 specifications were met [2], cold mass assembly and first horizontal tests under module conditions in the horizontal bi-cavity testing facility (HoBICaT) at HZB have been carried out [6].

Table 1: Main Parameters of Gun1.0

Max E_0	Max P_f	Q_L
30 (MV/m)	20 KW	$3\cdot10^6$ - $3\cdot10^7$

The cold mass consisting of the magnetic shielding, a blade tuner with a stepper motor and four piezo actuators, and the cathode insertion system, which includes a Petrov filter and a Helium gas cooler, was installed in HZB's clean room together with the fundamental power couplers. Figure 1 depicts the gun cavity's cold mass next to the HoBiCaT module. The installed coupler can stand an average input power up to 2 KW, but it is foreseen to equip later with modified warm part to allow 10 kW per coupler [7]. Unfortunately the penetration depth is lower than expected, which led to a higher Q_L and narrower bandwidth than expected. The last step in the cold mass assembly was to install the blade tuner including the motor and the piezo-actuators, whose pre-stress was adjusted by capacitance measurement. Table 1 shows the expected main parameters for the Gun1.0 cavity. The forward power will be delivered by two power couplers.

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* Work supported by German Bundesministerium für Bildung und Forschung, Land Berlin, and grants of Helmholtz Association

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LLRF CONTROL

After extensive tests to characterize the cavity Q_0 values and radiation levels, Lorentz force detuning measurement, piezo-actuators and stepper motor tuning range, helium pressure stability, and blade tuner transfer function were characterized using a phase lock loop system and a 15 KW solid state amplifier. The final values after cooling down are $Q_L=3\cdot10^7$ and a bandwidth of 43.29 Hz. The piezo actuators tuning range was measured with the four piezos connected in parallel and a total tuning range of 2.433 KHz was achieved. The tuning range and the hysteresis of the piezo actuators can be seen in Fig. 2. The measured Lorentz force detuning coefficient is 3.46 Hz/(MV/m)^2, making the piezo-actuators not sufficient to compensate it for higher fields. Lorentz force detuning compared to the piezo-actuators range can be seen in Fig. 3.

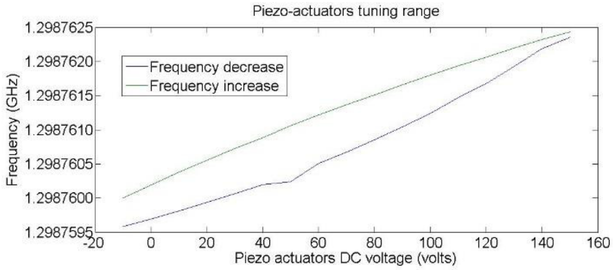

Figure 2: Piezo-actuators tuning range as the DC voltage is increased (blue) and decrease (green).

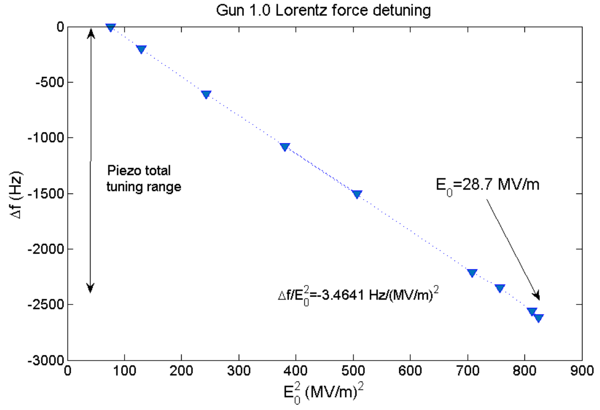

Figure 3: Lorentz force detuning.

Then the blade tuner and cavity transfer function was obtained using a lock amplifier and making a sweep in the frequency at two stepper motor positions, Fig. 4. Mechanical vibration modes can be extracted from the amplitude response, where the first mode can be found at around 160 Hz. The phase lag of the system can be obtained from the phase response, which gives a value of $\frac{\Delta\phi}{\Delta f} = 138\mu s$, theoretically allowing control up to 3.5 KHz.

The sensitivity of the cavity to helium pressure variations was also measured. Figure 5 shows the variations in the cavity resonance frequency increasing and decreasing the liquid helium pressure. The measured sensitivity value is 33.8 Hz/mbar, which is close to the design value.

Once all these values were characterized, the first LLRF control test were carried out. The hardware used was a VME-based digital board developed by Cornell University [8], as used in the past for a NbPb gun cavity and TESLA cavities in CW operation [9-10]. The hardware, consisting in two FPGAs and two DSPs, implements three control loops: RF amplitude and phase regulation, piezo actuators control loop and Lorentz force detuning compensation.

The first step was to operate the solid state amplifier in open loop to correct phase offsets and to find the correct parameters in the piezo actuators and Lorentz force detuning compensation loops. This step is vital for this gun cavity because Lorentz force detuning is high compared to the small bandwidth of the cavity. A three stub tuner was used in order to increase the power coupling and, thus, increasing the cavity bandwidth but not significant improvement was achieved ($Q_L=2\cdot10^7$, BW=65 Hz).

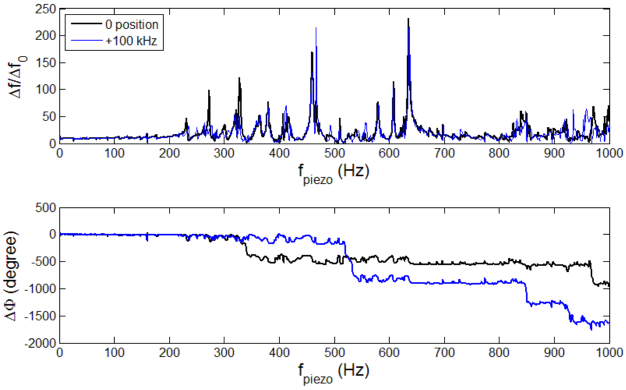

Figure 4: Amplitude response (up) and phase response (down) of the blade tuner and cavity at two stepper motor positions.

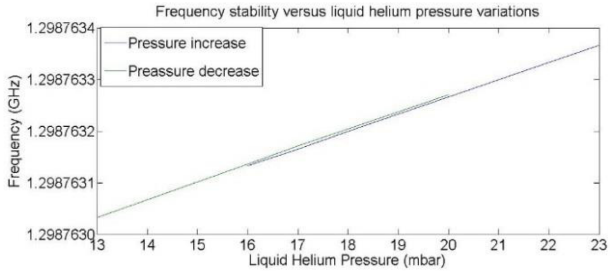

Figure 5: Frequency change due to liquid helium pressure changes.

Table 2: Amplitude and Phase Stability for Different Fields and Proportional Gain

E_0 (MV/m)	σ_f (deg)	σ_A/A	σ_f (Hz)	K_P
8	0.06	$2.6\cdot10^{-4}$	2.9	100
15	0.08	$2.6\cdot10^{-4}$	5.4	118
20.1	0.06	$2.6\cdot10^{-4}$	6.5	221

The next step was closing the RF control loop and increase the field in the cavity. The limit of available forward power, together with the narrow bandwidth and high Lorentz force detuning, reduces performance to lock under strong microphonics conditions. In Fig. 6 it can be seen that a maximum field of 21 MV/m was obtained. After this maximum, the motor was moved to try to increase it but the field tripped.

It can also be seen in Fig. 6 that there were several field trips at lower fields due to microphonics caused mainly by a near construction site. The used average and peak forward power is showed in Fig. 7. Table 2 summarizes the amplitude and phase stability values for different field levels. Note that the proportional gain of the loop had to be increased as the field level increased. It is also worth mentioning that the peak detuning increased for higher fields reaching up to ±18 Hz. The frequency components of the measured are in good concordance with the cavity-tuner transfer function, with a main component at 160Hz. But for high field values and some control loop parameters a 4 KHz oscillation was found whose cause still has to be investigated. These values, although are a good first result, still need to be improved to allow a field level of 30MV/m and a phase stability of 0.02°. In particular, plans for microphonics detuning compensation as shown in the past are foreseen [11].

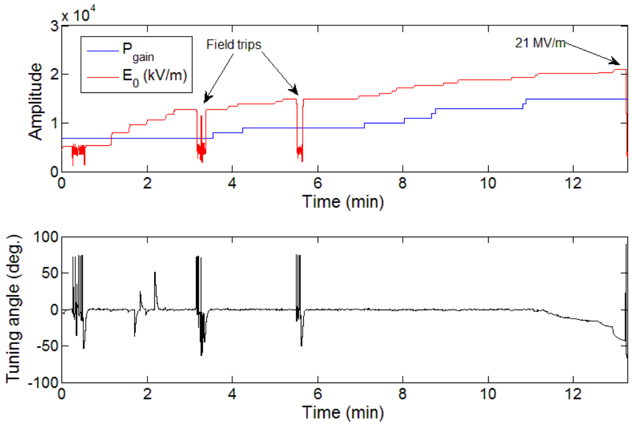

Figure 6: Field level and proportional gain (up) and tuning angle (down).

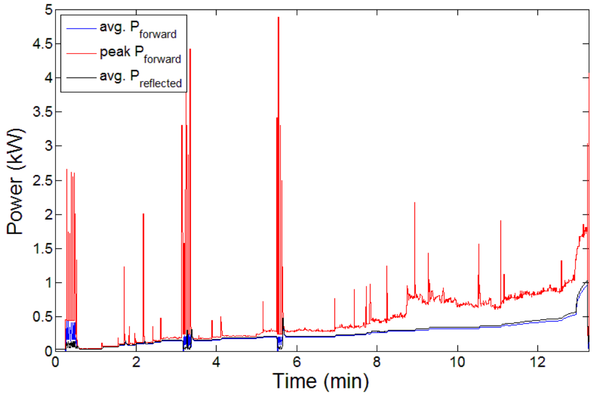

Figure 7: Peak and average forward power and reflected power.

mTCA.4 FIRST TESTS

For the future bERLinPro LLRF control implementation, the use of mTCA.4 system is foreseen. As each cavity will be fed by its own RF power source (klystron for gun and booster cavities and solid state amplifier for linac cavities) there is no need to calculate a vector sum. Therefore, the single cavity regulation approach will be used [12]. In this approach two slots of the crate are needed per cavity. The first slot will contain a SIS-8300L2 Advanced Mezzanine Card (AMC) and a DWC8VM1 as Rear Transition Module (RTM), both from Struck [13]. The latter contains a series of downconverters and a vector modulator to convert signals from RF to IF and vice versa. The former has a set of digitizers, an FPGA and DAC. Between these two boards, the amplitude and phase control will be closed and the calculated detuning angle will be sent to the other used slot. In this second slot the AMC is an FPGA mezzanine card with a MD22 board, which is a stepper motor control card from CAENels [13]. The RTM is a piezo controller able to drive up to four piezo-actuators. All these boards are connected through the backplane to a CPU AMC running Ubuntu [15] where the initial configuration, slow control and connexion to the control system is done.

Although all the hardware is in house, the lack of available experiment time at HoBiCat didn't allow to close the RF loop with the mTCA.4 system. The cavity detuning versus the stepper motor steps was measured using the MD22 board via the python bindings of the mTCA4U package [16]. Figure 8 shows the results of these measurement.

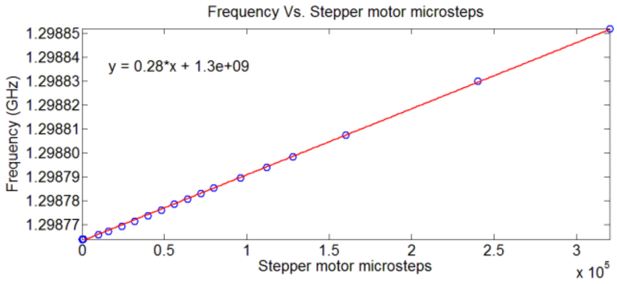

Figure 8: Cavity frequency vs. stepper motor microsteps.

OUTLOOK

In the following months, Gun1.0 will be taken from the HoBiCaT module and the installation of the so-called Gun Lab will begin. The normal conducting high quantum efficiency cathode will be attached to the cavity and the laser and diagnostics systems will be assembled, and by September 2016 dedicated beam tests together with LLRF test will be possible. Microphonics compensation and the possibility of ramping up the cavity using a self-excited loop will be studied. Around September 2017 the whole set up will be transferred to the bERLinPro accelerator hall and it will be ready for the installation of the booster module.

ACKNOWLEDGEMENTS

Authors would like to thank Martin Killenberg and Geogin Varghese at DESY for their development and support of the python tools to control the tuner's motor. Further thanks to Sascha Klauke, Michael Schuster, Andre Frahm, Frank Göbel, Jan Ullrich and Stefan Rotterdam for supporting the operation of HoBiCaT.

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