STATUS REPORT OF THE BERLIN ENERGY RECOVERY LINAC PROJECT bERLinPro[*]

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Abstract

The Helmholtz-Zentrum Berlin is constructing the Energy Recovery Linac Prototype bERLinPro, a demonstration facility for the science and technology of ERLs for future light source applications. bERLinPro is designed to accelerate a high current (100 mA, 50 MeV), high brilliance (norm. emittance below 1 mm mrad) CW electron beam. We report on the last year's progress, including the comissioning of the gun module as the first SRF component to be installed in bERLinPro.

INTRODUCTION

bERLinPro [1] is an Energy Recovery Linac Prototype, currently under construction at the Helmholtz-Zentrum Berlin (HZB), Germany. Application of superconducting radio frequency (SRF) systems will allow to accelerate currents at storage ring levels. The layout is shown in Fig. 1, the project's basic set of parameters is listed in Table 1. The bERLinPro injector, consisting of an photoinjector cavity (1.4 cell), followed by a Booster module containing three SRF cavities (2 cells), generates a high brilliant beam with an energy of 6.5 MeV. This beam is merged into the main linac section by means of a dogleg chicane and then accelerated in the three SRF cavities (7 cells) Linac to 50 MeV. With a racetrack magnetic lattice, the beam is recirculated for energy recovery and then sent into a 650 kW beam dump. Space is provided in the return arc to install future experi- ments or insertion devices to demonstrate the potential of ERLs for user applications. Major construction in the building was completed in 2017 so that machine component installation has begun. The accelerator installation is planned in two stages: the first stage, called "Banana", includes the entire low energy beam path from the gun to the high power beam dump, with a 5 mA gun (Gun1) and the Booster as well as a diagnostics line. The installation of the "Banana" is ongoing: after placing and aligning all girders and magnets in the beginning of 2017, rf and cryogenic installations are nearing completion. The Banana vacuum system will be assembled in the second half of this year, followed by the installation of the SRF modules (gun and booster). In the second project stage the installation and commissioning of the high current electron source, the linac module and the recirculation loop is planned to demonstrate efficient energy recovery with the full current, 50 MeV beam.

Table 1: bERLinPro's Main Target Parameters

parameter	value
maximum beam energy / MeV	50
maximum average current / mA	100
normalized emittance / μm rad	1.0
bunch length / ps	2.0 (0.1)
rf freq. & max. rep. rate / GHz	1.3
maximum losses	$< 10^{-5}$

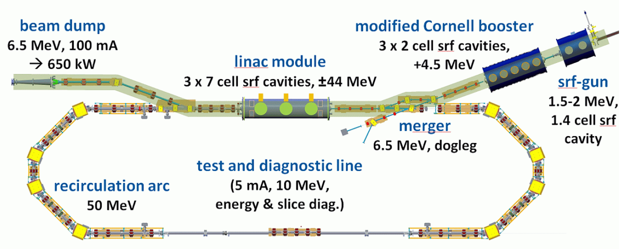

Figure 1: Basic bERLinPro layout. The green highlighted beam path is indicating the "Banana".

After the first SRF gun test at HZB in 2011 [2,3], in 2017 the second one took place in GunLab, a dedicated gun test laboratory [4]. Results of this run together with an overview of last year's progress of the various subproject groups is provided in this paper as well as update on the further project planning.

GUN COMMISSIONING

Since setup of the SRF Gun and diagnostics beamline [5] the goal was to complete technical commissioning of the diagnostics beamline and to start beam operation with Gun1, initially with metallic Cu photocathodes, later with multi-alkali CsK_2Sb photocathodes. We encountered several technical problems during the pre-beam check out phase. We were able to fix most problems in the warm part of the diagnostics beamline but were left with a short circuit in the

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current leads of the SC solenoid in the cold mass of the SRF gun module. This could not be fixed jeopardizing all beam dynamics related measurements planned for commissioning.

The drive laser beamline could be completed and is now serving both UV and green output wavelengths of the drive laser. For commissioning of Gun1 with Cu cathode UV at 260 nm can be generated from the drive laser fundamental wavelength, for the CsK_2Sb photocathode green laser pulses at 515 nm can be send to the cathode.

The goals related to photocathode R&D were preparation of Cu and CsK_2Sb photocathodes for the commissioning and the establishment of the particle-free UHV transfer chain [6] for these photocathodes. This transfer chain connects the preparation system which is located in a separate building than the SRF gun roughly 1000 m away. The transport chain is now fully operational and could be successfully tested with several Cu photocathodes.

Of particular interest during the last year was the setup and commissioning of two systems, monitoring the photocathode position inside the SRF gun cavity [7]. The position of the cathode surface with respect to the cavity backwall is strongly influencing the field distribution in the cavity and on the normal conducting cathode surface. It is thus defining both, the accelerating to focusing field ratio, an important parameter for the beam dynamics, and the ohmic losses in the cathode potentially leading to significant heating.

For this reason the cathode plug is movable and the position will be monitored with two independent systems. One is based on a laser distance meter, the other on a pack of three capacitive distance sensors.

We were able to prepare and transfer one Cu cathode into the SRF gun cavity. First beam could be generated and a small-scale program aimed at the characterization of the SRF gun cavity and the cathode (quantum efficiency mapping, dark current) with beam was started [8]. Then a multi-alkali CsK_2Sb photocathode with a quantum efficiency (QE) of 16.8% at 515 nm was prepared and transported into the SRF gun transfer system. The QE after transport was 5.3% at 515 nm after six days in the gun transfer chamber, limited by residual gas. During transfer into the SRF gun cavity we lost the photocathode plug due to a technical failure of the plug holding mechanism. Operation was stopped and concluded. We are now in the process to repair the SRF gun.

SRF SYSTEMS

GUN1.X: after installing GUN1.0 into the gun module in the first half of 2017, it has been commissioned and operated within the GunLab framework in the second half of 2017 (see [8]). In parallel the production of a second identical substitute gun (GUN1.1) was running, see [9] for details. This cavity will replace GUN1.0 and be installed into the gun module this year.

Booster: while still most activity of 2017 concentrated on the setup and commissioning of the first SRF photo-injector module, also the preparation to assemble the Booster module was intensified. Figure 2 displays a comparison between quality factor Q_0 versus mean accelerating field E_{acc} measured with the final vertical test at JLab [10] and horizontal data at HZB after controlled venting and pumping of the cavities in the cleanroom. They are now ready for cold string assembly. This can start, once the high power couplers are in house and conditioned in a dedicated test box [11]. As the vendor had issues with the electro-polishing of the solid Copper-made inner conductors of the cold part, delivery will be now expected for early fall this year.

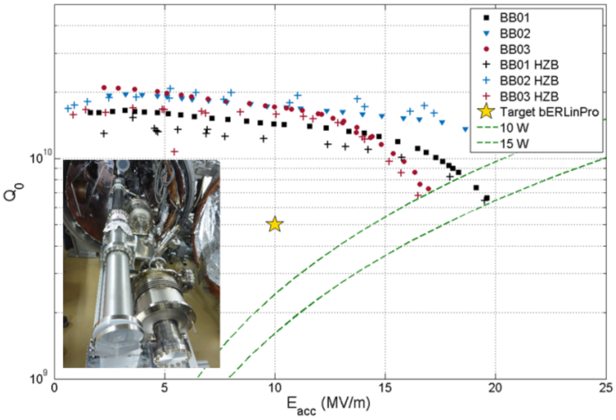

Figure 2: Comparison of vertical test at JLab to $Q_0(E_{acc})$ data measured in horizontal test setup at HZB in HoBiCaT (see insert).

WARM SYSTEMS

Magnets: the gaps of the low energy path magnets are open since their installation in Q I /2017, and will be closed by the BINP colleagues after installation and baking out of the vacuum-chambers in December 2018. At this time also all magnet-gaps of the recirculator will be opened to prepare for installation of the vacuum chamber.

Vacuum system: in March 2018 the first vacuum components for the "banana" have been delivered. Due to bi-metal components of low quality nearly all the already welded flanges hat to be exchanged. This caused a delay of delivery and installation schedules. The first half of the low energy, "banana" vacuum components will be installed in July 2018 followed by the second installation phase in October 2018. This work will be done under responsibility of the manufacturer. Nevertheless the preparation of the accelerator hall as well as the provision and operation of the clean room tents is on HZB's own authority. Nearly all the cables and wires for the diagnostic and vacuum components are installed and assembling is ongoing. All the electrical, cooling-water and pressed-air infrastructure for the warm system components is installed in the accelerator hall.

Beam dumps: in December 2017 the main dump was deliverer and is now installed in the accelerator hall, as the first vacuum component of the "banana". Vacuum and water tightness were tested at the manufacturer site. Cleaning and backing out of the big copper hat will take place before installation of the other low energy beam path components.

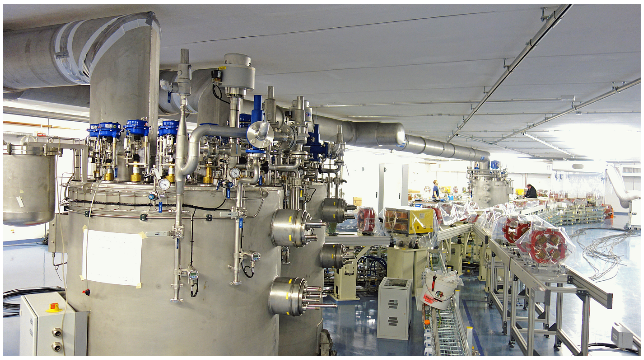

Figure 3: Feedboxes and cryolines in the bERLinPro accelerator hall. In the background the injector line and the end of the second recirculator arc can be seen.

Beam diagnostics: all main components of the diagnostics are delivered and tested in house. The strip-line sockets for the low energy path were measured before finial welding to the vacuum chambers. DCCTs and FCT were tested for different operation modes and the limits in stability and accuracy were examined. The beam loss monitor sensors withstood the radiation exposure tests and are in production.

Machine Protection System (MPS): the MPS will prevent severe machine damages caused by losses of the high power beam. It is specified to reach a reaction time of approximately 2 – 3 μs between receiving a diagnostic input signal and sending out a shut off output signal. The prototype of a scalable and distributed, FPGA based MPS with EtherCAT communication link to the EPICS based control system has been tested successfully. The production is on the way in order to provide the MPS in time.

RF AND CRYOGENICS

Cable, wave guide and controls installations are progressing well and will be timely finished. All gun and booster transmitter parts are in house. The first one is on power and currently tested, the others are put on place in the bERLinPro building. In April 2018 the call for tender for the linac solid state amplifiers (4 with 15 kW each) was started.

For the cryogenics system all parts in house: cold compressors, warm vacuum pumps and the module feed boxes, all flexible and rigid cryo lines are installed, see Fig. 3. In February the existing Helium liquifier L700 moved to the bERLinPro infrastructure hall.

RADIATION SAFETY

Besides the radioactivation of magnets and vacuum system [12] also that of the cooling water was considered. Since the heat exchanger are outside the accelerator enclosure the dose rate around the water tubes was determined as well as the activation concentration of the radionucleii with longer half lives. The later one gives the decline and thus storage times in case of a cooling water leakage.

In a first step we calculate the radionucleii and the dose rates with Fluka [13, 14] using a model with a 2 m long aluminum vacuum tube of elliptical shape including two cooling water tubes (diameter 1 cm) on both sides of the electron beam. A beam of 100 μA loss current is hitting the side of the vacuum tube with an angle of 20 mrad.

Table 2: Activitation Concentration, with the Limits of the German Radiation Protection Ordinance in the Last Column

nuclide	$A(t)$	$T_{1/2}$	$C/\frac{\mathrm{Bq}}{\mathrm{cm}^3}$	$C_L/\frac{\mathrm{Bq}}{\mathrm{cm}^3}$
${}^{3}_{1}\mathrm{H}$	1.159E+04	12.323 a	72.34	1000
${}^{7}_{4}\mathrm{Be}$	5.028E+04	53.29 d	313.82	30
${}^{14}_{6}\mathrm{C}$	87.7	5730 a	0.54	80

With the same Fluka run also the production rate $\dot{N}^+$ of the radionulceii has been calculated. From that the activities of the radionucleii was calculated (irradiation pattern: 8 h beam, 16 h decline, for 365 periods), using the activation equation, see e.g. [12].

By scaling these results with the full accelerator dimensions we get the activation concentrations for the complete water volume of the cooling circuit shown in Table 2. While the activation concentrations of Tritium and Carbon are far below the limit, the one of Beryllium is about one order of magnitude above the limit. Thus, the water has to be stored and controlled for a decline time of 10 half-lives before it could be given to effluents system.

In a last step from the activation concentrations the dose rates from the radionucleii were calculated, including also radionucleii with short half-lives. The dose rate is < 1 μSv/h even close to the water tubes, thus not significant.

PROJECT TIME LINE

Due to technical and delivery issues, as well the competing BESSY VSR project, slippage of the bERLinPro schedule has been unavoidable. Prioritized BESSY VSR development coincides with the planned assembly times of the high current gun and the main linac fully, straining available staffing and the infrastructure. Thus these components are currently on hold. To improve the situation, planning is currently under way to temporarily install one of the MESA modules from the Universität Mainz ERL project [15]. This option would allow for a mA class operation of bERLinPro, at nearly the project target energy and to demonstrate energy recovery. Table 3 provides the time line, including the MESA option. No times for the high current operation of bERLinPro with a dedicated linac module are given.

Table 3: bERLinPro's Updated Time Line

Q1/2017	building ready for machine installation, start of cryo system installation & comm.
Q3/2017	first electrons from GUN-1 @GunLab
2018	Refurbishment of GUN1
Q1/2019	start SRF operation GUN-1 @Banana
Q2/2019	first electrons in Banana
2020	first electrons with MESA option GUN-1, Booster, MESA module & recirc.

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