COMMISSIONING CONSIDERATIONS FOR bERLinPro*

M. McAteer†, M. Abo-Bakr, T. Kamps, G. Klemz, J. Kuszynski
Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany
I. Will, Max-Born-Institute, Berlin, Germany

Abstract

bERLinPro is an energy recovery linac project whose goal is to establish the accelerator physics knowledge and technology needed to produce 50 MeV beams with high current, low normalized emittance, and low losses. The machine will be commissioned in phases beginning in 2018, and extensive planning is underway for start-up of the machine and to prepare for measurements to verify the achievement of target beam parameters. This paper outlines the planned phases for the commissioning of the machine, details the operational modes, and gives an overview of the diagnostics available for beam-based measurements to verify the achievement of performance goals.

INTRODUCTION

bERLinPro is a 50 MeV energy-recovery linac which will be commissioned starting in 2018 [1]. A primary purpose of bERLinPro is to demonstrate low normalized emittance (1π mm mrad), high-current (100 mA) ERL operation with low losses. bERLinPro will be commissioned in several phases. In the first several phases of commissioning the recirculator will not yet be completed so the beam will travel from the electron gun directly to the main dump, a path which is referred to as the “Banana”.

For the initial commissioning neither the booster nor the linac will be installed, so the maximum kinetic energy will be 2.7 MeV. At this time only a 50 MHz laser will be in use rather than the planned 1.3 GHz laser, which will limit the average current to a maximum of ~4 mA. At this stage the low-energy beam will likely only be transported to the diagnostics line rather than to the main dump.

During the second phase, shortly after the initial commissioning, the booster will be installed and the maximum kinetic energy will increase to 6.5 MeV. The current will still be limited to ~4 mA due to the 50 MHz laser.

During the third phase, in 2019, the 1.3 GHz laser and a new electron gun with high power couplers (Gun 2) will be installed, allowing for average currents of 100 mA at 6.5 MeV [2].

During the final phase the linac and the recirculator will be installed, allowing for the production of 100 mA, 50 MeV beam with energy recovery.

The target beam parameters for both the various commissioning phases are shown in Tables 1 and 2.

* Work supported by the German Bundesministerium für Bildung und Forschung, Land Berlin and grants of Helmholtz Association
† Meghan.McAteer@helmholtz-berlin.de

Table 1: Target bERLinPro Parameters

Parameter	Value
Bunch charge	77 pC
Emittance (norm.)	<1 π mm mrad
Bunch length	<2 ps
Beam loss	$<10^{-5}$

Table 2: Parameters During Commissioning Phases

Parameter	Ph. 1	Ph. 2	Ph. 3	Ph. 4
E_{kin} [MeV]	2.7	6.5	6.5	50
F_{laser} [GHz]	0.05	00.05	1.3	1.3
I_{avg} [mA]	4	4	100	100

OPERATING MODES

Machine Modes and Beam Modes

The operational state of the machine is defined by both a “machine mode” and a “beam mode”. The machine mode determines the physical path that the beam will take through the machine, and the current limit for each machine mode is defined by the capacity of the relevant beam dump. There will be six machine modes in bERLinPro, four of which will be relevant for the initial low-energy commissioning phase (see Fig. 1 and Table 3).

There will be two beam modes: a diagnostics mode with current limited by the damage threshold of the invasive diagnostics (~0.5 μA) and a high-current mode with a limit of 100 mA. The effective current limit of the machine in a given machine mode/beam mode state will be the lower of the two current limits.

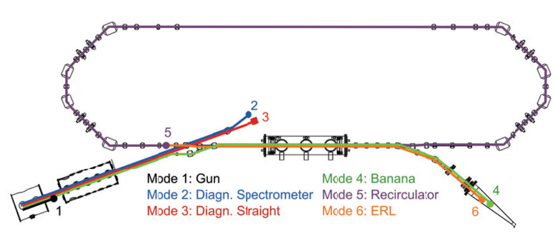

Figure 1: Machine modes in bERLinPro.

Laser Modes

The photocathode drive laser is being developed in a collaboration between HZB and Max-Born-Institute in Berlin. The laser will be capable of generating three pulse patterns: single bunches, macro-pulses, or continuous wave. The average beam current can be controlled either by altering the

ISBN 978-3-95450-182-3

Table 3: Machine Mode Current Limits

Mode	I_{avg} limit
1. Gun	30 μA
2. Diagn. Spectr.	10 μA
3. Diagn. Straight	5 mA
4. Banana	100 mA
5. Recirculator	1 μA
6. ERL	100 mA

repetition rate of full-charge bunches or by reducing the charge per bunch for CW bunches. The maximum laser power on the cathode (25 W) produces a bunch charge of 77 pC when the cathode quantum efficiency is 1% [3].

50 MHz laser The initial commissioning of bERLinPro will be done using a 50 MHz laser, which will have only two modes: single bunch (SB) and continuous (CW) (see Fig. 2). In SB mode the average beam current is altered by gating some laser pulses with Pockels cells, allowing for delivery of single bunches at a variable rep rate. A 10^{-8} extinction level is expected for the gated bunches. Single bunches can be delivered at a variable rate of 1 Hz to 100 kHz, giving a beam current between 77 pA and 7.7 μA.

In CW mode, the 50 MHz laser pulses are not gated. The bunch charge can be varied quasi-continuously between 0 and 77 pC, allowing for a quasi-continuous ramping of beam current from 0 to 3.85 mA.

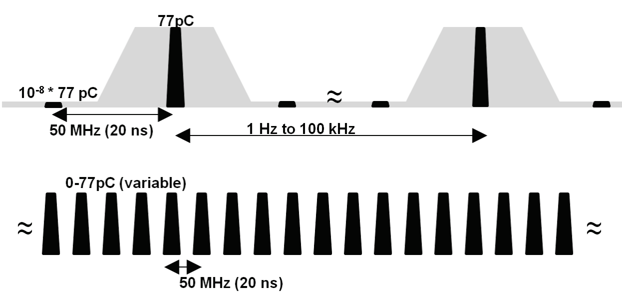

Figure 2: Pulse patterns during initial commissioning with the 50 MHz laser. The laser will be able to produce single bunches at a variable rate of 1 Hz to 100 kHz (SB mode, top) or continuous 50 MHz bunches (CW mode, bottom).

1.3 GHz laser After the 1.3 GHz laser is commissioned in 2019, three laser modes will be available: single bunch (SB), macro-pulses (MP), and continuous (CW) (see Fig. 3).

Single bunch mode will be exactly the same as described in the previous section, using the 50 MHz laser.

In macro-pulse mode some pulses from the 1.3 GHz laser will be gated using Pockels cells, resulting in macro-pulses of electron bunches with variable duration and variable repetition rate. The rise time of the Pockels cell, which is expected to be approximately 10 ns, is longer than the spacing between the 1.3 GHz pulses, so approximately 13 partially-extinguished pulses will fall within each edge of the gate. The duration of the macro-pulses can be varied between 60 and 200 ns ($\approx$ 78 to 260 bunches per macro-pulse), and the macro-pulse rep rate can be varied between 1 Hz and 1 kHz. The corresponding average beam current is between ~ 5 nA and 20 μA.

In CW mode, the 1.3 GHz laser pulses are not gated. The bunch charge can be varied quasi-continuously between 0 and 77 pC, allowing for a quasi-continuous ramping of beam current from 0 to 100 mA.

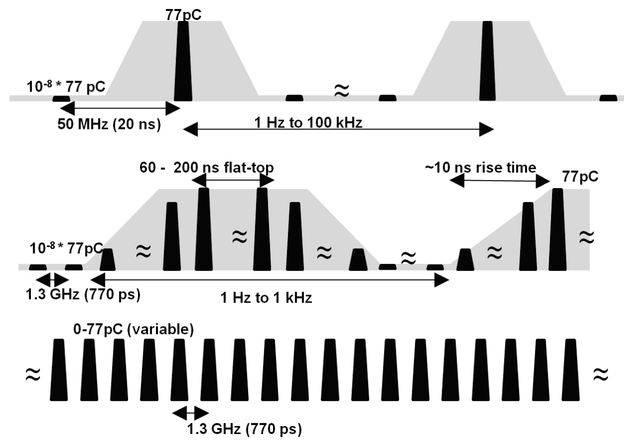

Figure 3: Pulse patterns after the 1.3 GHz laser is installed. The 50 MHz laser will produce single bunches at a variable rate of 1 Hz to 100 kHz (SB mode, top), and the 1.3 GHz laser will produce macro-pulses of 1.3 GHz bunches at a variable rate of 1 Hz to 1 kHz (MP mode, center) or continuous 1.3 GHz bunches (CW mode, bottom).

INSTRUMENTATION

A primary purpose of bERLinPro is to demonstrate high-current, low-emittance, low-loss ERL operation, so thorough measurements are needed in order to verify the achievement of target beam parameters [4]. This section outlines the diagnostics devices that will be available during the first phases of commissioning (in the "Banana") for making beam-based measurements, which include YAG:Ce view screens (FOMs), Faraday cups, stripline beam position monitors (BPMs), integrating current transformers (ICTs), and a DC current transformer (DCCT). The location of the devices is shown in Figure 4 and the intended current range for each device is summarized in Table 4. In some cases low-resolution measurements may be possible outside of the ideal ranges; further testing is pending.

YAG:Ce Screens

The YAG:Ce view screens (FOMs) are movable and will only be inserted during the diagnostics beam mode. The damage threshold for the FOMs is estimated to be 0.5 μA, which defines the current limit for the diagnostics beam mode. This average current can be produced using any of the three laser pulse patterns: single (full-charge) bunches at a 6.5 kHz rep rate, macro-pulses approximately 100 ns long

ISBN 978-3-95450-182-3

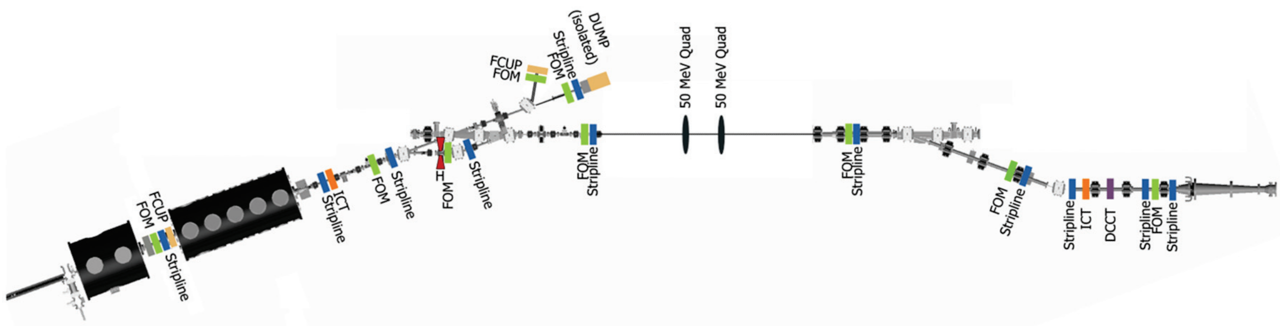

Figure 4: Diagnostics in the Banana.

at a 50 Hz rep rate, or continuous bunches with the laser power/bunch charge reduced by six orders of magnitude. For most diagnostics measurements, using single bunches will be preferable because low-charge bunches (either the partially-gated bunches in macro-pulse mode, or the intentionally low-charge bunches in CW mode) will have different beam dynamics due to space charge effects.

Faraday Cups

The three Faraday cups include a small movable cup which can be inserted into the beam line just downstream of the gun cavity, a small cup which is located at the end of the diagnostics spectrometer line, and a medium-power (5 mA) beam dump in the diagnostics straight line which can be used for charge measurements. The two smaller Faraday cups have a power limit of 100 W, which corresponds to an average current of approximately 30 μA for low-energy beam after the gun and approximately 15 μA for higher-energy beam in the diagnostics line.

Beam Position Monitors

The stripline BPMs have resolution of about 0.1 mm with beam currents greater than approximately 1 mA. Lower-resolution measurement with currents as low as 10 μA may be possible with certain fill patterns and a lower resolution of about 0.25 mm, but this remains to be tested.

Current Transformers

The DCCT is located just before the main dump. For best resolution the DCCT must integrate over at least one second, in which case the measurement has a precision of approximately 0.1% for currents greater than 1 mA and as high as 10% for low (∼10 μA) currents. Temperature changes of a few degrees can cause a drift in the current reading of about 10 μA.

The two ICTs, which are located just downstream of the booster and before the main dump, can only be used with bunched fill patterns. The measurement resolution is best when there is a gap of at least 70 ns between single bunches or macro-pulses, and when the macro-pulses are less than 100 ns long, but lower-resolution measurements can still be made with somewhat smaller bunch spacing or longer pulses. The maximum average current for which ICTs have good resolution is 10 μA (using macro-pulse laser mode with 100 ns pulses at a 1 kHz repetition rate). The ICTs may be capable of low-resolution measurements of 50 MHz CW beam, but this remains to be tested. They will not be usable at all for 1.3 GHz CW beam. With high-current beam, current measurements in the injector can be made using the sum signal from a BPM, which is expected to have ∼1% resolution.

Table 4: Current Ranges for Diagnostics in Banana

Device	#	Ideal Range
FOMs	10	<0.5 μA
Faraday cups	3	<10 μA - 5 mA
BPMs	11	>1 mA
DCCTs	1	10 μA-100 mA
ICTs	2	<10 μA

SUMMARY

The commissioning of bERLinPro will be done in several phases beginning in 2018, and details of those commissioning phases are given here. The planned machine modes, beam modes, and laser modes are also discussed. The available diagnostics devices, which will allow for verification that bERLinPro achieves its target beam parameters, have been overviewed.

REFERENCES

[1] M. Abo-Bakr *et al.*, “Status Report of the Berlin Energy Recovery Linac Project bERLinPro,” in *Proc. IPAC’16*, Busan, Korea, May 2016, TUPOW034, pp. 1827-1830.

[2] B. Hall *et al.*, "120 kWRF Power Input Couplers for bERLinPro", in *Proc. IPAC’17*, Copenhagen, Denmark, May 2017, MOPVA046.

[3] J. Kühn *et al.*, "Measuring the Spectral Response of Cs-KSb Photocathodes for bERLinPro", in *Proc. IPAC’17*, Copenhagen, Denmark, May 2017, TUPAB028.

[4] M. McAteer, J. Knedel, G. Kourkafas, J. Völker, “Simulations for Beam-based Measurements in bERLinPro,” in *Proc. IPAC’17*, Copenhagen, Denmark, May 2017, MOPVA007.