BEAM POSITIONS MONITORS FOR PERLE INJECTOR*

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on behalf of PERLE collaboration

Abstract

PERLE is an Energy-Recovery Linac (ERL) to be constructed at IJCLab in Orsay. It will be the First ever multi-turn ERL with superconducting RF (SRF) acceleration, and the first ERL with the ambition to reach 5 MW beam operation. Diagnostics are a key element for PERLE operation and among diagnostics, Beam position monitors (BPMs) cover a wide range of applications. This document reports BPM goals for a proper operation of PERLE, it also details the design of BPM detectors and eludes the steps for their realization. it finally discusses the design of BPM electronics to match the presence of multiple beams which need to be individually diagnosed and controlled.

INTRODUCTION

PERLE facility is a new generation energy recovery machine covering the 5 MW power regime with 20 mA beam current and 250 MeV beam energy [1]. It is a compact multiple pass ERL to serve as testbench for the validation of various accelerator phenomena and technical choices for future projects.

An overview of PERLE is sketched in Fig. 1. The photocathode gun is on the far right with the injector section immediately following. In this configuration, the peak beam energy is 250 MeV. This is achieved by passing three times through a SRF LINAC .

Starting from a 7 MeV injector, the beam gains 82 MeV per turn, reaching successively 89 MeV, 171 MeV and a final energy of 250 MeV after 3 recirculation passes. After a path length shift of exactly half of RF period, it is then decelerated through the same linac structure to recover the beam energy up to the final dump at 7 MeV.

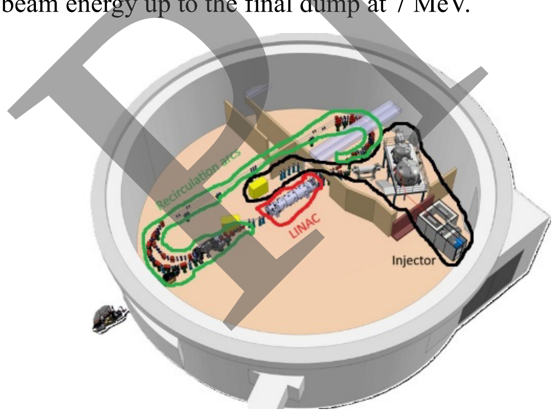

Figure 1: Overview of PERLE in Orsay.

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PERLE diagnostics should monitor specific beam properties at different locations. The following list outlines the diagnostic requirements for PERLE BPMs:

- Orbit, charge, and longitudinal length measurements at the output of the injector.
- Calibration of the LINAC cavity phases to optimize the operation of the LINAC [2].
- Beam path monitoring for each recirculation arc to precisely adjust the length of the path of each beam in the recirculation arcs.
- Monitoring of several beams: measurement of the position of each beam individually.

Some of these measurements are particularly challenging due the large dynamic ranges over which the beam might operate:

- Beam type: pulsed to cw
- Charge: 10 pC to 500 pC
- Energy: 350 keV to 250 MeV
- Current: 100 µA to 20 mA
- Longitudinal length: 3mm or 10 ps

This article first details the BPMs for the gun, then it focuses on the realisation steps for the other BPMs. Finally, it discusses solutions for BPM acquisition electronics.

BPMS FOR THE INJECTOR

PERLE is currently under construction in the IGLOO building at the IJCLab in Orsay, France. The project is progressing in successive phases, each designed to validate a key step toward the full ERL operation. The first phase, scheduled for late 2028, focuses on realization and the commissioning of the injector sketched in Fig. 2.

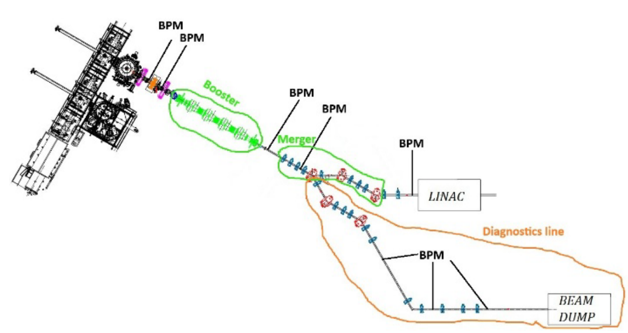

Figure 2: PERLE injector overview with BPMs locations.

Both commissioning and routine operation of the injector look for orbit measurement and correction capabilities with a precision of 100 µm. Although this requirement is stringent, it remains achievable based on the performance levels demonstrated in recent accelerators. Button BPMs are adequate regarding the bunch properties. Eight BPMs are needed in the injector. 2 button BPMs were already purchased with PERLE Gun: the BPM internal diameter is

Preprint

68.6 mm and the button diameter is 11 mm. The 2 BPMs are integrated with steerers as sketched in Fig. 3.

Figure 3: PERLE Gun BPM with steerers.

The electrical isolation of these two BPMs are conform. Each button was characterized with time domain reflectometry. Each BPM electrical offset was measured with the test bench already presented in [3] and matched to PERLE gun BPMs. The test bench measurement results are shown in Table 1.

Table 1: PERLE Gun BPMs Measured Offsets

Gun	X offset [µm]	Y offset [µm]
BPM1	62	-44
BPM2	43	86

Each 25 ns, a single bunch is driven through the injector. Position measurement for these bunches is typically performed at a predefined frequency F. For the gun commissioning, a temporary solution using a LIBERA Brilliance module [4] is privileged.

For post booster BPMs, the internal dimater is set to 60 mm and the buttons diameter is set to 11 mm. BPM position measurements will cover a range of ±10 mm from BPM center on both axes. CST simulations are exposed in Table 2. They show that the expected peak value of buttons output voltage covers an acceptable range for most acquisition systems.

Table 2: Simulation Results of Injector Button BPMs

Location	Peak min value [mV]	Peak max value [V]
Gun	8	4.8
Post booster	88	20

We remind that the values mentioned in Table 2 do not take into account the losses due to the cables (expected to be about 20 mm long) routing the signal from the buttons to the acquisition systems.

BPM MECHANICAL DESIGN

To handle possible housing and integration issues, BPM and steerers mechanical designs are separated. Either for the injector and the linac on one side (60 mm beam pipe diameter) or for the recirculation arcs on the other side (40 mm beam diameter), the BPMs to be realized stands within a CF63 flange with an overall thickness of 17.5 mm.

The new BPM mechanical design is shown in Fig. 4.

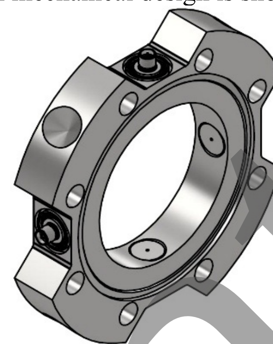

Figure 4: PERLE injector BPM mechanical design.

The SMA connectors are easily accessed and the positioning targets are also included.

As mentioned in [5], it's not possible to use a single frequency acquisition technique for the acquisition electronics of the BPMs located at the entrance and the exit of the LINAC and also for

the BPMs in the 89 MeV and 171 MeV recirculation arcs. Treating the buttons output signal in time domain remains the most appropriate way to measure bunch position and phase shift regarding linac reference signal. Therefore, the feedthrough design is optimized for operation over a large bandwidth to treat as close as possible the full button output signal.

Figure 5 shows the transmission coefficient of the designed feedthrough. There is less than 2.5 dB loss up to 10 GHz.

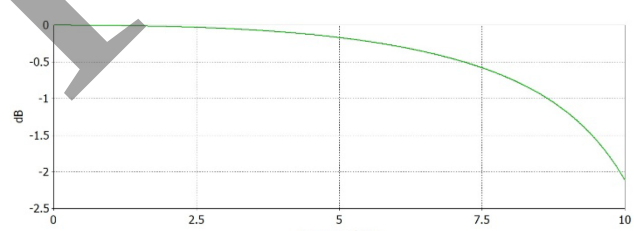

Figure 5: PERLE BPM feedthrough transmission coefficient.

BPM VALIDATION TESTS

The testing of BPM feedthroughs was traditionally conducted in reflection mode and at a specific frequency. However, the requirements of PERLE BPM acquisition electronics demand a broader bandwidth approach. These needs extend beyond reflection alone, encompassing both transmission and reflection modes. Thus, the validation methodology evolves to address both transmission and reflection scenarios.

A dedicated tests bench is under realization to handle this issue. A simplified design is sketched in Fig. 6.

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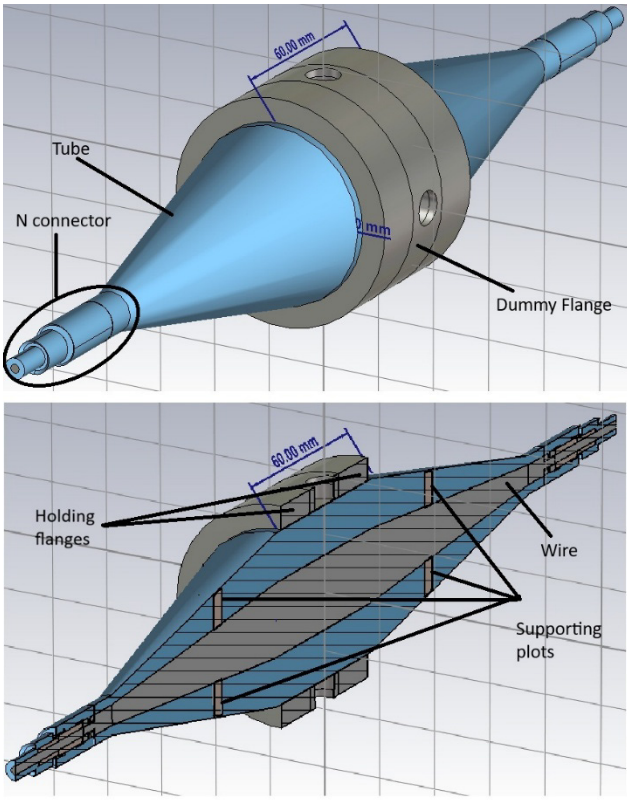

Figure 6: Dedicated test bench for PERLE BPM buttons validation; top: outside view, bottom: inside view.

The "wire" vehicles a VNA input signal. The conic shape of both the wire are intended to match the full structure to a 50 Ohm operation over 10 GHz bandwidth. The structure (without the "wire") is split into 3 parts. Left and right parts are identical with their respective holding flange. The supporting plots are added to ease the integration of the wire inside the test bench. The central part can be either a "dummy" flange one to four buttons can be fixed for testing, or the real BPM once it's fabricated.

With this test bench, all buttons can be tested at the same position. Both transmission and reflection ratios will both be measured over a large bandwidth. Therefore, a more accurate pairing of the buttons can be applied. It can be verified before and after buttons brazing in the BPM structure.

NEXT STEPS

Twelve buttons and two pre-series button BPMs will be realized within fall 2026 to assess and validate their fabrication and testing processes. BPM series should be quotes and ordered within 2027. Strong attention should be put on acquisition electronics. We hope for custom prototype ready within a year. We outlook to scope within PERLE realization phases.

CONCLUSION

An overview of PERLE beam position monitors is reported. Focus was put on the design, the realization and the validation of these BPMs.

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