Measurement of Momentum Halo Due To the Reduced RFQ Voltage During Beam Commissioning of LIPAc

Kouki Hirosawa¹, A. De Franco¹, K. Masuda¹, A. Mizuno¹,
S. Kwon¹, K. Kondo¹, M. Sugimoto¹, K. Hasegawa¹,
I. Moya², F. Scantuamburlo², F. Benedetti²,³, D. Gex², H. Dzitko², Y. Carin²,
I. Podadera⁴,⁵, J. C. Morales Vega²

¹QST, ²F4E, ³CEA, ⁴Ciemat, ⁵IFMIF-DONES España

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Linear IFMIF Prototype Accelerator (LIPAc)
Rokkasho Fusion Institute (BA Site)
Outline

- LIPAc Overview
- Phase-B+ Beam commissioning
- Momentum Halo due to the reduced RFQ voltage
- Summary and Discussion
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To validate low energy part (≤ 9.0MeV) of the IFMIF accelerator for testing material for the fusion power plant.

### Phase-B+ Layout

**Ion species**

<table>
<thead>
<tr>
<th>Ion species</th>
<th>( D^+ ) (H(^+) for start-up/tuning)</th>
</tr>
</thead>
</table>

**Peak current**

Up to 125 mA

**RFQ output energy**

5 MeV

**SRF output energy**

9 MeV

**RF frequency**

175 MHz

**Bunch width**

0.1–0.7 ns (sim.)

**Duty factor**

\( 10^{-2} – CW \)

**Pulse length**

\( 10^2 \mu s – CW \)

**Beam power**

Up to 1.125 MW

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**Previous Phases**

**Phase-A (Apr. 2015 - Aug. 2017)**

Injector + Diagnostic box

100keV, -125 mA, 12.5kW, CW beam


Injector + RFQ + MEBT + D-Plate + BD (Beam Dump)

5MeV, -125mA, 625kW, Pulsed beam

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Strategy of the Phase-B+

Phase-B+ Mission

- Injector CW operation
- RFQ CW operation
- 125mA 5MeV D⁺ beam in high DC

- To Validate diagnostics
- Preparation for Phase-C
Strategy of the Phase-B+

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Now

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- The Pilot beam (10mA H⁺ and 20mA D⁺) were tested.
- Chopper pulsing has been confirmed.
- Alignment of full beam transport was check in beam-based method.
- Newly installed components were checked.
  - Validation of diagnostics → Stage-2 and -3 in high current and DC.
- Measured beam size could be reproduced by the simulation.
- Evaluation of space charge compensation degree.

Interesting topics observed from this stage
- Transient of chopper and space charge compensation.

LIPAc Phase-B+ Stage-2

Stage-2 (Aug. 2023 – )
Developed point – Learnt from Stage-1, Alignment corrected, Injector CW commissioning completed.

Objective and Results:

☐ Recheck what we confirmed during stage-1, in the high current operation.
  ✓ Chopper worked well.
  ✓ Beam-based alignment was performed.

☐ Transport the 5MeV 125mA D+ beam to the BD.
  ✓ Beam transported to the BD (112mA D+ 150us with 120us plateau, 1Hz).

☐ Validation of the Interceptive/non-interceptive diagnostics.
  ✓ Interceptive devices worked well. Details ➔ Oral session by S. Kwon (FRC1I2)
  ✓ Visibility of all BPMs has been confirmed by steering scan.

☐ Study dynamics of space charge compensation degree.
  • Testing the effect of Kr gas flow rate to the transient
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Measurement by ACCTs (7th / Sep. 2023)

~125mA ~112mA

Phase-B+ lattice

ACCT positions
LIPAc Phase-B+ Stage-2

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Phase-B+ lattice

3 of 14 BPM positions
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  - Testing the effect of Kr gas flow rate to the transient measurement by ACCTs (7th / Sep. 2023)

**Measurement by ACCTs (7th / Sep. 2023)**

**Centroid motion in a pulse measured by BPM.**

- **After RFQ**
- **MEL center**
- **Near D-plate slit**

**9-13 Oct. 2023**

**HB2023 @CERN, Switzerland**

**~125mA**

**~112mA**
LIPAc Phase-B+ Stage-2

Influence of Kr gas flow rate.

- Kr=0.00 sccm
- Kr=0.40 sccm
- Kr=0.80 sccm
- Kr=1.20 sccm
- Kr=1.25 sccm
- Kr=1.65 sccm
- Kr=2.35 sccm

MEBT ACCT (RFQ exit.)

LIPAc RFQ (4 vanes type) spec.
- Length : 9.8m consists of 18 modules
- RF Frequency : 175MHz
- RFQ vane voltage : 132kV → 137kV (new nominal)
- Kilpatrick : 1.8
- RF source : 8 chains, 200kW / chain

Simulation work

- Original source: TraceWin and Toutatis Input file designed by L. Bellan

Coming from Luca’s work. (L. Bellan, 2nd CBO workshop)
LIPAc Phase-B+ Stage-2

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  - Kr=0.40 sccm
  - Kr=0.80 sccm
  - Kr=1.20 sccm
  - Kr=1.55 sccm
  - Kr=1.65 sccm
  - Kr=2.35 sccm

**Current [mA]**

- 100
- 80
- 60
- 40
- 20
- 0
- -20

**Time [μs]**

- 0
- 50
- 100

104% (137kV) is better.
Outline

LIPAc Overview

Phase-B+ Beam commissioning

Momentum Halo due to the reduced RFQ voltage

Summary and Discussion
Motivation

• Reduced RFQ voltage induces spreading distribution following discrete energy levels.
• Phase-C configuration has a cryomodule LINAC with 8 superconducting solenoids and cavities, which has 10W margin of the heat as the whole helium tank.
• Phase-B+ is a good chance to test beam dynamics depend on RFQ voltage, aggressively.
• By testing it in this phase, we are considering to prepare a kind of Interlock for losses in the cryomodule.
Momentum Halo due to the reduced voltage

RFQ simulation: applied vane voltage = 90% (119kV) - 105% (138kV)

Particle distributions for longitudinal phase space

Not properly accelerated particles, called "Momentum Halo", are included in the same duration just after RFQ.
Downstream simulation for the cryomodule

Beam loss in the cryomodule was checked by particle tracking simulation. Less than 94% can produce beam loss > 10W in the simulation (1M pt.), without error study. At least, 95% is one threshold.
Check Beam Loss in the Phase-B+

Estimation by tracking simulation was done to know good monitoring position if we can detect the effective beam loss along the downstream BT.

Effective beam loss can be detected by:

- BLM13 and 14, and 3rd $^3$He detector (Beam loss around z~8m)
- BLM 19, 20, and 21, an 5th and 6th $^3$He detectors (Beam Loss around z~13.8m)
Mean Energy vs RFQ voltage

As a measurable value for our system, mean energy of each bunch is one candidate.

For the RFQ exit beam,
Not accelerated particles $\rightarrow$ Not detectable in BPM
Only core and its tail $\rightarrow$ Maybe measurable by ToF
(4.3MeV- particles)

![Energy distribution (Logscale)](image)

Less than 95%, ~ 5keV resolution is good to distinguish distributions of several RFQ voltages.
Upper region requires ~1keV resolution.

Previous results of BPM
Preliminary test of BPM ToF

Evaluation of visibility of BPM phase measurement in a pulse. 150μs pulse, 1Hz, 112mA at RFQ exit ACCT

50 pulses raw data: BPM MBP01 electrode-L (+x)

As the mean energy resolution, < 0.5keV for 350MHz can be expected. → Enough to see 1% difference.
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LIPAc is now in the beam commissioning Phase-B+.

- Aims to High current, High DC

Beam to the BD : 5MeV-112mA $D^+$ beam in 150us-1Hz DC.

Good agreement between sim. and meas. for the pilot beam.

Study of the space charge compensation is being proceeded.

For momentum halo due to the reduced RFQ voltage,

- Loss monitor approach near bend is planned in the Phase-B+.
- Resolution of BPM-ToF looks enough (< 0.5keV) to draw the energy carve.
Thank you for your attention!