BEAM DYNAMIC SIMULATION FOR THE BEAM LINE FROM CHARGE BREEDER TO ALPI FOR SPES PROJECT

M. Comunian, L. Bellan, A. Pisent, INFN/LNL, 35020 Legnaro, Italy
A. Ziiatdinova, NRC "Kurchatov Institute"-ITEP, 117218 Moscow, Russia

Abstract

The SPES project (Selective Production of Exotic Species) is under development at INFN-LNL. This facility is intended for production of neutron-rich Radioactive Ion Beams (RIBs) by ISOL method. The +1 charged beams will be transformed to n+ charge by Charge Breeder (Electron Cyclotron resonance ion source) and reaccelerated by the ALPI (Acceleratore Lineare Per Ioni) superconducting LINAC. This paper includes results of beam dynamic simulation at the beam line from Charge Breeder to ALPI.

INTRODUCTION

In the framework of the SPES project [1], the post-acceleration will be performed via an ECR-based charge breeder, delivering the obtained q+ radioactive beam to a being-built CW RFQ and the being upgraded superconducting LINAC ALPI (final energy 9 MeV/A for a mass-to-charge ratio A/q=7) [2].

SPES LAYOUT

To increase the exotic beam charge state for efficient post-acceleration of SPES, an ECR-based charge breeder (SPES-CB) has been chosen, which was developed by LPSC (Grenoble, F) and delivered to LNL, after completion of the acceptance tests [3]. The downstream beamline was designed to characterize the device with stable beam and for regular operations with rare ions. In Fig. 1 the layout of SPES is reported, while Table 1 summarizes the specification of all the elements from CB to experimental rooms. The high charge state exotic beam injector consists of three main sections: an electrostatic 1+ beam line aimed at full SPES-CB input beam characterization; a magnetic q+ beam line from the SPES-CB to the RFQ; a Medium Resolution Mass Spectrometer (MRMS, $\Delta M/M = 1/1000$) on a -120 kV platform between the CB and the RFQ to purify the beam. The MRMS will ensure post-acceleration of clean radioactive beams from the SPES-CB stables contaminants [4]. From MRMS the beam is transported to the RFQ. After the RFQ the beam will be injected, with a matching line, to the ALPI superconducting LINAC. The SPES RFQ, is designed to accelerate exotic isotopes in CW mode with A/q= 3÷7 [5].

After the RFQ, a transport line, including 2 normal conducting QWR for longitudinal matching, delivers the exotic beam to the existing SC LINAC ALPI. Several upgrades are being implemented, to improve both the performance (in final energy and current values) and the reliability of ALPI: the replacement of the old 10 magnetic lenses with 50% higher gradient ones, expected to improve beam transmission along the machine; displacement of 2 QWR cryostats from the PIAVE stable beam injector to ALPI, to make them available as matching section for both stable and exotic beams. It is planned to add two fully new cryostats at the end of ALPI, to achieve the final energy of 10 MeV/m for the reference SPES beam $^{132}Sn^{19+}$.

All along the facility, proper beam instrumentation for both pilot and exotic beam will be provided: beam current is measured via normal Faraday cups, equipped with low noise amplifiers; position and transverse profiles via wire grids and MCP-based electron monitors; emittances via wire-grid and Allison scanners.

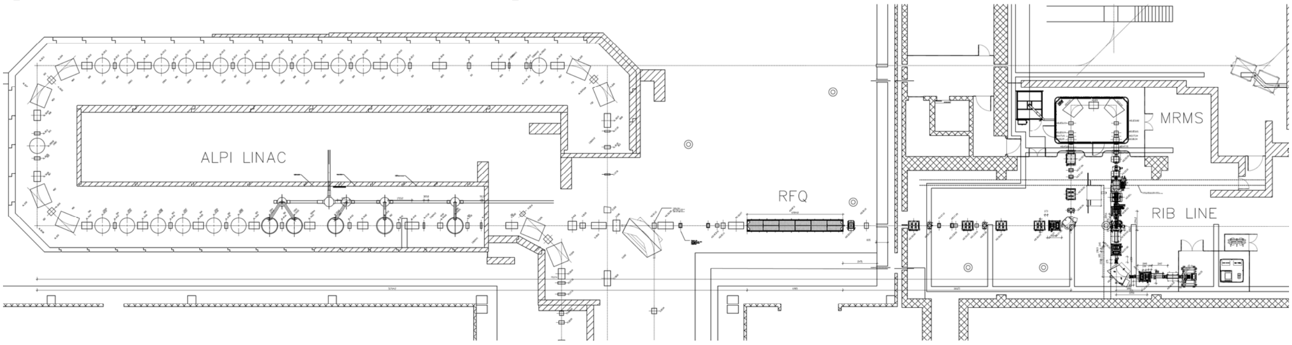

Figure 1: SPES Layout from Charge Breeder to ALPI LINAC (ref. V5).

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAK022

BEAM DYNAMICS

The pilot beam line will be used to set the RFQ parameters with a stable beam in preparation of the coming radioactive ions from the ISOL target. The line from CB to RFQ presents the largest geometric emittance of ALPI in table 1 are reported the mains input Beam dynamics parameters. Moreover, specific difficulties are present due to the matching conditions from the RFQ and the low energy of ALPI due the low longitudinal acceptance of the linac.

For this reason, two bunchers are used to match longitudinal the beam from the exit of the RFQ to the object point of the ALPI input. A couple of steerers are foreseen to correct misalignments of the beam center at the exit of the RFQ. The transverse matching to ALPI is guarantee by using 3 triplets. A couple of steerers are placed between the above quoted triplets to correct possible beam center misalignments and angles. After each triplet is foreseen a diagnostic box.

At the begin of ALPI is foreseen the installation of the two cryostats already used for PIAVE, in a configuration like one triplet, four QWR, one triplet, four QWR.

This period is shorter respect to the standard period of ALPI: one triplet eight QWR, to match the low energy coming from the new RFQ of SPES and the SRFQ of PIAVE. To improve the whole transmission of ALPI is planned to increase the gradient of the triplets from 20 T/m to 30 T/m.

The cavities of ALPI are all used, for the first two QWR at 4 MV/m, for the low and medium beta at 4.5 MV/m, for the high beta at 6.5 MV/m, with one cryostat kept off as spear.

The simulation code used is TraceWin with integrated the full map of all the QWR [6].

Table 1: Beam Dynamics Input Specifications

	Value	**Units**
RMS Transverse Emittance	0.1	mm*mrad
RMS energy spread	4	eV
Ion Mass	132	amu
Ion charge	+19	
Energy	40	KeV

In the table 2 is reported a summary of the beam dynamics results from the CB through the SPES RFQ to experimental hall (FC7).

Table 2: Beam Dynamics Output

	Value	**Units**
RMS Transverse Emit.	0.1	mm*mrad
RMS Longitudinal Emit.	1.2	MeVdeg
Transmission	79	%
Total length	200	m
Final Energy	1200	MeV

The beam dynamics is still in evolution to optimize the transmission, with a larger longitudinal acceptance, see Fig. 2, and to increase the final energy.

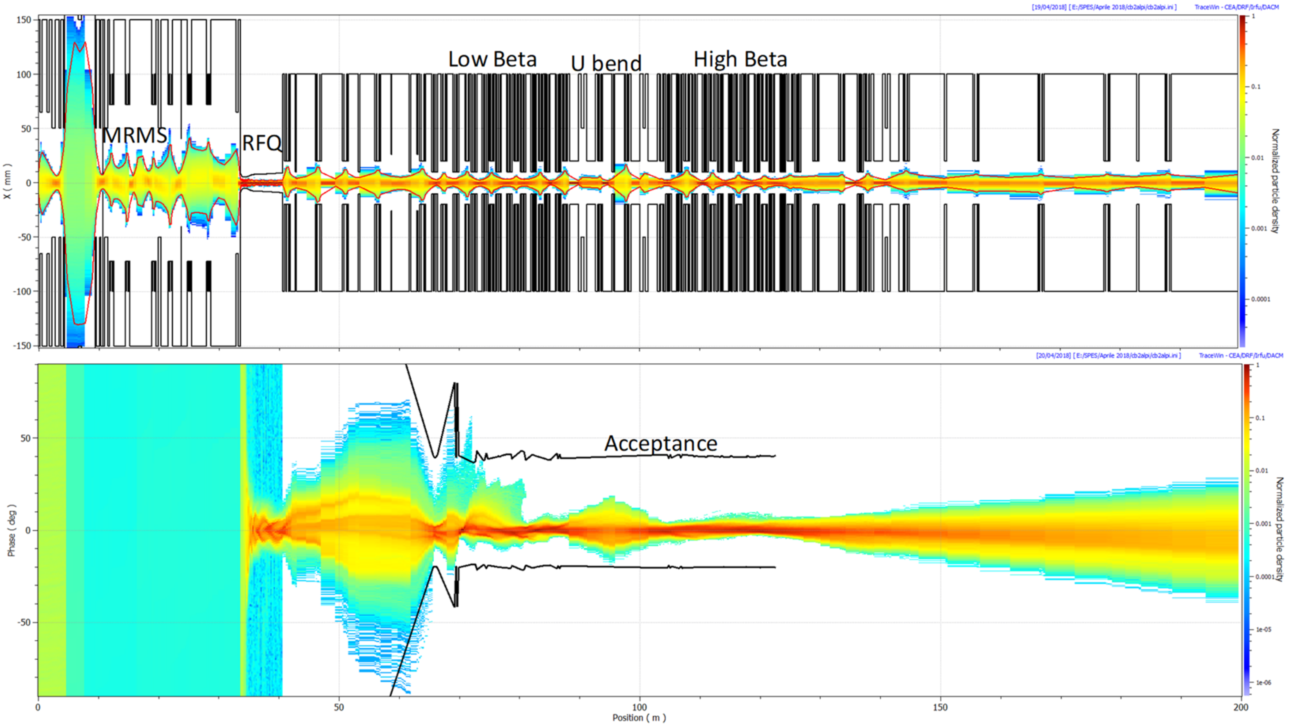

Figure 2: X [mm] beam density and phase density from Charge Breeder to experimental hall (FC7) the overall zone simulated is about 200 meters.

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ERROR STUDY

To study the impact of the real accelerator a 2000 runs of various machine configuration has been studied. The errors apply form the CB to the RFQ are reported on table 3 and the resulting losses at the SPES RFQ exit on Fig. 3.

Table 3: Errors Apply from CB to RFQ

Errors Kind	Max Tolerances Used
Quad. misalignment	$\pm 100\ \mu m$
Quad. tilt	$\pm 0.15°$
Quadrupole gradient error	$\pm 0.3\%$
Bending gradient error	$\pm 0.02\%$
Quadrupole multipolar component (up to 12°)	$\pm 0.6\%$

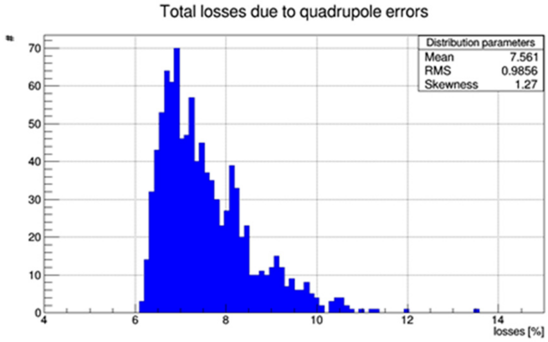

Figure 3: Losses from the errors study result at the SPES RFQ exit.

With the same philosophy an errors study has been done in the zone from the SPES RFQ to ALPI. The main results to preserve a whole transmission, from CB to experimental hall, better than 80% are reported on table 4. To improve the quality of beam simulation a campaign of comparison between simulation and real setup of the machine is started. In the shift of delivery lead ion 206Pb32+ (A/q=6.4) from PIAVE to ALPI done in February 2018, the results on the percental difference in the setup of quadrupole are less than 20% in most of the quadrupole setup on Fig. 4 the blue plot. In a specific test of transport from PIAVE to low beta of ALPI with A/q=7, the difference as been reduced to less than 5% on Fig. 4 the orange plot.

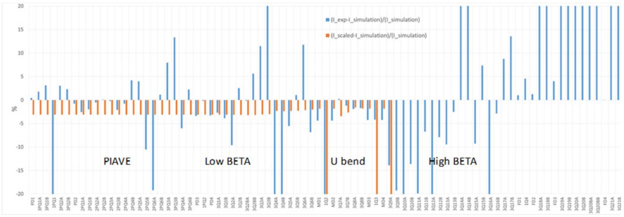

Figure 4: experimental set of magnets versus the simulation values.

At this stage, the error study is still to be established by a global error overview with correctors like steerers.

The error study shows a high sensitivity on the quadrupole position.

Table 4: Tolerance Required on ALPI

Single Error Type Applied	Required Tolerance
Phase error (dynamic)	± 0.5 deg
Cavities amplitude (dynamic)	± 0.5 %
Cavities transverse position	± 0.2 mm
Quad. amplitude (dynamic)	± 0.1 %
Quad. transverse position	± 0.1 mm
Bending amplitude (dynamic)	± 0.05%

CONCLUSION

For the SPES project, an accurate simulation of the ALPI linac is mandatory. For this goal a long-range plan to compare simulation versus real settings of the various elements is started. All along the facility, proper beam instrumentation for both pilot and exotic beam must be provided to permit the comparison of simulation vs reality and the possibility to scale the parameters from pilot to rib beam.

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