STATUS OF THE FAIR PROTON SOURCE AND LEBT

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Abstract

The unique Facility for Antiproton and Ion Research – FAIR will deliver stable and rare isotope beams covering a huge range of intensities and beam energies. A significant part of the experimental program at FAIR is dedicated to antiproton physics that requires an ultimate number 7x10^{10} cooled pbar/h. The high-intensity proton beam that is necessary for antiproton production will be delivered by a dedicated 75 mA/70 MeV proton linac.

The injector section of this accelerator is composed by an ECR source, delivering a pulsed 100 mA H^+ beam (4 Hz) at 95 keV and a low energy beam transport (LEBT) line required to match the beam for the RFQ injection. The proposed design for the LEBT is based on a dual solenoids focusing scheme. A dedicated chamber containing several diagnostics (Alisson scanner, Wien filter, SEM grid, Iris, Faraday Cup) will be located between the two solenoids. At the end of the beam line, an electrostatic chopper system is foreseen to inject 36 µs long beam pulses into the RFQ.

The status of LEBT simulations, design and fabrication of the FAIR proton injector will be presented.

INTRODUCTION

In the next years, the new international accelerator facility FAIR, one of the largest research projects worldwide, will be built at GSI.

In the final construction, FAIR consists of eight ring colliders with up to 1,100 meters in circumference, two linear accelerators and about 3.5 km of beam pipes. The existing GSI accelerators together with the planned proton-linac (p-linac) will be used as injector for the new facility. The double-ring synchrotron will provide ion beams of unprecedented intensities at high energy in order to produce intense secondary beams (unstable nuclei or antiprotons) [1].

An important part of the experimental program at FAIR is dedicated to antiproton physics. For various experiments up to 7×10^{10} of cooled pbar/h are required. Taking into account the pbar production and cooling rate, the chain of accelerators composed by a proton linac and the two synchrotrons SIS18 and SIS100 has to provide 2×10^{16} protons/h [1].

The 70 MeV/70 mA linac is currently under design and construction. This accelerator is composed by an ECR source, a LEBT, a 3 MeV RFQ and a DTL based on CH-cavities [2].

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The design, the fabrication and the commissioning of the FAIR proton-linac source and LEBT is performed in the framework of a Germany-France collaboration. The present paper will present an overview of the status of this apparatus which is currently under construction at CEA/Saclay.

ION SOURCE & LEBT REQUIREMENTS

The purpose of the FAIR p-linac source & LEBT is to produce a 100 mA/95 keV proton beam and to transport and match it for its injection into the next accelerating section, which is a RFQ. The main beam parameters that are required are summarized in Table 1.

Table 1: FAIR p-linac Ion Source & LEBT Requirements

Parameters	Value
Specie	Proton
Energy	95 keV
Intensity	100 mA
Time structure	Pulsed at 4 Hz
Energy spread	< 60 eV
Final emittance	$\leqslant 0.33\ \pi$ mm.mrad
α Twiss parameter	$0.27 \leqslant \alpha \leqslant 0.59$
β Twiss parameters	$0.037 \leqslant \beta \leqslant 0.046$ mm/π.mrad

FAIR PROTON LINAC ION SOURCE AND LEBT LAYOUT

General Layout

A scheme of the general layout of the FAIR p-linac source and LEBT is given on Fig. 1. The main components (ion source, beam line and beam diagnostics) are more precisely described in the following sections.

Ion Source

The design of the FAIR p-linac 2.45 GHz ECR ion source is based on the SILHI source [3]. It will be operated in pulsed mode, by pulsing the injected RF power. The repetition rate will be fixed at 4 Hz while the length of the beam pulses extracted from the source will be a few milliseconds.

The axial magnetic field will be provided by 2 coils, identical to the SILHI ones, which are independently tunable in term of current and position. The magnetic field on the axis is generally adjusted to obtain the first ECR zone (B_{ECR} = 0.0875 T) located just at the RF input in the plasma chamber while the second one takes place in the extraction system

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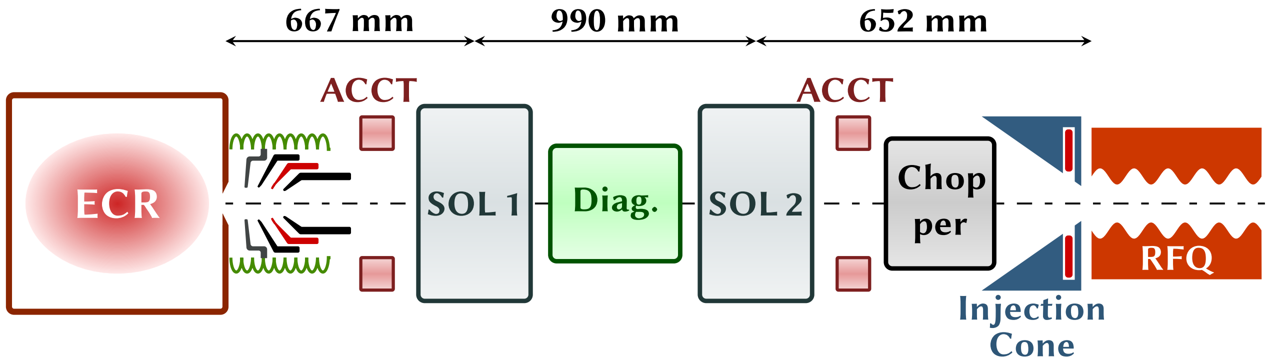

Figure 1: Schematic layout of the FAIR proton linac ion source and LEBT.

at about 30 mm from the extraction aperture (position of the inner face of plasma electrode is chosen to be the zero reference).

Nevertheless, the mechanical design of the source has been simplified in comparison with SILHI. Because of the low beam duty cycle, all cooling parts have been eliminated and the geometry has been simplified. Extraction electrodes are now machined in one block.

LEBT

In order to transport and optimize the beam for its injection into the RFQ, the optics of the LEBT relies on a two solenoids focusing scheme. In order to facilitate fabrication and purchasing, the solenoids that have been chosen for the FAIR p-linac LEBT are the same as the IFMIF injector ones [4]. They are of course over dimensioned for a 95 keV proton beam compare to the 100 keV deuteron beam of IFMIF. For this reason, 450 A power supplies will be used instead of 600 A. The cooling system will be also less demanding. The solenoids pole length is 240 mm (total length 300 mm with the iron shielding). Horizontal and vertical magnetic dipole correctors have been inserted inside the solenoids. Magnetic simulations have proven that a couple of 160 mm length correctors, each wounded on a cylinder with 2 different radius and separated in angle by 90 degrees, are able to provide the necessary dipole correction in both planes required by the beam dynamics.

In order to minimize the effects of the space charge on the beam (that can lead to emittance growth), the length of the FAIR LEBT has been reduced as much as possible. Nevertheless, it was necessary to insert, between the two solenoids, a vacuum valve and a diagnostic chamber (see next section).

The ion source will deliver ion beam pulses of a few ms length with a rise time of around one ms. However, the downstream accelerating sections of the p-linac require short beam pulses (~ 36 µs) with sharp edges. To do so, an electrostatic beam chopper is inserted in the LEBT, after the second solenoid.

In order to intercept the chopped beam and the unwanted species produced by the source (H_2^+ and H_3^+) and injection cone is placed just before the RFQ injection. A negatively biased electrode is located as close as possible to the RFQ inner flange in order to prevent the secondary electrons (produced by ionisation of the residual gas by the beam) to be attracted by the RFQ electric field; that way, the zone where the ion beam is not space charge compensated is minimized [5].

Finally, the total length of the beam line, from the plasma electrode to the internal face of the RFQ entrance flange is 2.39 m (see Fig. 1).

Beam Diagnostics

The LEBT will be equipped by several diagnostics in order to qualify the beam during the commissioning period but also for daily operation.

In order to measure the beam intensity, two current Alternative-Current Current Transformers (ACCT) are foreseen. The first one will be located after the source extraction and the second one, after before the chopper. Theses ACCTs are designed and fabricated by the Bergoz company. Compared to standard ones, these devices need to be magnetically shielded to be operated in the solenoids fringe field environment.

Between the two solenoids, a dedicated diagnostic chamber has been designed to host the following diagnostics:

- A Secondary Electron emission grid (64×64 wires) to measure vertical and horizontal beam profile (developed by GSI).
- A set of slits (diamond shape) to control the beam size or to limit the beam intensity (developed by GSI).
- An Allison scanner [6] to measure the beam emittance (developed by IPHC Strasbourg).
- A Wien filter to measure the proportion of the different species extracted from the ion source.
- A beam stopper which is considered as a safety device to protect the vacuum valve; however, it will be insulated in order to evaluate the beam intensity.

A smaller diagnostic chamber (called "diagnostic box" in this paper) that is able to host several diagnostics (Alisson scanner, Wien Filter, Faraday cup) has been developed to be employed during the beam commissioning. In order to make some measurements it will be possible to mount this chamber just after the source or at the end of the beam line. During the beam commissioning, a slit-grid emittancemeter, provided by GSI, will also be used to perform emittance measurements at the end of the LEBT.

BEAM DYNAMICS

Ion Source Extraction System

Numerical simulations of the five-electrodes ion source extraction system were performed with AXCEL-INP [7]. The particle distributions after the source have been calculated by tracking them through the extraction system. Those beam distributions (100 mA of H^+, 23 mA of H_2^+ and 3.6 mA of H_3^+) are taken as inputs for the LEBT simulations (see next section).

Transport in the LEBT

The LEBT simulation and optimization have been performed with TraceWin [8]. These simulations start with at the position of the repelling electrode of the source extraction system (35 mm after the plasma electrode). The magnetic field maps of the solenoids, computed by finite element method, have been used. A constant conservative value of 80% for the space charge neutralization has been considered. The beam transport through the FAIR low energy beam line is shown on Fig. 2

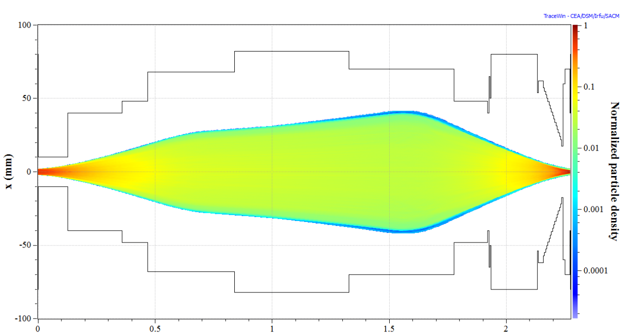

Figure 2: Results of a beam transport simulation: beam density along the LEBT.

Finally, the simulated beam emittance at the RFQ entrance is 0.18 π mm.mrad. The solenoid values have been optimized in order to reach the range of the required Twiss parameters for the beam injection into the RFQ: α=0.48 and β = 0.38 mm/π.mrad.

BEAM COMMISSIONING PLAN

The beam commissioning in CEA/Saclay will be divided in three main phases:

Phase 1 The diagnostic box is placed just after the source. The beam intensity, emittance and species proportion extracted from the source are measured.

Phase 2 The LEBT is assembled without the chopper. The diagnostic box is placed after the second solenoid (see Fig. 3). The beam intensity, profile, emittance and species proportion are measured between the two solenoids. The beam intensity and emittance are measured at the RFQ entrance position.

Phase 3 The nominal source and LEBT apparatus is assembled. All the diagnostics of the central diagnostic chamber are available. The chopper is tested. The beam intensity and emittance are measured after the injection cone. The FAIR p-linac source and LEBT are validated.

Figure 3: CAD view of the FAIR p-linac source and LEBT for the phase 2 of the beam commissioning.

CONCLUSION AND PERSPECTIVES

Most mechanical parts of the FAIR p-linac ion source and LEBT has been designed and fabricated and are now mounted in CEA-Saclay. The final design of a few elements like the chopper system and the Faraday cup is to be achieved in the next weeks.

In November 2014, the diagnostics and control system developed by GSI will be installed in Saclay. The ion source coils power supplies should be delivered in Saclay by the end of 2014.

The first beam extracted from the ion source is planned for the beginning of 2015.

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