THE RIB DYNAMICS OF THE SPIRAL 2 TRANSFER LINE

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Abstract

The design of the SPIRAL 2 RIB extraction and mass analysis is the result of previous experiences at GANIL (SIRa) and SPIRAL and concerns the ISOL process [1]. The layout presents different beam sections of optical interest starting after the target ion source (TIS) with a conventional Einzel lens, a 1 T solenoid, a triplet of magnetic quadrupoles and a magnetic dipole for the mass analysis. The down-stream 1+ ions transfer line to the users is designed following a conservative solution composed of emittance limitation, homothetic betatron matching, passive and symmetrical optical lattices (point to point and unitary transport) as well as beam instrumentation enabling the control of the losses (pepperpots, slits, beam profilers, Faraday cup, etc.). This contribution will mainly focus on the description of the beam line, its characteristics and on some side effects which have to be taken into account in order to match the beam properly during the operations.

INTRODUCTION

The SPIRAL 2 Project

The SPIRAL2 project is based on a multi-beam driver for both ISOL and low-energy in-flight RIB production. A superconducting light/heavy-ion linear accelerator capable of accelerating 5 mA deuterons up to 40 MeV and 1 mA heavy ions up to 14.5 MeV/u is used to feed both thick and thin targets. The intense RIBs are produced by several reaction mechanisms (fusion, fission, transfer, etc.) and technical methods (ISOL, recoil spectrometers, etc.). The production of high intensity RIBs of neutron-rich nuclei will be based on fission of a uranium target induced by neutrons, obtained from a deuteron beam impinging on a graphite converter (up to 10^{14} fissions/s) or by direct irradiation with a deuteron, ^{3}He or ^{4}He beam. The post acceleration of RIBs in the SPIRAL2 project is provided by the existing CIME cyclotron, which is well adapted for separation and acceleration of ions in the energy range from about 3 to 10 MeV/u for masses A~100-150. SPIRAL2 beams, both before and after acceleration, can be used in the present experimental area of GANIL [2].

The RIB Lines

The RIBs have a relatively large beam emittance, therefore a dedicated beam transport system is built to extract, separate and transport the desired single-charged ion 1+ beam. The beam lines are designed to accept a transverse geometric emittance of 80 π mm.mrad, in horizontal and vertical planes. Most of the contaminants must be suppressed by means of slits, collimators and magnetic analysis. This is the role of the Beam Production Zone (ZPF), see top part of Figure 1. The beam lines must connect different areas of the SPIRAL 2 project (identification station IBE, low energy experiments area DESIR, N+ multi-charged ion beam line leading to the existing GANIL facility). This is the role of the Beam Transport Zone, see bottom part of Figure 1. In order to achieve all the requirements a structure divided into "stages" or "sections" has been developed. The different sections are described in the following. All the ion-optical simulations except for the high current beam calculations have been performed with the TraceWin code [3].

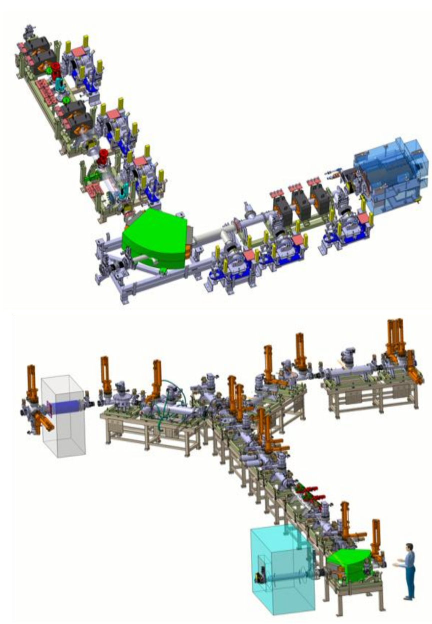

Figure 1: 3D view of the Beam Production Zone (top) and Beam Transport Zone (bottom) of the SPIRAL2 1+ lines.

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LATTICE DESCRIPTION AND BEAM SETTINGS

Beam Extraction

The beam is extracted from the source and sent to the first optical section ("optical section 0"), which is composed of an Einzel lens (LR1-EIN01), a solenoid (LR1-SOL01) and a magnetic quadrupole triplet (LR1-Q01 to LR1-Q03). The Einzel lens (and the solenoid to a lesser extent) allows different tunings of the optical section for different beam sizes at the extraction, without having to change the tuning of the quadrupole triplet. Slits and collimators positioned at the beam image point ensure that the most intense beam contaminants, mainly the support gases used for the beam extraction, are suppressed. The structure of this optical section is shown in the top part of Figure 2. An example of beam envelope for a 122 u reference mass and a 50 pμA beam current is shown in the bottom part of Figure 2.

Mass Analysis

After the beam image point, the beam propagates through a mass analyser designed to separate the ions of interest from the isotopic contaminants. The mass resolving power at the first dipole image point (D1 on Figure 3) has been evaluated as about 300 (with ± 3 standard deviations) for a reference beam of mass 122.

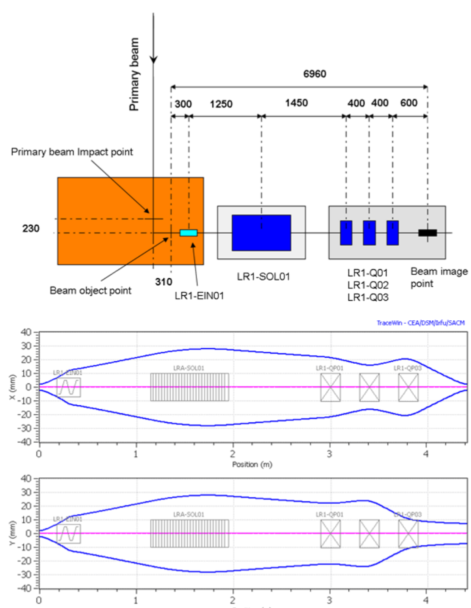


Figure 2: (top) Structure of the "optical section 0". All distances indicated are in mm. (bottom) Horizontal and vertical beam envelopes at first order of a mass 122 u beam with 60 keV energy, 1+ charge and 50 pμA current going through the optical section.

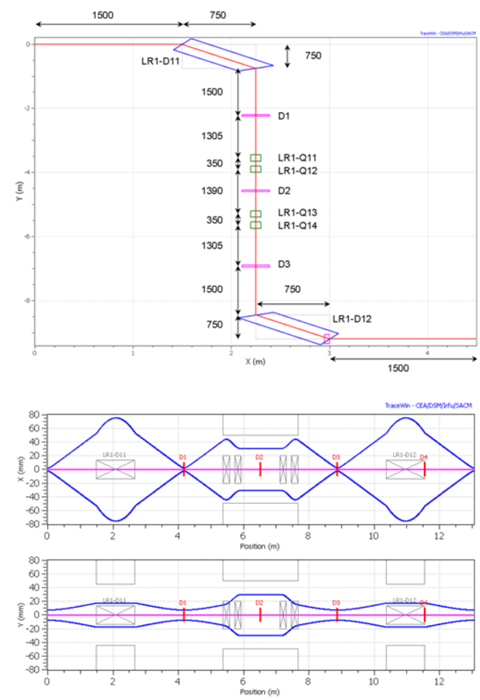


Figure 3: (top) Structure of the "optical section 1". All distances indicated are in mm. (bottom) Horizontal and vertical beam envelopes at first order, of a mass 122 u beam with 60 keV energy, and 1+ charge going through the optical section.

Achromatic Deviation

The "optical section 1" consists of two opposite signs dipoles (LR1-D11 and LR1-D12), the first being the mass analyzer described above. Two magnetic quadrupole doublets (LR1-Q11 to LR1-Q14) are located around the intermediate image point of the optical section. The quadrupoles control the achromatism provided by the two dipoles and the symmetry of the beam envelope. The structure and the first order beam envelope of the optical section are seen in Figure 3.

Betatron Matching

Once the contaminants have been rejected, the beam goes through an adaptation section composed of four electrostatic quadrupoles, where the beam size is modified and adjusted to the following sections.

Beam Switching Yard

A switching electrostatic deflector (LR1-D51) is used to send the beam of interest to three different branches (IBE identification station, charge breeder or DESIR). When the beam is deviated from ± 45° it is sent to the IBE station or to the charge breeder. Then, the beam goes through an electrostatic quadrupole triplet, and a second deflector (LR1-D61 or LR1-D71) which makes the complete section achromatic and deflects the beam by an additional 45°. When the upstream electrostatic deflector (LR1-D51) is switched off, the beam is transferred to the DESIR area. In order to send the beam to the IBE and charge breeder beam lines, a 2° kicker is placed in front of the deflector in order to reach the 45° total deviation. The overview of the "optical section 7", with the beam being sent to the charge breeder, and the corresponding optics are shown in Figure 4. The "optical section 6" going to the IBE identification station is identical by symmetry around the first electrostatic deflector.

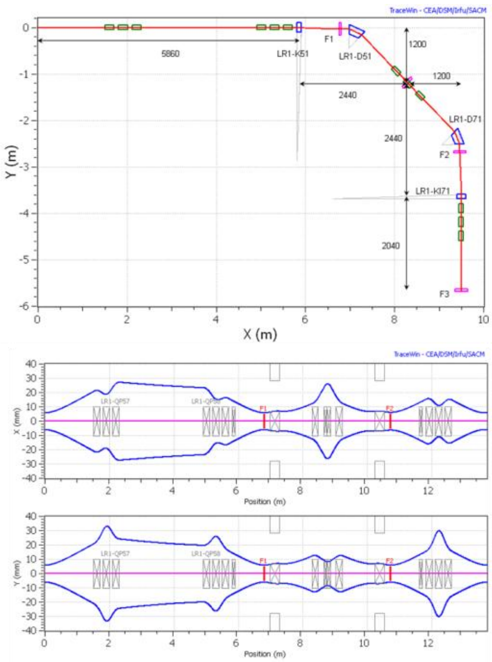


Figure 4: (top) Structure of the "optical section 7". All distances indicated are in mm. (bottom) Horizontal and vertical beam envelopes in first order, of a mass 122 u beam with 60 keV energy, and 1+ charge going through the optical section.

BEAM DIAGNOSTICS

MIPPS

In both beam production and beam transport areas, a MIPPS (Measurement of Intensity in Particles Per Second) system has been implemented to allow the beam current measurement even for very low intensities. A small electrostatic deflector is placed in front of a Faraday cup, which is itself shifted from the beam axis to be able to stop the deflected beam. The deflector will be switchable with appropriate time structure so that around 10 % of the beam is deviated to the Faraday cup.

Conventional Diagnostics

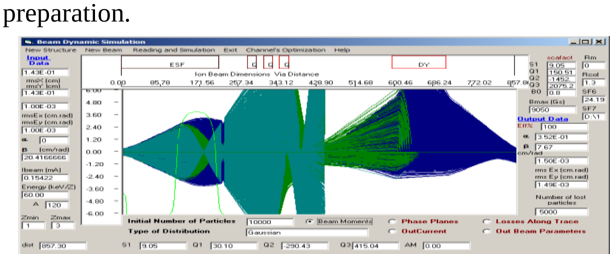
The conventional (diagnostics FC, BPM, etc.) are mainly used in the Beam Production Zone (BPZ) as radiation, mechanical integration and maintenance constraints are too severe to enable some equipment in the BPZ.

SIDE EFFECTS

High Current Multi-Species Beam Extraction

The beam extraction section down to the analysing magnet has been investigated with a numerical model and the MCIB04 beam dynamics code [4]. As seen in other facilities [5, 6], perturbations of the beam transport happen with demanding conditions, i.e. with high current supporting gas used in Electron Cyclotron Resonance Ion Source (ECRIS) and high current contaminants. The formation of a hollow in the beam distribution of interest is related to the solenoid focusing placed between the ion source and the analysing magnet. The focusing length of the solenoid for the lighter ions (with a smaller mass-to-charge ratio) is less than for the beam of interest. For this reason in the region between the solenoid and the analysing magnet the lighter ion beams have significantly smaller transverse dimensions compared to the reference beam. In the region out of the lighter ion beam boundary, the defocusing field decreases as inverse distance of the ions from the axis of the beam. For larger intensities of the lighter ion beam, the space charge effect leads to the hollow structure formation of the beam of interest just after the analysing magnet and increases the emittance of the injected ion beam, see Figure 5 [7].

An experiment with a stable beam and comparable conditions has been performed on the SPIRAL 2 low energy beam line LBE1 at LPSC during last winter. A 40Ar+ beam extracted from an ECRIS source with nitrogen as supporting gas has been analyzed and observed with a BPM in order to reproduce the hollow effect. Despite the fact that a perturbation has been clearly observed, see Figure 6, an unequivocal answer was not possible due to some experimental artefacts. A further experiment with direct beam observation (quartz) is in preparation.



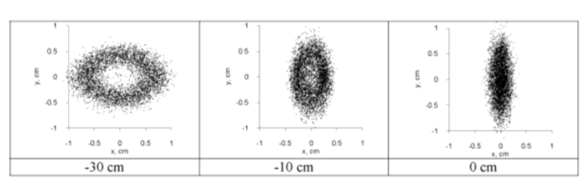


Figure 5: (top) Simulation of the behaviour of 1µA A=120 u ion beam at 60 keV mixed with a co-extracted Nitrogen beam (800 µA) used as supporting gas in the ECRIS. One can see a strong focusing inside the solenoid (left) and the beam separation (right) inside the analysing magnet. (bottom) Hollow beam at different distances prior to the analysing magnet focal plane, depending on the beam matching conditions.

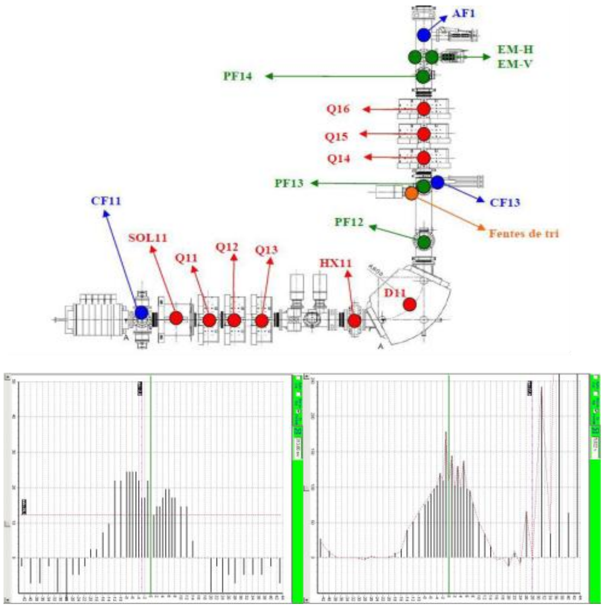


Figure 6: (top) LBE1 test beam line. (bottom) Beam profile with and without hollow effect observed with BPM on focal plane.

Beam Losses

The supporting gases used in the ECRIS help ionizing efficiently the radioactive atom of interest but on the other hand generate parasitic low charged beams. Those beam contaminants have a very different behaviour compared with the reference beam due to their different magnetic rigidity. This means that a large fraction, if not all, of these contaminants will be lost in the upstream part of the beam line, in the "optical section 0". For all beams produced by fission, the losses will mostly occur before the quadrupole triplet of optical section 0. Figure 7 shows the example of nitrogen mixed with the mass 122 setting.

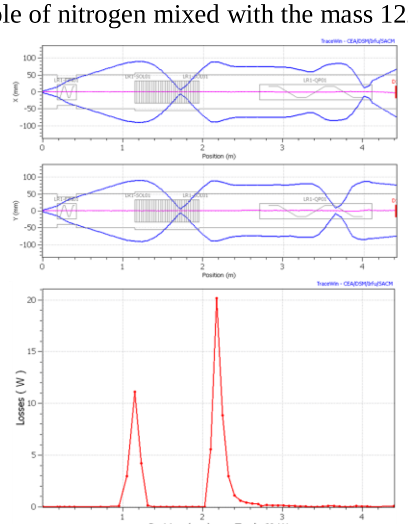


Figure 7: (top) Horizontal and vertical beam envelopes at first order, of a 1 mA $^{14}N^{+}$ beam and 60 keV energy, with the setting on mass 122 u as described before. (bottom) Power losses of the same $^{14}N^{+}$ beam along the beam line.

CONCLUSION

A complex beam line system, being able to extract, separate and transport the RIBs from the ion source to the different branches of the SPIRAL2 project has been described. It achieves the specifications goals for the transport of large emittance beams up to 80 pi.mm.mrad, and for the separation of the beam of interest from the neighbouring isotopes. Several side effects have been identified. The hollow effect has been identified as a potential perturbation of the beam of interest dynamics at the beginning of the beam line. The loss effect of large amount of parasitic co-extracted beams induced by the use of a supporting gas in the ECRIS has to be further investigated to avoid heating and activation problems.

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