THE STATUS OF BEAM DIAGNOSTICS FOR THE HIE-ISOLDE LINAC AT CERN*

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Abstract

The HIE-ISOLDE project aims at upgrading the CERN ISOLDE radioactive ion beam facility for higher beam intensities and higher beam energies. New beam diagnostic devices have to be developed as part of this upgrade, in particular for the measurement of intensity, energy, transverse and longitudinal profiles, and transverse emittance. The beam energy ranges from 300 keV/u to 10 MeV/u and beam intensities are between 1 pA and 1 nA. Faraday cups will be used for the measurement of the beam intensity while silicon detectors will be used for the energy and longitudinal profile measurements. The transverse profiles will be measured by moving a V-shaped slit in front of a Faraday cup and the beam position will be calculated from the profiles. The transverse emittance can be measured using the existing REX-ISOLDE slit and grid system, or by the combined use of two scanning slits and a Faraday cup. The final design of the mentioned devices will be presented in this contribution, including the results of the experimental validation tests performed on prototypes during the last two years.

INTRODUCTION

A major upgrade of the on-line isotope mass separator facility ISOLDE at CERN is taking place since 2010 under the HIE-ISOLDE project [1]. The technical challenges for beam diagnostics include the development of new instruments for low-intensity ion beams with energies up to 10 MeV/u. Moreover, in the inter-cryomodules regions of the superconducting LINAC, the longitudinal space available for beam instrumentation is very limited (58 mm) due to restrictions coming from the beam optics design. As a consequence all the devices need to be designed with a very compact geometry.

The diagnostic requirements of HIE-ISOLDE beams are [2]:

- Beam intensity measurements: an absolute accuracy of 1 %, for pilot beams of stable ions such as oxygen and neon, with intensities in the range of 10 pA to 1 nA.
- Transverse profile and position measurements: an accuracy of 10 % in the beam size measurement and of $\pm$ 0.1 mm in the beam position determination. Beam sizes are in the range of 1 to 5 mm (1 $\sigma_{\rm rms}$).
- Longitudinal profile measurements: the energy spread and bunch length should be measured with resolutions of <1 % (2σ) and <100 ps respectively.
- Transverse emittance meter: a target accuracy of $\pm$ 20 % is expected, for beam currents up to 1 nA.

DIAGNOSTIC BOXES

The installation of stage 1 for the HIE-ISOLDE LINAC includes two cryomodules with five cavities each. It is scheduled to deliver the first beams for physics in October 2015. More cryomodules will be added at a later stage, increasing the beam quality and final energy per nucleon.

A total of five short Diagnostic Boxes (DBs) and eight long DBs will be required for the accelerator and its two transfer lines to the experiments. Their location is schematically presented in Fig. 1. The short DBs are located between the cryomodules and have a very compact design in the longitudinal direction compared to the long DBs. All DBs include a Faraday Cup (FC) and a scanning slit that will be used for the beam intensity and transverse profile measurements. All DBs are also equipped with circular and/or vertical collimators for beam cleaning purposes, with four DBs including carbon stripping foils to allow modification of the beam charge state. Two DBs will contain silicon (Si) detectors for longitudinal beam profile measurements.

In Fig. 2 a cutaway drawing of a short DB is presented. The modular, six port design of the box allows up to five instruments or devices to be attached, with one port reserved for the vacuum system. A FC, scanning slit and collimator blade with four circular collimators are shown, with the remaining extra ports available for the installation of a Si detector and a blade with stripping foils. The main tank is an octagonal-shaped box machined from a single block of 316L stainless steel, with a beam pipe aperture of 40 mm. Top and bottom faces are integrated with alignment and support devices respectively.

The position of the various devices is controlled by means of linear actuators driven by stepper motors. As the precision on the positioning of the scanning slit is critical for the accuracy of the transverse beam profiles measurements, a special mechanism was designed for that movement, which includes a robust guiding system with two rods. The plane of movement of the scanning slit, collimators and stripping foils is located slightly upstream of the plane of movement of the FC and the Si detector, al-

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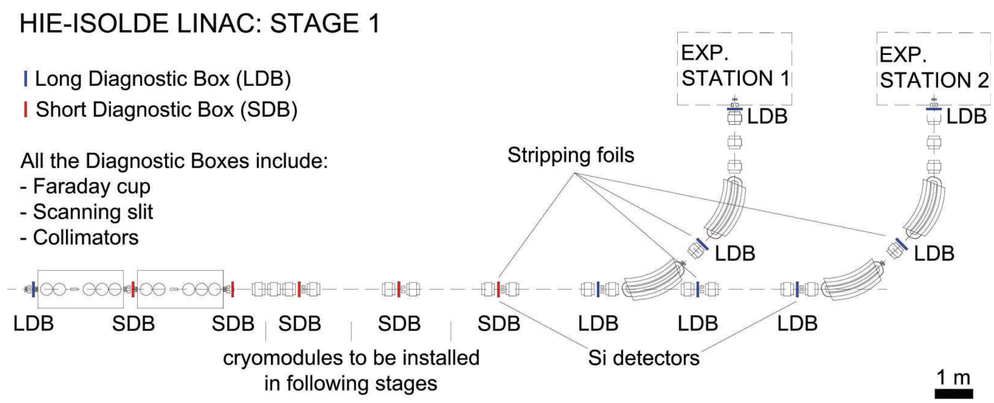

Figure 1: Location of the diagnostic boxes in the HIE-ISOLDE LINAC and High Energy Beam Transfer lines.

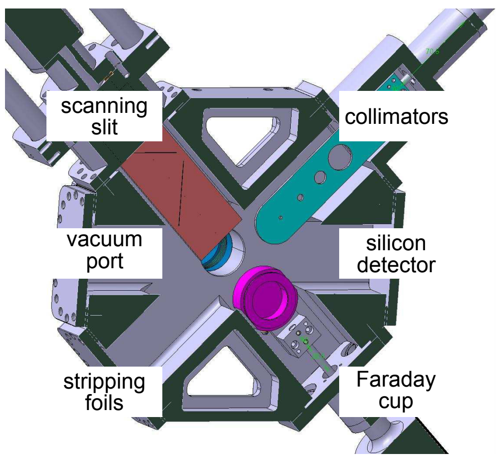

Figure 2: Cutaway drawing of the short diagnostic box with instruments inside.

lowing the insertion of one collimating or stripping device in front of a detector in the same box.

BEAM INTENSITY

The beam intensities will be measured with Faraday cups, of which the final designs are presented in Fig. 3. The diameter of the cup aperture is 30 mm. The collector plate will be connected to a current-sensitive preamplifier and the repeller cylinder will be biased to -100 V in order to suppress the loss of low-energy secondary electrons. The material chosen for the metallic parts is aluminium, while the insulators will be Vespel® (polyimide). The design of the short FC (which will be used in the short DBs) included an extensive research and development campaign as its geometry does not respect the usual aspect ratio of FCs (with a longitudinal length of the collector similar to the FC aperture diameter for increasing the geometrical capture of the secondary charges). Both cups have been tested with beams of energies and composition similar to the ones that will be used on HIE-ISOLDE, using the REX-ISOLDE [3] accelerator at CERN and the ISAC-II accelerator at TRIUMF [4]. The results obtained (Figs. 4 and 5) satisfy the requirements in terms of beam intensity measurements accuracy.

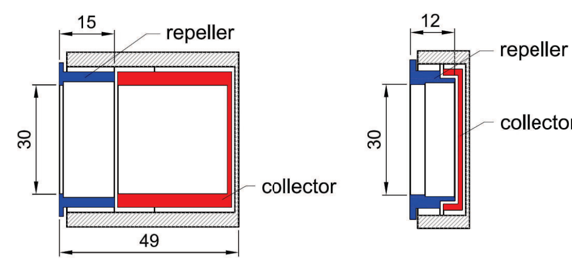

Figure 3: Final design of the HIE-ISOLDE Faraday cups (distances in mm). Left: long FC. Right: short FC.

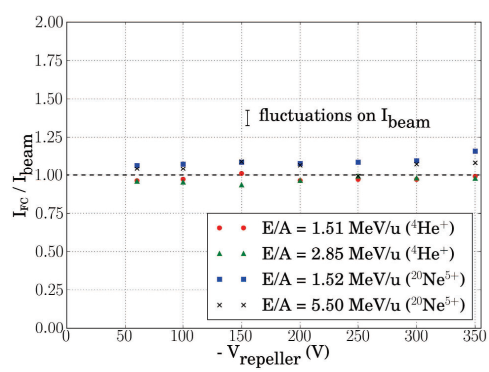

Figure 4: Beam current measurements with the HIE-ISOLDE long Faraday cup.

TRANSVERSE PROFILE AND POSITION

The transverse beam profiles will be determined by moving vertical and horizontal collimators in front of a FC detector. The so-called scanning slit is comprised of an aluminium blade (3 mm thick) that is inserted at 45° of the vertical with a V-shaped slit drilled onto it. A picture of a prototype blade, which will be inserted in one of the diagonal ports of the diagnostic box, is shown in Fig. 6.

The moving blade acts as a scanning collimator that stops any particle that does not have the currently selected

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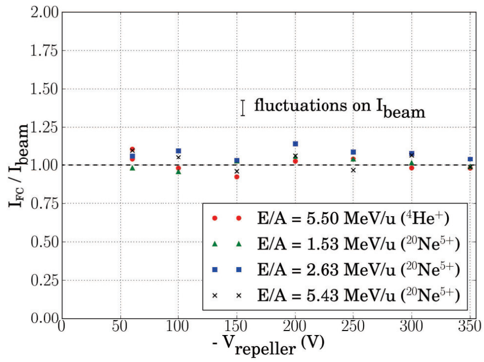

Figure 5: Beam current measurements with the HIE-ISOLDE short Faraday cup.

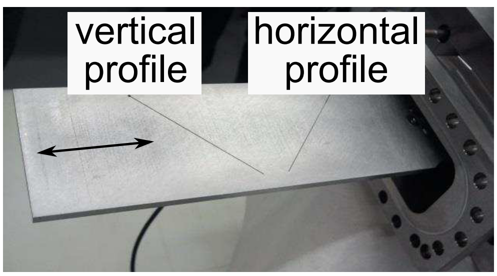

Figure 6: Scanning slit for HIE-ISOLDE. An aluminium blade with a V-shaped slit is moved at 45° of the vertical to collimate the beam, in order to obtain the transverse beam profiles by measuring the transmitted beamlet intensity as a function of the blade position.

horizontal (or vertical) position. By registering the FC signal for different slit positions a direct measurement of the transverse beam profile is obtained. Fig. 7 shows a vertical beam profile obtained with a REX-ISOLDE beam (E/A = 2.85 MeV/u and A/q = 4, mostly ^{20}Ne^{5+}) with a total beam current I_{beam} = 18 pA. The presented beam profile was acquired with a prototype scanning slit which had an slit width of 0.2 mm. Montecarlo simulations of beam profile measurements were performed with a selection of simulated HIE-ISOLDE beams, determining an optimal slit width of 1 mm for the final design. The larger slit width as compared to the one used in the prototype tests will increase the amplitude of the acquired signal without introducing major distortions in the beam profile and size determination. The transverse position of the beam is calculated directly from the measured profiles.

LONGITUDINAL PROFILE

The longitudinal beam profiles, i.e. the energy spread and bunch length, will be measured using two silicon detectors from CANBERRA (model PIPS TMPD50-16-300RM). Details about experimental tests of those detectors, including energy and timing spectrometry and their application to the cavity phase tuning, can be found in [5]. By acquiring the time of arrival of the particles at two dif-

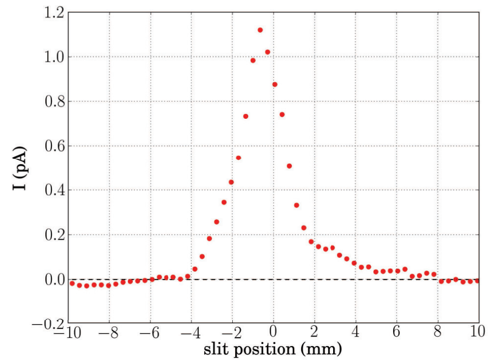

Figure 7: Vertical profile of a REX-ISOLDE low intensity beam, obtained with a prototype scanning slit of 0.2 mm width.

ferent locations of the beam transfer line, absolute time of flight measurements are obtained and can be used for calibrating the energy per nucleon of the beam. With the present solution using Si detectors, timing measurements with both detectors cannot be done at the same time. An alternative solution using annular Si detectors is under analysis.

TRANSVERSE EMITTANCE

The transverse emittance measurements will be done using the existing REX-ISOLDE emittance meter based on the slit and grid method [6]. As a complementary solution, a two-slit scan technique can be implemented using two diagnostic boxes. The achievable resolution for the emittance measurements using the two slits was studied by means of Montecarlo simulations. A diagram representing the main simulation parameters is presented in Fig. 8. The initial beam current is I_{beam}. The slit positions (horizontal or vertical) are x_1 and x_2, the width of the slit is w and the distance between the slits is d. A Faraday cup placed downstream of the second slit detects the transmitted particles. By scanning the slits in turn and recording the transmitted intensity the profile of each beamlet can be reconstructed, from which the emittance can then be calculated. Noise contribution is simulated with the addition of a current I_{noise} to the collected intensity I_{FC}.

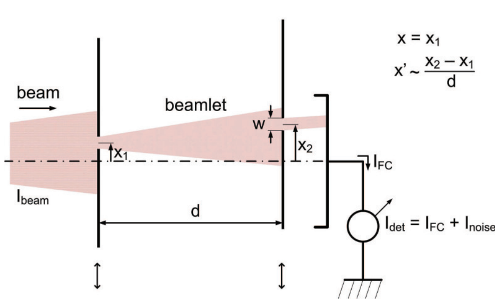

Figure 8: Schematic representation of the two slits-emittance measurement.

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The simulations performed included scans of the two slits in both horizontal and vertical directions. Typical HIE-ISOLDE beams measurements were studied, with I_{beam} in the range 100 to 1000 pA and an added noise contribution I_{noise} with standard deviation 0.1 pA, for three different slit widths (w = 0.2, 0.5 or 1 mm). The separation between the slits was d = 2.6 m, which is the distance between consecutive DBs in the HEBT lines. For the data analysis, an algorithm including a threshold was applied to reduce the influence of noise in the final evaluation of the emittance. In all the studied cases a slit width of 1 mm was found to be optimal. With such a slit width value, the transverse emittance was simulated to be measurable within the requirements for beams with intensities $I_{beam} \geq 400$ pA.

ACTUATORS TEST

The position accuracy of the linear actuator for the movement of the scanning slit of the HIE-ISOLDE DBs was characterised using a prototype short DB designed and built by the company AVS [7]. The mechanism includes two guiding rods and a lead screw, with a full stroke of 135 mm. To test the system a specially designed blade was mounted on the actuator and the transverse position monitored with a camera-based optical system while moving the actuator. The blade had two slits of 0.2 mm width at 45° from the axis of movement and six holes of 0.1 mm diameter drilled in the axis that were used for monitoring the transverse position of the blade. Two optical viewports were mounted on the beam pipe flanges of the DB vacuum tank to allow the installation of a light source and a CCD camera on either sides of the tank. Their supports were independent and mechanically detached from the DB support to avoid coupling any vibration generated by the actuator movement to the optical devices. The position of the slit was controlled by means of a stepper motor. The system also included limit switches and a temperature monitor connected to the external casing of the stepper motor.

The test procedure consisted of tracking the position of the drilled holes for different blade positions while it was moved at speeds of up to 10 mm/s. When the scanning blade crossed the beam aperture, the light passing through the drilled holes (or the slits) was detected by the camera. By analysing the size and position of the light spots frame by frame, the displacements of the blade due to mechanical vibrations were determined. To better reproduce operating conditions these tests were carried out under high vacuum conditions ($P \sim 2 \cdot 10^{-6}$ mbar). After several measurements at different blade speeds, it was concluded that the reproducibility in the positioning of the blade is better than 20 μm. This value allows the determination of transverse beam profile and position within the requirements of the functional specification [2].

ELECTRONICS AND CONTROLS

A new VME board has been designed, built and tested to control the devices on each diagnostic box. It has the capability of controlling up to eight stepper motors, as well as the complete acquisition chain of a FC (DAC/ADC, gains, integration time selection, external trigger, and a programmable high voltage power supply). A new front-end preamplifier has also been produced for the measurement of beam intensity with the FC. In addition, two main Front End Software Architecture (FESA) [8] servers have been developed specifically for HIE-ISOLDE to handle the beam intensity acquisition, the collimator movement, and the energy and time spectra obtained with the Si detectors.

ACTUAL STATUS AND FUTURE WORK

The design of the instruments for the HIE-ISOLDE project has been finalised. Tests with prototypes have been performed with all the devices, showing that they fulfill all the functional specifications. The production of the fully assembled diagnostic boxes (six short and nine long) is currently in its final stages, with contracts signed with external companies. The series production of the electronic cards and preamplifiers will be delivered in October 2014. Installation of the equipment in the HIE-ISOLDE hall is forseen to start at the beginning of 2015, with commissioning with beam scheduled to start in July 2015.

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