BEAM INSTRUMENTATION FOR THE HIE-ISOLDE LINAC AT CERN*

A. Sosa[1,2], E. Bravin[1], M.A. Fraser[1], J. Galipienzo[3], Y. Kadi[1], A. Larman[3], D. Voulot[1], C.P. Welsch[2], F. Wenander[1], F. Zocca[1]
[1]CERN, Geneva, Switzerland
[2]Cockcroft Institute and The University of Liverpool, UK
[3]AVS, Eibar, Spain

Abstract

In the framework of the High Intensity and Energy (HIE)-ISOLDE project at CERN, a beam instrumentation R&D program is on-going for the superconducting upgrade of the REX-ISOLDE heavy-ion post-accelerator. An overview of the foreseen beam diagnostics system is presented, focusing on the challenging specifications required by the HIE-ISOLDE linac. Due to the low beam intensities, the beam instrumentation will be based on high-sensitivity intercepting devices. The project includes intensity, position and transverse profile monitors to be installed in the very narrow space available in between the superconducting cryomodules. In addition, spectroscopy and time of flight (ToF) monitors are foreseen downstream of the linac to measure the energy and time distribution of the beams and to allow for a fast phase tuning of the superconducting cavities. An emittance meter will finally provide transverse emittance measurements based on the phase space sampling technique. The design status of the different instruments is presented as well as the results of some experimental tests.

INTRODUCTION

Today the REX post-accelerator in ISOLDE provides radioactive ion beams (RIB) with beam energies ranging from 0.3 to 3 MeV/u for ions with a mass-to-charge of $A/Q \leq 4.5$. ISOLDE beams are charge-bred by a combination of a Penning trap and an electron beam ion source (EBIS) providing low-emittance, highly charged ion beams. These are post-accelerated in a compact normal conducting linac which comprises an RFQ and a combination of IH structures and 7-gap resonators operating at frequencies of 101.28 MHz and 202.56 MHz. The operation of the REX post-accelerator started in 2002 and today it produces a wide variety of radioactive ion beams [1].

The HIE-ISOLDE project aims at increasing the energy and intensity of the RIBs delivered at ISOLDE. In the context of the energy upgrade of the REX linac, it is proposed to increase the maximum energy to 10 MeV/u for ions with A/Q=4.5 by extending and replacing part of the normal conducting linac with four superconducting cryomodules, each one containing five or six Nb sputtered Quarter Wave Resonators (QWR). More details about the cryomodules can be found in [2].

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BEAM INSTRUMENTATION

Diagnostic boxes will be placed in the region between each cryomodule. The same design will also be used in the High Energy Beam Transfer lines (HEBT) after the linac. A total of 15 diagnostic boxes (7 in the linac and 8 in the transfer lines) will be needed for phase 1 of the upgrade. A detailed layout of the linac and the transfer lines to the experiments can be found in [3]. The 3D model of the box is shown in Fig. 1.

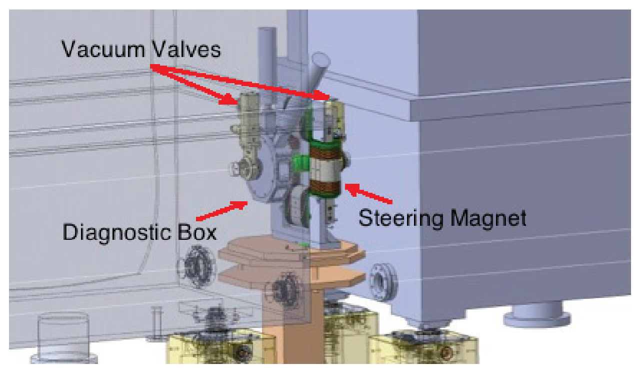

Figure 1: 3D model of a diagnostic box in the region between cryomodules.

The number and type of devices in each box will change depending on the location in the machine. The different devices that are being developed comprise a compact Faraday cup (FC), a solid-state detector, a collimator blade, stripper foils and a slit scanner. Each box will provide at least intensity, transverse profile and beam position, with additional features where needed. A computer model of a diagnostic box with 3 devices and a pumping port is shown in Fig. 2.

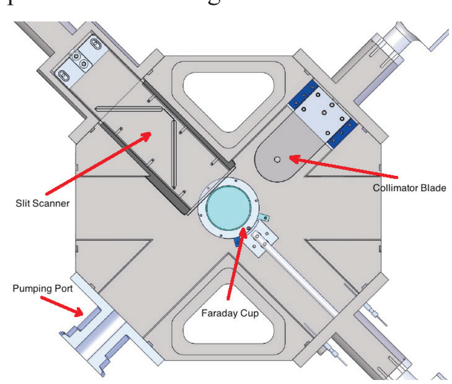

Figure 2: 3D model of the diagnostic box (Developed by AVS).

The previously used FC has been redesigned into a much shorter version, due to the short longitudinal space available in the inter-tank region. The length of the new FC is only 20 mm, compared to the 60 mm of the present type used at ISOLDE. This device, when connected to a picoammeter (PAM) can read currents ranging from 1 pA up to 500 pA, and will thus only be able to measure the current of the radioactive beams if it is large enough.

The Faraday cup has an outer bias ring that is set to a negative voltage, to avoid secondary emitted electrons escaping the cup. A simulation of the potential distribution in the cup is shown in Fig. 3.

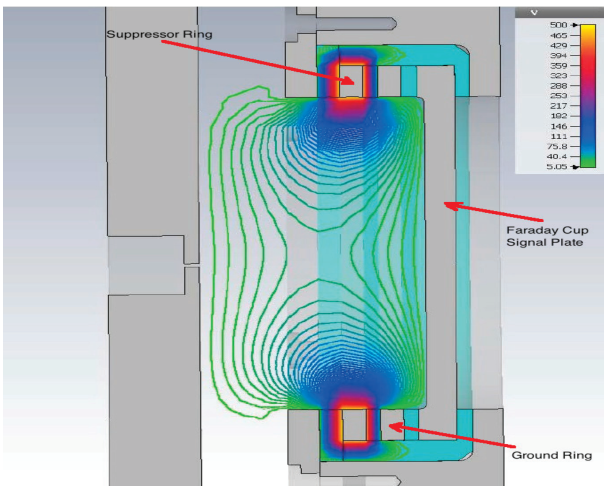

Figure 3: Simulation of the potential distribution in the Faraday Cup.

When the FC is used together with the slit scanner, the transverse profile is obtained by sampling the beam current behind the slit scanner, with the value of the measured current recorded as a function of the slit position. A sketch of this technique is shown in Fig. 4.

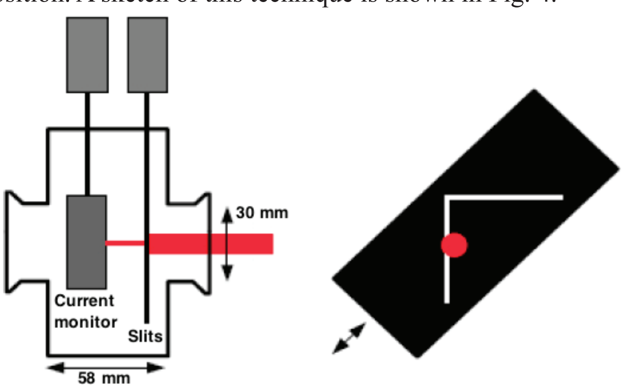

Figure 4: Operating principle of the profile monitor based on a slit scanner and the FC.

For some unstable beams, the current can be from as low as 1 pA down to a few particles per second, requiring a sensitive detector in order to measure these very faint currents. One option consists in measuring the particle arrival rate using a solid-state detector. For this task, an R&D study in solid-state detectors is under way. The two main candidate materials are silicon and diamond. The ultimate solid-state detector will have to withstand radiation damage, be sufficiently durable, as well as effectively measuring the currents of the radioactive ion beams. Another option could be using secondary-emission-electron-multipliers, which generate secondary electrons and then amplify the signal by means of electron multipliers (channeltrons or multi-channel plates). Of course, proper read-out electronics will also need to be developed. The measurement time is related to the integration time needed to get a reliable measurement.

A Si-detector based monitor has been developed for relative energy measurements. This device can be used for a fast and eventually automated phasing of the RF cavities. It can also provide energy and energy spread information. An energy and arrival time spectrum is shown in Fig. 5. More details can be found in [4]. A time of flight measurement system for absolute energy measurements is being considered, however this can only be used when a chopper is installed.

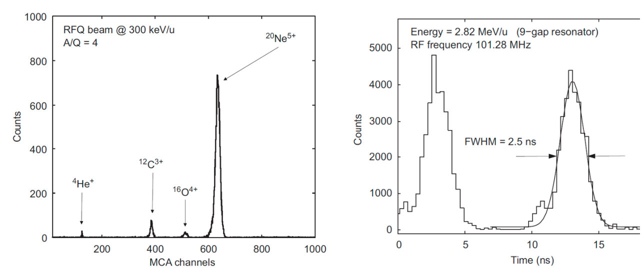

Figure 5: Energy and time spectrum of the Si-det. [4]

An emittance meter based on two consecutive diagnostic boxes is foreseen for transverse emittance measurements. The system is comprised of two blade scanners, each containing two slits, one horizontal and one vertical, that are combined into a V-shape at 45 degrees just as for the transverse profile monitor. The measurement of the transverse emittance is based on a phase space sampling technique. The particles isolated using the slits come from a well-defined position within the beam. The angular distribution in the resulting beamlets can be measured by allowing them to drift through a drift space before detection. Since all the particles have the same position at their point of origin but different velocities their resulting transverse positions after the drift will be a function of their initial transverse velocity. The drift space therefore converts the angular distribution into a position distribution. If this process is repeated, scanning consecutive slices of the whole beam, one can plot the complete phase space distribution. The operation principle of the transverse emittance meter is shown in Fig. 6.

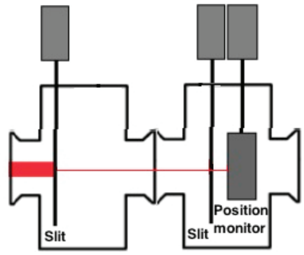

Figure 6: Operating principle of the emittance meter.

A number of supplementary collimator blades are required in order to be able to precisely define the beam shape in one or both planes when tuning the accelerator, to clean the beam halo of off-axis or off-momentum particles, or to measure the energy spread in a dispersive section (thin slit at the spectrometer entrance). These apertures should be in the beam path at the same time as the Faraday cup. Two variants of collimator blades are foreseen, one with circular holes of different diameters and the other one hosting vertical slits of different widths.

DIAGNOSTIC BOX DESIGN

The diagnostic boxes for HIE-ISOLDE have a modular design. They have 6 ports available for devices in an octagonal shape, which can house different diagnostic instruments and a pumping port. These boxes will be placed in the inter cryomodule region of the linac, where they will share the space with a warm steering magnet and two vacuum valves (Fig. 7). The longitudinal space is a tough constraint as there are only 90 mm available for the diagnostic box and its flanges. This requires deep studies in the trajectories of secondary emitted electrons and the correct suppression voltage. The diagnostic box is therefore designed for a length of only 58 mm excluding the flanges. The design of the diagnostics box is almost ready. This design is carried out by an external company, AVS.

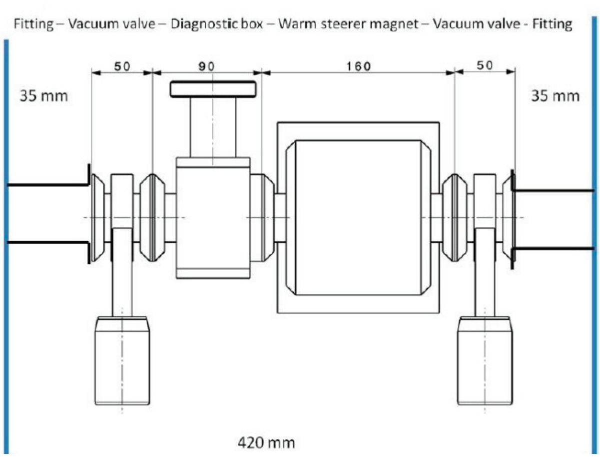

Figure 7: Layout of the inter cryomodule region.

MATERIALS AND VACUUM ASPECTS

The diagnostic boxes will work under vacuum at a pressure lower than 10^{-7} mbar. The cryomodule walls and flanges in contact with the diagnostic boxes will be at room temperature. Due to the superconducting RF cavities, the whole linac is very sensitive to contamination, and the diagnostic boxes are no exception, as they are integrated in the beam line. The diagnostic boxes therefore need to be properly cleaned and assembled in a clean room.

OUTLOOK

The design of the HIE-ISOLDE diagnostics box is almost complete. A prototype will be delivered to CERN soon, where various tests will be carried out. A single design will be used in the whole linac and transfer lines. Future research will focus on the optimization of the integration of solid-state devices in the diagnostic boxes.

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