THE DESIGN, CONSTRUCTION AND OPERATION OF THE BEAM INSTRUMENTATION FOR THE HIGH INTENISTY AND ENERGY UPGRADE OF ISOLDE AT CERN

W. Andreazza, E. Bravin, E.D. Cantero, S. Sadovich, A.G. Sosa, R. Veness,
CERN, Geneva, Switzerland
J. Carmona, J. Galipienzo, P. Noguera Crespo, AVS, Elgoibar, Spain

Abstract

The High Intensity and Energy (HIE) upgrade to the online isotope separation facility (ISOLDE) facility at CERN is currently in the process of being commissioned. The very tight space available between the superconducting acceleration cavities used and a challenging specification led to the design of a compact 'diagnostic box' (DB) with a number of insertable instruments on a common vacuum chamber. The box was conceived in partnership with the engineering firm AVS and produced as a completed assembly in industry. 14 diagnostic boxes have been installed and are now operational. This paper will describe the design, the construction and first results from operation of these HIE-ISOLDE diagnostic boxes.

INTRODUCTION

The High Intensity and Energy (HIE) ISOLDE project is a major upgrade of the ISOLDE and REX-ISOLDE facilities at CERN. The aim of the HIE-ISOLDE project is to greatly expand the physics programme compared to that of REX-ISOLDE. The energy of the post-accelerated radioactive beams will be increased from 3 MeV/u to 10 MeV/u. At the same time the intensity of the source will be increased with higher beam power on the production target, from 2 kW to 10 kW.

The HIE-ISOLDE diagnostic boxes are installed in the Linac between the cryomodules and in the High Energy Beam Transport (HEBT) line, between the quadrupoles of the doublet transport channel, in the dispersive sections of the double-bend achromats and before the experimental target positions.

BEAM DIAGNOSTIC REQUIREMENTS

The beam diagnostic system must provide a wide range of possibilities for measuring properties of the beam during set-up and operation of the HIE-ISOLDE facility, specifically: measurement of beam intensity using a Faraday cup; measurement of beam transverse profile and beam position using a Faraday cup in parallel with a scanning slit; collimation of the beam using collimator slits; charge-state cleaning using stripping foils; measuring energy and longitudinal profile using silicon detectors [1].

DESIGN

The design of the diagnostic boxes (DB) was driven by the very tight space available between the superconducting acceleration cavities installed in the LINAC (Fig. 1 & 2). Two cryomodules have been installed so far with four more units planned to be added over the next few years. The LINAC layout allowed a maximum inter-cryomodule distance of 250 mm, where the DBs are located. Two different versions of boxes were designed and produced, equipped with various selections of the same instruments. Five so-called "short DBs" are installed in the HIE-ISOLDE LINAC and eight "long DBs" provide beam instruments in the HIE-ISOLDE experimental lines.

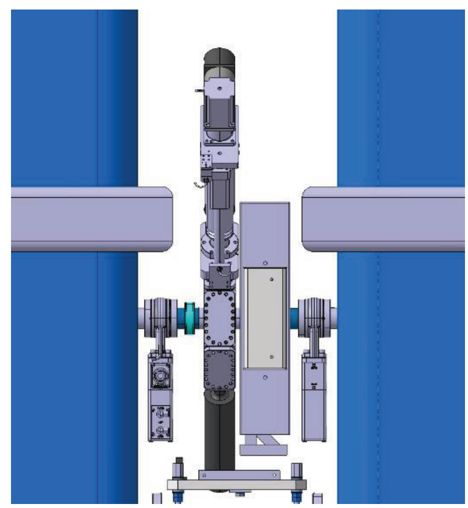

Figure 1: Schematic of the inter-cryomodule region with a short diagnostic box installed.

The design had to allow for installation of the following ultra-high vacuum (UHV) compatible instruments:

- Faraday cup
- Scanning slit
- Collimating slit
- Silicon detector
- Stripping foil

Two edge welded bellows allow the diagnostic box to be aligned with the surrounding components, with a permanently installed survey target used for fiducialisation.

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Figure 2: A short DB containing a faraday cup, a scanning slit and a collimating slit installed beside a cryomodule.

DB MAIN BODY

The strict constraints for space, flexibility, UHV compatibility and precision led to the development of a very compact unit where the main structure is an octagonal shaped tank made out of austenitic stainless steel with six ports available for the insertion of the instruments (Fig. 3). Two edge welded bellows with conflat flanges are welded on both sides.

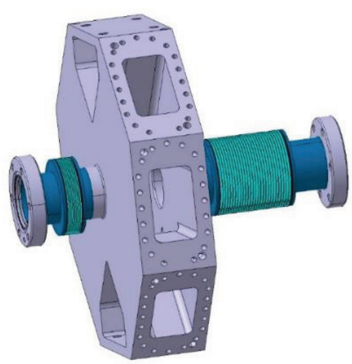

Figure 3: 3D image of the DB main body.

FARADAY CUP

A very compact Faraday cup (Fig. 4) was designed and tested to cope with the very limited space available. The length of both the collector plate and the repeller were severely reduced compared to a standard Faraday cup and optimised to keep a good accuracy [2]. A first version of the short FC was tested and did not achieve the expected results. A second iteration led to a newer, more elegant design which significantly reduced secondary particle loss. The structure materials were also all selected with their both their mechanical and electrical properties kept in mind. This design was built at CERN and tested at the TRIUMF facility in Canada. Although the geometry of the HIE short FC is very different to that used in standard cups, these differences were shown to have only a minor effect on the overall performance. The current ranges from 1 to 100 pA for stable beams while for radioactive beams it can range from a few pA down to a few particles per second.

The Faraday cup is mounted on a UHV linear feedthrough in order to allow its insertion and extraction from the beam line. The Faraday cup can be used together with either the scanning or the collimating slits.

In the initial design, the material for the insulator was polyimide. However, this was later changed to MACOR®, a machinable ceramic, to minimise the chance of contaminating the nearby superconducting cavities.

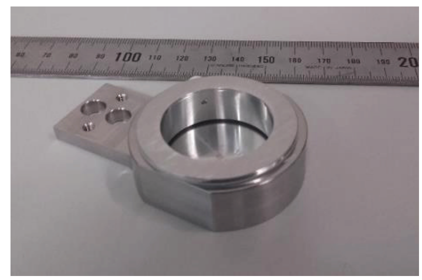

Figure 4: Short Faraday cup.

SCANNING SLIT

In order to measure the transverse position and beam profile a customized UHV Linear Shift Mechanism was developed (Fig. 5) to precisely move a scanning slit located in front of a faraday cup or silicon detector. It consists of a metallic blade with a V shaped slit of 1 mm width that moves at 45° across the beam to allow reconstruction of both the horizontal and vertical profiles. The required accuracy for the measurement of the transverse position was 100 μm. A first prototype with an in-vacuum guiding system and a commercial linear motion actuator did not pass a stress test (10000 cycles) and the decision was taken to develop a customised linear motion actuator. The system has a stroke of 135 mm with guiding rods surrounding a high precision ball bearing screw connected to a stepper motor.

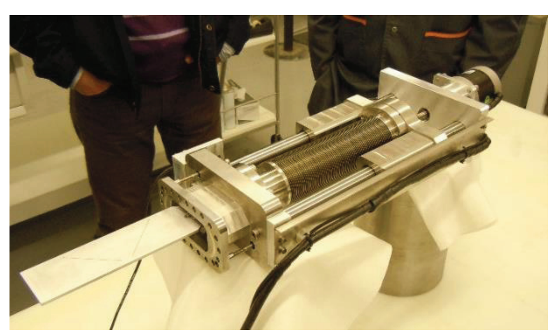

Figure 5: A scanning slit fully assembled.

An acceptance test of the new prototype was performed at the AVS headquarters in February 2014. A special blade with a slit and six holes of 0.1 mm was built for the test. The test consisted of tracking the position of the drilled

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holes for different blades position, either with the blade fixed or while moving, using a system with an illuminator and a camera (Fig. 6). When the scanning blade crossed the beam aperture the light passing through the holes (or the slit) 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 (Fig. 7). Results showed that the position variation was less than 20 μm [3]. With the instrument performing to specification the design was approved for production.

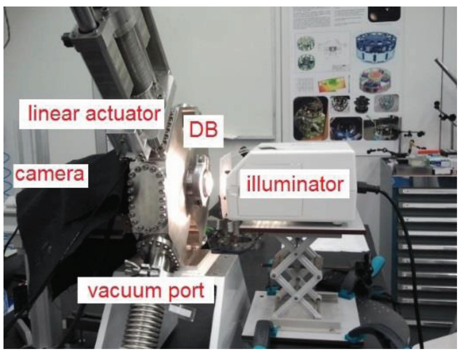

Figure 6: Scanning slit acceptance test set up [3].

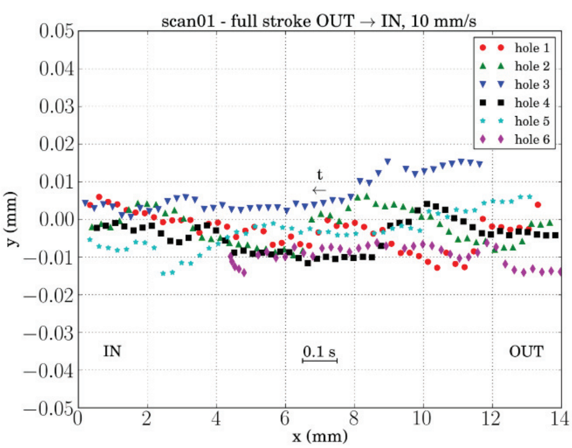

Figure 7: Tracking of the hole positions in the x-y (camera) plane. The blade speed was 10 mm/s, and the movement was from the fully OUT to the fully IN positions.

COLLIMATING SLITS

Two types of collimating slits were designed to fulfil the requirement for supplementary fixed position aperture measurement. These devices are used to reproducibly define the beam position in one or both planes when tuning the accelerator, to clean halo produced by off-axis or off-momentum particles, or to measure the energy spread in the dispersion section when a thin slit is placed at the spectrometer entrance. All measurements are performed in combination with a faraday cup.

Two different collimating slits are installed. Type I (fig. 8) with four circular holes (from 2.5 mm to 20 mm) is mainly used for quick centring and tight collimation of the beam while type II (four vertical slits with widths from 2 mm to 15 mm) is used for position determination for energy measurement.

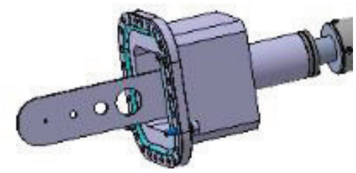

Figure 8: 3D image of a Type I collimating slit.

SILICON DETECTOR

A silicon detector is used to optimise the operational settings of the accelerator by measuring the energy of the beam after each accelerating structure for different values of the RF phase. The silicon detector can also be used to measure the beam energy and the beam purity as well as to analyse the time structure of the beam.

It consists of a commercial Passivated Implanted Planar Silicon (PIPS) detector installed onto a UHV linear feedthrough in order to allow its insertion and extraction from the beam line. The silicon detector can be used together with either the scanning or the collimating slits.

STRIPPING FOILS

Lightweight carbon stripping foils of varying thicknesses in the range of tens or hundreds of $\mu g/cm^2$ are needed for beam charge-state cleaning. The instrument consists of a metallic blade with 2 holes of diameter 30 mm over which the foils are mounted using a separate frame (Fig. 9). The blade is attached to a linear motion feedthrough that allows movement of the different foils onto the beam. The foils need to be “in beam” together with Faraday cup.

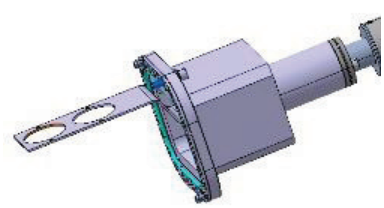

Figure 9: 3D model of a stripping foil mechanism.

OPERATIONAL EXPERIENCE

After a first period of commissioning the DBs have shown that their behaviour is within the required specification and have been used during regular machine operation since the summer of 2015. Some examples of their use are described below.

Figure 10 shows beam profiles obtained by scanning the scanning slit in front of the Faraday cup. The vertical axis shows the intensity of the beam that impinges on the FC after passing through the slits, while the x axis shows the

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position of the blade. The profile on the left corresponds to the vertical plane while the one on the right to the horizontal plane.

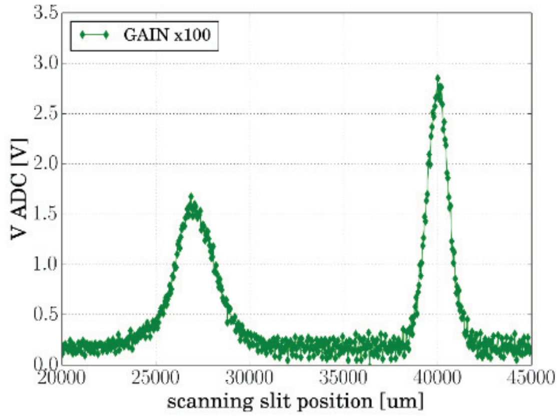

Figure 10: Beam profile measurement.

Figure 11 shows the energy spectrum of the beam for two different operational configurations measured with the silicon detector. The blue curve shows the spectrum obtained when the ISOLDE target is irradiated with protons while the red curve is obtained when the proton beam is turned off. The picture shows that when protons hit the ISOLDE target the beam is made predominantly of $^{76}Zn^{22+}$, while the main contaminant (protons off) is $^{38}Ar^{11+}$. Such measurements can be used to study and optimise the composition and purity of the beams.

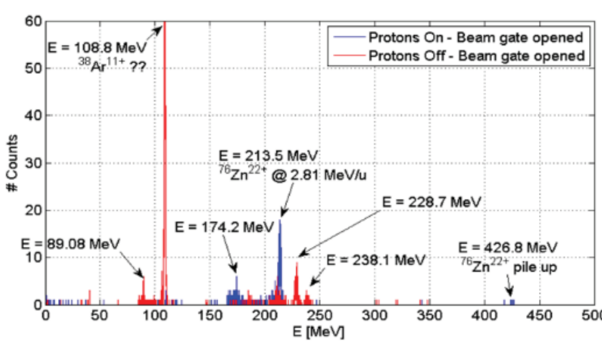

Figure 11: Particle energy spectrum.

Histograms of the particle energy as function of the phase of the RF in a superconducting cavity are shown in Figure 12. Each colour refers to a particular phase setting, while the different peaks of each trace correspond to different particle species (the probe beam used contains several elements). It is evident how the average beam energy changes as function of the RF phase. This type of measurements is routinely used to adjust the RF phase to the most appropriate value.

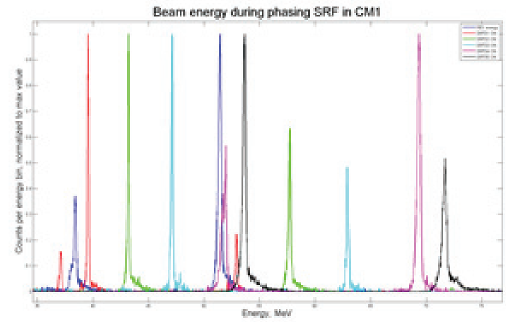

Figure 12: RF cavity phasing.

CONCLUSIONS

Two types of diagnostic boxes were designed and produced in collaboration with private industry with a total of 14 units now installed at the HIE-ISOLDE facility. The beam instrumentation provided by these diagnostic boxes have shown very good accuracy and reliability and have been essential for both commissioning and everyday operation.

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