

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2017). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

SOFTWARE APPLICATIONS USED AT THE REX/HIE-ISOLDE LINAC

E. Fadakis[†], N. Bidault, E. Matli, J.A. Rodriguez, M.L. Benito, E. Siesling, S. Sadovich,
 E.O Gonzalez, CERN Switzerland

Abstract

The HIE-ISOLDE Linac (High Intensity and Energy) [1] is a recent upgrade to the ISOLDE facility of CERN, increasing the maximum beam energy and providing means to explore more scientific opportunities. The main software tools required to set up the new superconducting post-accelerator and to characterise the beam provided to the experimental stations will be presented in this paper. Emphasis will be given to the suite of applications to control all beam instrumentation equipment which are more complex compared to the ones in the low energy part of ISOLDE. A variety of devices are used (Faraday cups, collimators, scanning slits, striping foils and Silicon detectors). Each serves its own purpose and provides different information concerning the beam characteristics. Every group of devices required a specific approach to be programmed.

INTRODUCTION

ISOLDE is one of the leading research facilities in the field of nuclear physics. Radioactive Ion Beams (RIBs) are produced when 1.4 GeV protons impact in a target.

The RIB of interest is extracted and transported to different experimental stations either directly or after being accelerated in the post-accelerator. In the latter, RIBs are transported to the REX-TRAP [2], charge-bred in the REX-EBIS [3] and accelerated to 2.85 MeV/u in the REX normal conducting section of the linac before being accelerated further (9.3 MeV/u for beams with $A/q = 4.5$ and to 14.3 MeV/u for $A/q = 2.5$) in the HIE-ISOLDE superconducting section of the linac. Software applications used for HIE-ISOLDE can be divided into two categories, Beam Set-Up related and Machine related. The first category contains the applications that enable the Engineers In Charge (EIC) to set up the desired beam regardless if it is stable (e.g. 39K) or radioactive beam (e.g. 76Zn). The second is for the applications that provide information about the status of critical systems. All applications in the second category are in PVSS.

One is the vacuum application [4]. With this the pressure for each sector of the machine is monitored and it allows opening or closing the vacuum sector valves in the beam-line. The second application is used to monitor the status (i.e. temperatures, flows, LHe levels etc) of the cryoplant, the cryoline and the cryomodules. The Warm magnet Interlock Control system (WIC) is used to monitor the temperature of the normal conducting magnets.

In this paper more detail will be given on the first category.

BEAM SET-UP RELATED APPLICATIONS

This category includes the large majority of the applications used. The ones that will be described in this paper are: Equipment Array, EBIS Slow Extraction, HIE Beam Diagnostics (HIE-BD), HIE Silicon Detector (HIE-SD), HIE Energy Measurement, HIE Phasing, HIE Count Rate.

Equipment Array Application

Different types of equipment, such as electrostatic or magnetic elements, normal or super conducting cavities are used in the ISOLDE beam lines. They are all available to the EIC to set up the beam to its final destination. The Equipment array application is based on comma separated values (csv) files. They consist of 4 columns; name of device, buffer value, requested (CCV) value and Acquisition (AQN) value. On the loaded file the EIC can change the value of each device. Once the set-up is finalised a separate file can be saved. One can also scale the buffer values either by mass to charge ratio or by energy per nucleon. As an example, eight equipment arrays are typically used to characterize a set-up to deliver beam to the experimental station at the end of the first HEBT line.



Figure 1: The Beam Diagnostics application main panel.

Beam Diagnostics Application

For phase 2A of the project, In the HIE-ISOLDE section of the linac and the High Energy Beam Transfer lines (HEBTs) there are 18 diagnostic boxes [5] housing 70 devices. Those are divided into 18 Faraday cups (FC), 18 scanning slits (SL), 18 collimator slits (CS), 5 stripping foils (SF) and 5 Silicon detectors (SD). In the applications main panel (see Fig.1) every row represents a diagnostic box and every column is a different type of device. Every

[†] efadakis@cern.ch

diagnostics box is divided into two physical layers. Depending on the devices that each box is equipped with on each layer, specific interlocks are put in place.

All devices share a common functionality which is the movement. The stepping motors used to insert/retract each diagnostic device can be turned on or off (see Fig. 1, No 2) to reduce the electromagnetic noise when sensitive measurements need to be conducted.

End switches confirm that the device has been fully inserted or retracted. Upon every touch of the retraction end switch the stepping motor is recalibrated and this position is set as zero. All devices have been configured with fixed positions. For some like the FC (see Fig. 1, No 3) and SD these positions are as simple as in or out. For the scanning slits the user can select between out, horizontal slit, vertical slit and a collimator hole. For the collimators (see Fig. 1, No 5) the user can select between four different apertures; 2.5 mm, 5 mm, 10 mm, 20 mm. Two of the collimators are actually slits and not apertures. Their positions are: 2mm, 5mm, 10mm, and 15mm. Carbon foils (see Fig. 1, No 6) with two different thicknesses (50 and 75 $\mu\text{g}/\text{cm}^2$) can be inserted. The motor of each device can be moved in either direction at any time unless the layer is busy (see interlocks paragraph). In addition, a value in mm can be inserted, by which the device will be shifted in relation to its current position. Apart from that the functionalities defer.

The button beside number 1 within figure 2 allows the EIC to stop the beam. This is achieved by turning off one of the plates of an electrostatic deflector.

The FCs are able to measure beam currents lower than a pC/pulse. The user can change the gain of the amplifier of the FC by a factor of 1, 10, 100, and 1000. The voltage of the electron suppressor can be modified as well. The user can save the data of the plot from within the dedicated FC panel. The position in mm of the FC and the state of the layer are depicted as well.

Scanning Slits

The metallic plate of the SLs has two slits that allows the characterization of both vertical and horizontal profiles of the beam. In the panel of the application for using the SL (see Fig.2) the EIC needs to select a type of measurement, meaning which slit should pass through the beam. Each SL can perform two similar types of measurement.

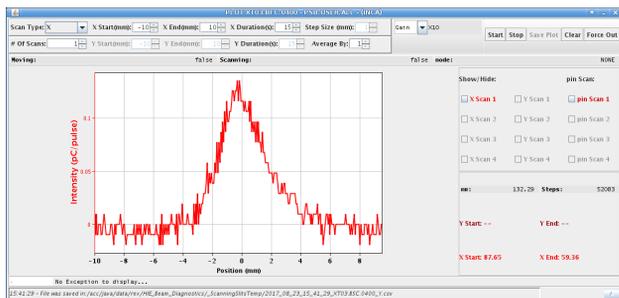


Figure 2: Scanning slit main panel after a horizontal beam profile measurement.

In the first the slit moves continuously whereas in the second one it moves in pre-defined steps. For both types of

movement one can select between both horizontal and vertical planes (X-Y), only horizontal plane (X), only vertical (Y) scan types. By default the horizontal axis is selected. The user must select the start and stop positions for each type of scan. These values are in mm offset with respect to the zero position for each slit.

Depending on the length of the measurement selected, the application calculates the fastest time possible for the slit to move, based on the maximum speed of the stepping motor. The user can perform an even slower movement if required. The EIC can perform consecutive scans once the above configuration is set. In this case the latest four measurements will appear in the graph.

The stepping scan feature is used when synchronisation with the pulsed beam is required, in order to reduce the EM noise from the stepping motors. While performing the measurement the speed is governed by the configuration on the SL panel.

A step size in mm must be declared in addition to the previous configuration. Each measurement is saved in a predefined path, using a timestamp as part of the file name, together with the name of the device and the type of measurement.

The gain of the FC which performs the measurement can be changed in real time. On the top right the EIC can either start or stop a measurement, clear the graph or force the SL to extract. Regardless the position of the SL, once the start command is send, it would move to the start position and perform a movement until the stop position. In order to gain time, additional logic was inserted in the high level application.

The application compares the current position of the slit to both the start and the end positions. The one that is the closest to the current position becomes the start of the measurement. This also applies for the consecutive scans which were mentioned above. Below the controls, three labels inform if the slit is moving, if it is performing a measurement and what its current measurement mode (normal or stepping) is. The EIC can select to perform an X-Y measurement. In this case setting start and stop positions for both horizontal and vertical planes is needed. The application will compare the distance of all four positions to the current one and decide which plane and position will be considered as the beginning. The two plots will be shown on the X-axis and a new vertical axis will be created for the vertical measurement. The later will be depicted in a different shade of the same colour as the first one.

On the middle right of the panel the user can select to depict both of the plots or either one of them. If a consecutive X-Y measurement was selected, eight plots in total would be shown in the graph. On the bottom right the user can see the actual position of the slit on axis. At the same time the converted value for horizontal and vertical planes are shown. The SL axis is at 45 degrees angle compared to them.

Content from this work may be used under the terms of the CC BY 3.0 licence © 2017. Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

Silicon Detectors

The Silicon detectors have a dedicated application since they have many functionalities. The main panel follows the architecture of the HIE Beam diagnostics application. Each row is a different diagnostics box. The possibility to turn on and off all stepper motors of a certain box is available through the main panel. There is a dedicated panel per Silicon detector where the EIC can see information about the channel status, the layer and the position of the Silicon detector in mm. The channel settings can be also configured. The voltage applied to the SD can be controlled and both the voltage and leakage current are shown. The device is sensitive enough to measure single ions. The SD can be operated in two different ways.

In the oscilloscope mode (see Fig. 3), a voltage signal proportional to the beam energy deposited is shown as a function of time.

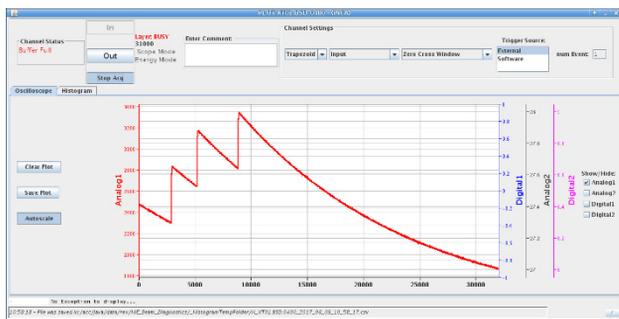


Figure 3: SD measuring few consecutive ions.

Second mode is the histogram (see Fig.4). The high level application accumulates events in order to create a histogram with the energy distribution so that all isotopes can be identified.

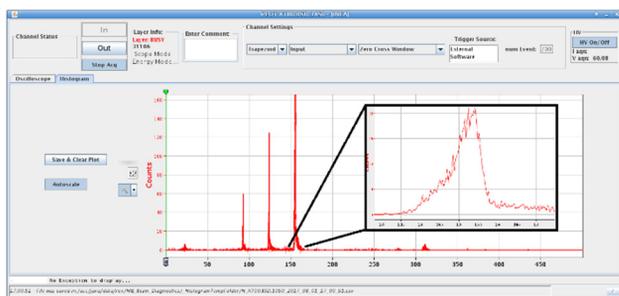


Figure 4: SD panel during a histogram mode. Zooming in to better distinguish the energy.

Future Implementations

There is still work to be done to further augment the means of characterising the beam. Information concerning the time of arrival of the beam on the SD, will contribute to the list of functionalities (e.g. the Time of Flight TOF). For SL and FC an averaging of each set of data points is essential in order to further reduce noise level.

The Slow Extraction Application

A prerequisite to the injection in the linear accelerator is to enhance the charge state of the ions in the REX-EBIS

charge breeder. After a certain confinement time in REX-EBIS, corresponding to the time needed to reach the suited charge state, the ions are extracted accordingly to the voltage modulation of the extraction tube.

A slow extraction scheme has been developed to achieve a lengthening of the time structure of the ion beam from 0.2 ms to 2 ms and consequently allow a reduction in the instantaneous beam current and a more efficient event discrimination at the experimental stations in comparison to the fast extraction mode for which all ions are condensed in a ~0.1 ms pulse.

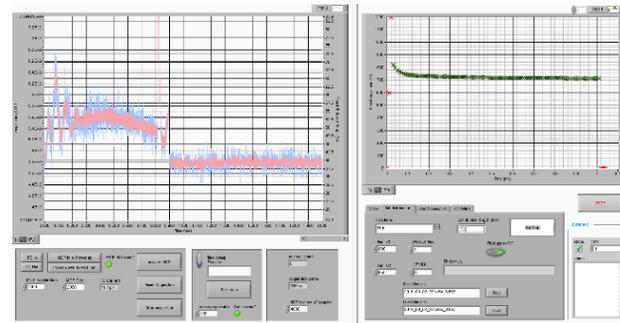


Figure 5: Slow Extraction application panel. MCP signal on the left graph and voltage modulation on the right.

The Slow Extraction application, made with LabVIEW, is divided into two parts (see Fig.5): the extraction tube’s voltage modulation on the right and a Micro-Channel Plate (MCP) scope displaying the time structure of the beam, on the left. The first step of the procedure is to measure the axial energy distribution of the extracted beam from REX-EBIS. This is done automatically via progressively measuring the intensity of the beam passing above the extraction tube potential while sweeping its value from total confinement at 1200 V to full opening at 0 V. The EIC has the choice between Faraday cups and a MCP for acquiring the evolution of the beam intensity related to the axial energy distribution reconstruction. Subsequently, an algorithm within the application estimates an ideal extraction tube’s voltage distribution that will stretch the time structure accordingly to a length specified by the EIC.

In addition to the extraction tube’s potential distribution calculated by the algorithm, the application provides refinement tools to manually lessen the remaining variations from flat top of the time structure. It is feasible to fit the voltage distribution with a two-exponential function and to adjust this function’s parameters (three amplitude constants and two time constants). More trivially refinement possibilities include the adding of a constant and positive or negative slopes controlled by amplitude and defined time range. The EIC can furthermore easily switch between Slow Extraction mode, Fast Extraction mode, previously saved settings or other types of distribution offered by the application (linear modulation, inverse of an error function and power functions).

Concerning the time structure visualisation, one distinguishes two cases linked with ISOLDE diagnostics’ capabilities: low intensity (in the range of 10 to 100 pico-Ampere) and very low intensity beams (under the pico-

Ampere order of magnitude). The time structure of low intensity ion beams can be directly displayed on the MCP scope of the application. The poor signal-to-noise ratio is essentially a consequence of the device aging and it defines the beam intensity limit for this acquisition method. The raw data are juxtaposed with their average over REX-EBIS pulses during the acquisition time. The MCP provides a good approximation of the envelope of the beam time structure, in accordance with other detectors (Silicon detector and MINIBALL [6] experiment), when operated with an acceleration voltage and a gain voltage set in the range of 80% to 90% of their maximum values.

Very low intensity beam analysis in the HIE-ISOLDE accelerating line, requires the use of a Silicon detector. Silicon detectors set in single event detection mode, deliver at each REX-EBIS cycle, notably one array with the time-stamps of the particles detected and one array with their energies. A LabVIEW application was made to set the single event mode for a chosen Silicon detector, to subscribe to the two relevant arrays and to reconstruct the time structure of the ion beam. Both arrays have to be processed to eliminate noise generated, artificial events or unresolved events and to reconstruct the time position of a particle in the pulse within regard to its time-stamp. For this specific purpose, the time resolution of the Silicon detector is 10 ns, which is sufficient to display time distributions of several hundreds of micro-seconds. The scope of the application (see Fig.6) is a histogram with the number of detected particles on the y-axis, the time positions of the particles in the pulse on the x-axis and a colour weight for each event representing its energy. The binning size of the histogram can be changed while acquiring data.

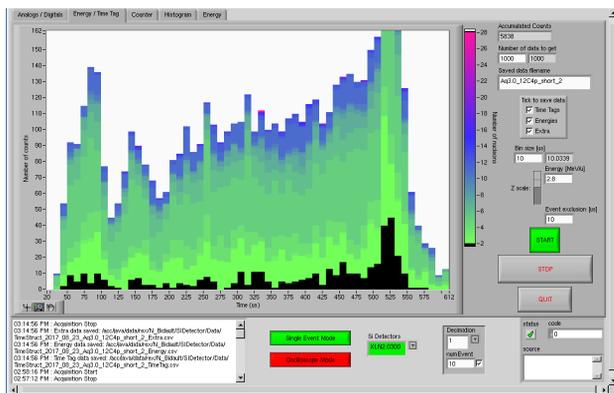


Figure 6: Time structure from Silicon detector acquisition.

Phasing Application

The phasing of a series of RF cavities is necessary to match the time of flight of the ions between cavities, with the oscillating electric field across the cavity gaps. In the HIE-ISOLDE linac this relation is subject to change every time a new isotope is accelerated.

A standard procedure has been developed using one of the dipoles in the experimental line at the end of the linac to measure the intensity of a fixed energy beam, as we vary the phase of the RF cavity. Faraday cups or Silicon detectors can be used to measure beams in different intensity

ranges. One or several vertical slits can be positioned in front of the detector to increase the resolution of the measurement. The signal-to-noise ratio can be improved by increasing the number of acquisitions for each measurement.

The magnetic field of the dipole is set to the value corresponding to the energy of the beam injected into the cavity. As the phase is scanned over a range of 360 degrees we identify two peaks separated by 180 degrees corresponding to the two zero crossings of the cavity. Once the zero crossings are identified, the operational phase is calculated (the nominal synchronous phase for the superconducting cavities is -20 degrees). After validating the setting of the cavity the dipole's magnetic field is set to the value corresponding to the new beam energy and the procedure is repeated for the next cavity.

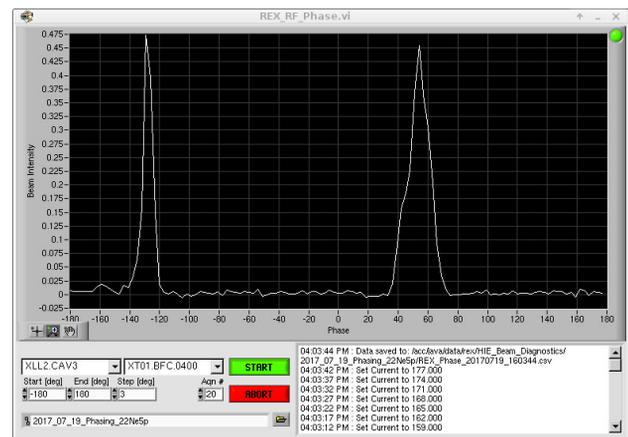


Figure 7: Two zero crossing peaks of an SRF cavity, separated by 180 degrees.

A LabVIEW application (see Fig.7) has been developed to automatize this lengthy procedure. The user can select from a dropdown menu the cavity to be phased and the device to measure the beam intensity. The complexity of the different HW is hidden to the user who only needs to set the scanning parameters: phase range, steps and number of acquisitions to take at each point. An extra delay can be set after the cavity phase stabilises before performing the beam intensity measurement. The data are saved in csv file for further analysis.

Energy Scan

The Energy Scan application (see Fig.8) is used in tandem with the Phasing application to precisely determine the beam energy, based on the same principle described before.

A dipole current is scanned between a start and end value while the intensity of the beam is monitored with a detector positioned after the magnet. A set of three vertical slits (two before the dipole and one just in front of the detector) are used to select only the beamlet of particles that have a small angular deviation from the beam axis.

A very simple interface allows the user to select the pair of magnet/detector to use and a basic set of values such as start, end, and step. To reduce the statistical error, the number of measurements at each position can be increased at

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2017). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

the expense of a longer measuring time. The A/q input is used to compute the beam energy based on the magnetic field acquired from a Hall probe positioned inside the dipole. A dropdown menu allows the user to change the x scale between: Beam energy, B Field and Current.

The Phasing and Energy measurement applications uses CERN's RADE LabVIEW framework [7] to access the control system. The two applications will be merged into a more complete application that will allow supervised phasing of all cavities in the HIE-ISOLDE linac.

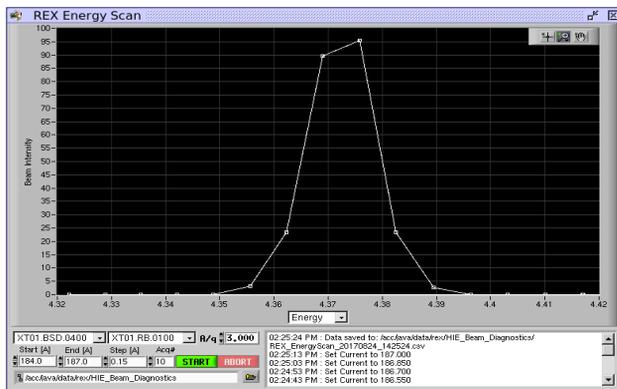


Figure 8: Energy measurement using a silicon detector.

Count Rate

The SD can be used as a very low intensity FC. As an example the Count Rate application (see Fig.9) is utilised to identify beam instabilities. On the application panel the SD can be selected together with an averaging value. Measurements can be performed in combination with other beam diagnostics instruments.

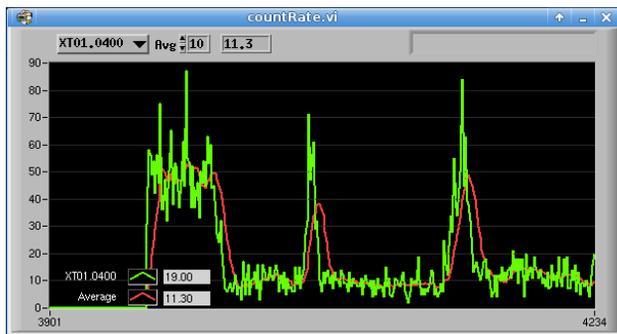


Figure 9: A count rate measurement using a silicon detector.

CONCLUSION

Higher energies and super conducting cavities are essential if the variety of physics possible from the ISOLDE facility is to be broadened. This has required great amounts of work in planning, installation, hardware and beam commissioning [8]. The later includes many high level applications developed in order to properly and efficiently operate the facility and satisfy the new physics requests from users around the world.

ACKNOWLEDGEMENT

Parts of the applications were created or modified during, either the hardware or beam commissioning. We would like to thank all equipment groups that assisted the operations team to resolve any issues. We would like to gratefully acknowledge all the technical teams and the CERN management for their continuous support.

We acknowledge funding from the Belgian Big Science program of the FWO and the Research Council K.U. Leuven as well the receipt of fellowships from the CATHI Marie Curie Initial Training Network: EU-FP7-PEOPLE-2010-ITN Project # 264330.

REFERENCES

- [1] HIE-ISOLDE, <https://cds.cern.ch/record/1001782/files/CERN-2006-013.pdf>.
- [2] O. Forstner, "Beam-Preparation with REXTRAP for the REX-ISOLDE Experiment" – TU Wien – 2001.
- [3] F. J. C. Wenander, "Charge Breeding and Production of Multiply Charged Ions in EBIS and ECRIS" – Chalmers University – 2001.
- [4] S. Blanchard *et al.*, "The New Control System for the Vacuum of ISOLDE", in *Proc. ICALEPCS'11, Grenoble, France*
- [5] A. Sosa *et al.*, "Beam instrumentation for the HIE Isolde linac at CERN", in *Proc. IPAC'12, N. Orleans, USA, May 20-25, 2012*.
- [6] N. Warr *et al.*, "The MINIBALL spectrometer", *Eur. Phys. J. A* (2013) 49: 40
- [7] O. Ø. Andreassen *et al.*, "The LABVIEW RADE Framework Distributed Architecture", in *Proc. ICALEPCS'11, Grenoble, France, 10 - 14 Oct 2011*
- [8] J. A. Rodriguez *et al.*, "Beam Commissioning of the HIE-ISOLDE Post-Accelerator", in *Proc. IPAC'16, Busan, Korea, May 2016*.