An Operators Tool for Advanced Synchrotron Injection Diagnostics

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Abstract

The operation of an accelerator facility like that at GSI Helmholtz Center for Heavy Ion Research near Darmstadt, Germany is very complex. The beam setup for a dedicated experiment requires the measurement of several beam parameters, e. g. stripping efficiency, energy, revolution frequency and so on. Different beam diagnostics along the accelerator and beam transport lines provide for this purpose appropriate signals. As beam time is rare due to great demand the operators are asked to setup beam in less and less time. One approach to enable that is to simplify the handling of beam diagnostic tools and to preprocess those signals so that the operator gets a measurement result in a minimum of time. We report on the development of our Schottky analysis in the SIS18 as an example for that. The history is summarised and the control room front end is presented.

INTRODUCTION

The accelerator complex at GSI consists of the UNIversal LInear ACcelerator UNILAC, the heavy ion synchrotron SIS 18 and the Experimental Storage Ring ESR (see Fig. 1). All machines deliver ion beams from protons up to uranium. The main linac, an Alvarez DTL, is on one side supplied with beam from the High Charge state Injector HLI and its ECR ion source on the other side from the High Current Injector HSI and its two ion sources (MUCIS/ MEVVA and Penning type). The ions are accelerated from 2.2 keV/u at the entrance of each injector up to 11.4 MeV/u after the DTL. Via a transfer channel (TK) the beam is delivered to SIS 18. The synchrotron supplies the ESR and the experimental area with ion beams of various energies.

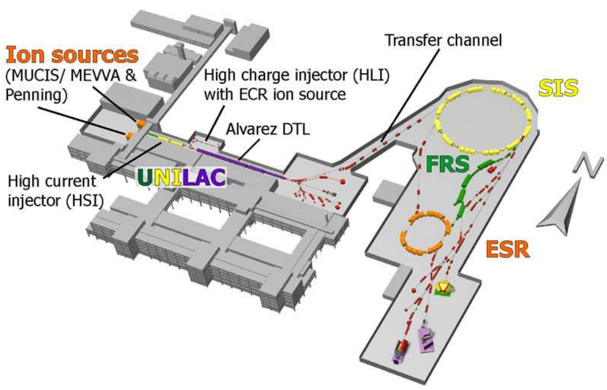

Figure 1: Overview of GSI and accelerators.

All accelerators are operated from the main control room (see Fig. 2) which consits of five consoles. Three of them are equipped with beam diagnostics and operating tools for UNILAC, SIS 18 and ESR. The remaining two consoles are used for dedicated beam diagnostics at the synchrotron, which is mainly used by experts during machine experiments, and the operation of the ion sources and the safety system.

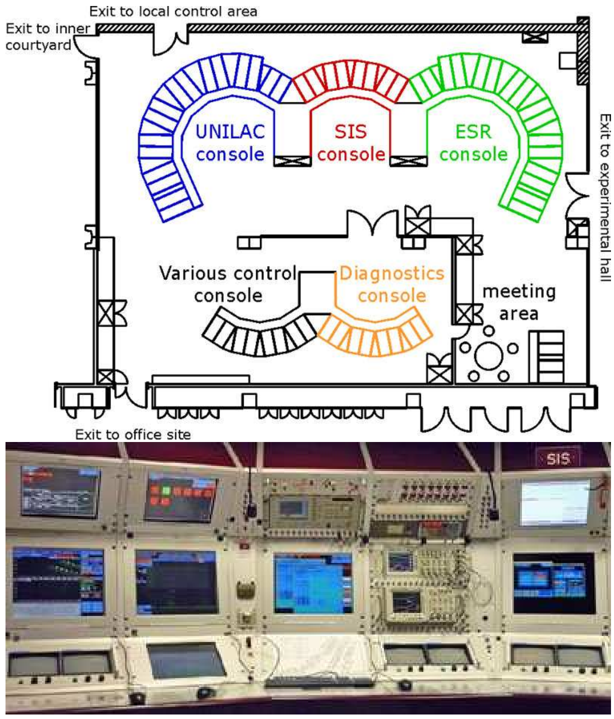

Figure 2: Top: Sketch of the main control room. Bottom: Part of the SIS 18 console with several monitors for operating software, oscilloscopes and a spectrum analyser.

OPERATION OF SIS 18

Figure 3 gives an overview of the SIS [2]. It has a circumference of 216 m and consists of 12 congeneric sections of three quadrupoles (for doublett and triplett focusing) and two dipoles. The latter have a maximum bending power of 18 Tm and a bending radius of 10 m. The beam injected from the UNILAC in section 12 is accelerated with two ferrite cavities, that operate in a frequency range of 0.8 to 5.6 MHz, and extracted in section 6. The maximum energy of protons amounts 4 GeV/u ($\beta = 0.98$) and that of $^{238}U^{73+}$ 1 GeV/u ($\beta = 0.88$).

The beam delivered from the UNILAC consists of a bunch train of 300 μs length, from which a part of 160 μs length is cut by a chopper for injection to SIS 18 (see Fig. 4). About 165 micro pulses are injected per turn (multiturn injection) with respect to the HSI rf frequency of 36 MHz. Cooling the beam with the electron cooler several bunch trains can be injected in a multi-multiturn injection

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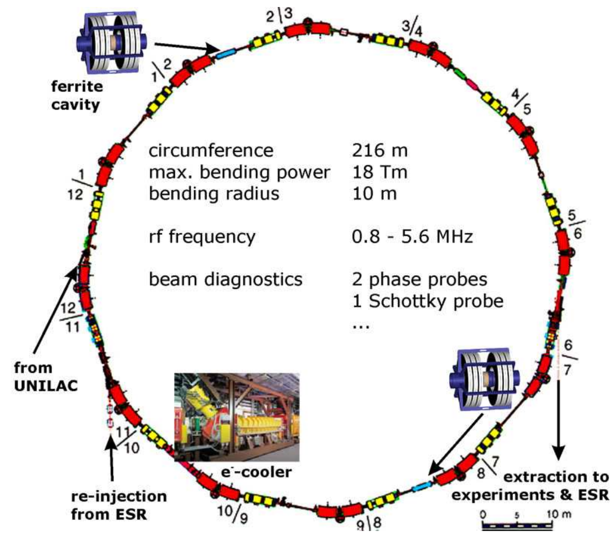

Figure 3: Schematic overview of SIS 18.

scheme.

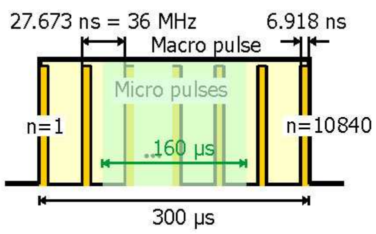

Figure 4: Timing of the UNILAC ion beam.

For the operation of SIS 18 two tasks have to be fulfiled, beam setup and monitoring of beam parameters. In both cases beam intensity and energy as well as momentum spread take centre stage. The sensitivity of the usually used beam current transformers is too low in order to optimise beam intensity during beam setup. A signal from a phase probe can be used to get a better signal-to-noise ratio as described in the next section.
The injection energy can be determined by a time-of-flight measurement with phase probes along the transfer channel to SIS 18. Using those probes, also the energy spread of the UNILAC beam of $\Delta E \approx \pm 100$ keV/u can be adapted with two re-bunchers to the SIS 18 acceptance of $\Delta E \approx \pm 23$ keV/u, but the methode takes a lot of work, is unsuited for monitoring and has no quantitative result. In both cases it is favourably to use Schottky analysis as it results in most precise values, can be performed quickly and is suited for online monitoring.
Using a spectrum analyser and a dedicated data aquisition all those measurements and monitoring tasks can be performed using only one device.

BEAM DIAGNOSTICS

Beside other beam diagnostics two phase probes and one Schottky probe as shown in Fig. 5 are mounted in SIS 18. In order to use them for the above mentioned operation tasks a dedicated data aquisition is needed. The front-end device in the main control room is an Advantest R3132 Spectrum Analyzer 9 kHz - 3 GHz (SA), which is triggered at a certain timing event of SIS 18. It can be remote controled with GPIB commands via IEC-Bus [1]. The signal of the Schottky probe is directly connected to the SA over a signal selector as shown in Fig. 6.

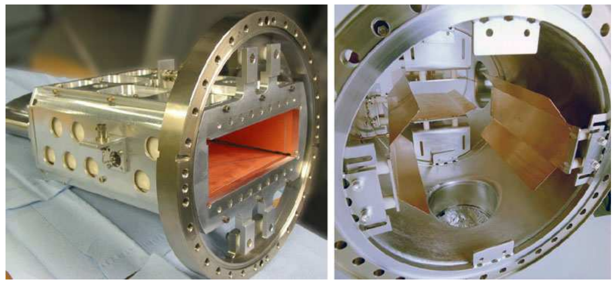

Figure 5: Pick-up probes as mounted in SIS 18, left: phase probe, right: Schottky probe.

Mostly during beam setup intensities of the order of 10^6 particles have to be measured. Therefore the signal of a phase probe is mixed with the rf master signal of one of the accelerating cavities which increases the sensitivity of this measurement, because all frequencies that do not belong to the beam are suppressed.

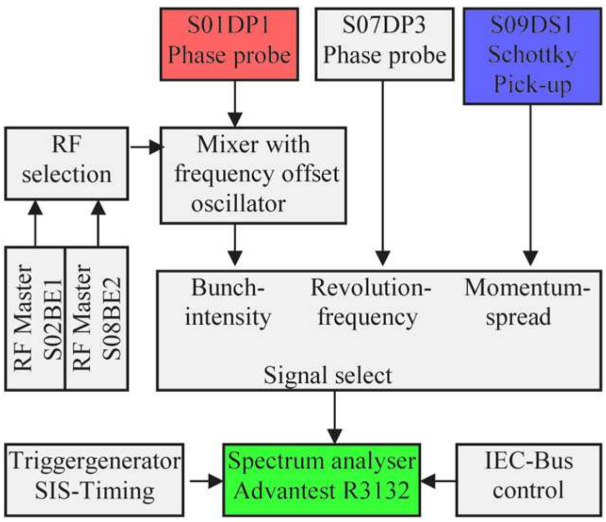

Figure 6: Schematic overview of the data aquisition.

THE SIS-BEAM-DIAGNOSTICS TOOL

Due to the complexity of the above described data aquisition and the SA itself the operation of this system for non-experts is a real challenge. In order to integrate it into usual accelerator operation a development of a dedicated front-end software to control the data aquisition and the SA was necessary. The requirements to this software are simplification of operation of the complete system and suitability for monitoring.

Boundary Conditions for the Development

The control system of the accelerator at GSI is based on VMS. In the near future it will be substituted by a system based on Linux, but up to few years ago operation software had to be exclusively developed on VMS with the programming language Fortran 95 and X11/ Motif for the GUI design. For the latter an in-house generated widget-set is used as well as a widget construction tool which helps the software programmer to build the GUI code.

There are two main constraints new operation software has to fulfill. First, the GUI must be operable intuitively, i. e. also people who have low experience with a certain GUI should be able to work with it. Second, the look of a new GUI should be similar to existent ones so that the acceptance is as high as possible.

History & Challenges

During the commissioning of SIS 18 1989/ 1990 most tasks were performed by experts, thus e. g. Schottky scans were performed using a phase probe as an electrostatic pick-up. A system for intensity measurements with high signal-to-noise ratio existed. One year later the Schottky pick-up probe as shown in Fig. 5 was mounted and an adequate DAQ allowed experts to perform the analysis. Since then Schottky analysis was mainly used during experiments for machine development.

Since 2001 several upgrade measures at UNILAC and SIS 18 started to increase the beam intensity and to fulfill requirements of the proposed and approved Facility for Antiproton and heavy Ion Research (FAIR) at GSI [3]. As the improvement of beam quality during normal operation can only be received increasing the quality of machine setup several new beam diagnostics tools were developed in parallel and it was decided to provide Schottky analysis for non-experts.

Thus, in 2005 the development of the so called SIS-BeamDiagnostics software, that should combine measurement tasks with phase and Schottky probe. Mid of 2006 the 1st version of this software was provided to the main control room. Until 2009 it was tested and modification requests were collected so that during the 1st half-year of 2009 the software could be revised. Since mid of 2009 the most convenient version is more and more used during normal operation by non-experts.

During the development different challenges had to be overcome. Some essential topics of the 1st specification like to read, write and set the revolution frequency could not be realised as the main control software of SIS 18 is a more or less standalone software and the communication to other software is limited to essential needs. The limited possibilities of VMS, X11/ Motiv and the widget-set made some compromises for the GUI necessary.

The most limiting problems however concern to the remote control of the Advantest SA. As not all GPIB commands work properly it was decided to call setup profiles for different measurements locally stored at the SA. Periodical requests of status, settings and measurement results disturb local operation of the SA, e. g. by experts who use the software only for setup, because contrary to the manual the SA cannot be set into local operation mode via GPIB. As the SA and the terminal on which the software runs are located in the same console periodical requests were avoided.

There were two main reasons for the development time of about 4.5 years, the shift-work of the DAQ developer and the circumstance that no offical request and thus only a low priority for the software development existed.

GUI of SIS-Beam-Diagnostics Tool

Figure 7 shows the top level GUI, where subprograms to perform device settings and measurements are called. In Fig. 8 an example for the structure of a measurement GUI is given. This is equal in all measurement programs but of course the possibilities to setup the devices are adapted to the different measurements.

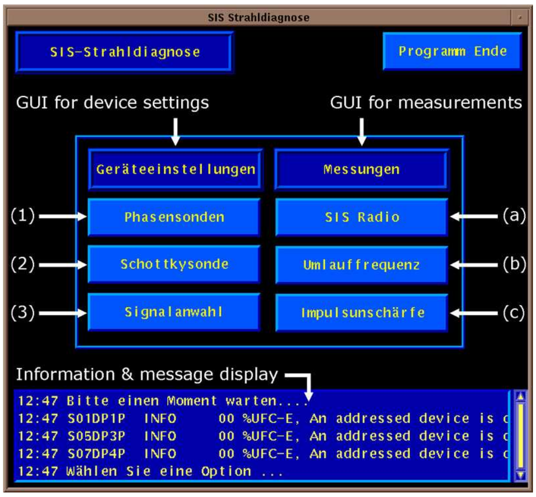

Figure 7: GUI of the top level program. Buttons on the left: subprograms for device settings of phase probe (1), Schottky probe (2), others (3). Buttons on the right: subprograms for measurement of beam intensity (1), revolution frequency (2), $\Delta p/p$ (3).

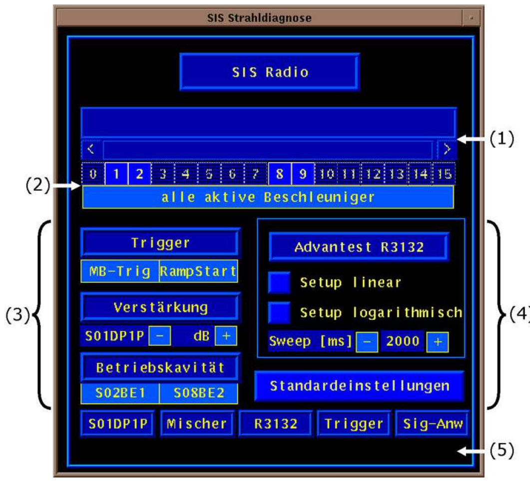

Figure 8: Example for the structure of a measurement GUI. Top: display for beam parameters (1) and selectors for virtual accelerators (2). Mid left: setup parameters of DAQ devices (3). Mid right: setup parameters of SA (4). Bottom: Status display (5).

RESULTS

In this section several measurement results as they were achieved during machine setup and monitoring machine parameters are presented.

Figure 9 shows an example for intensity monitoring using the phase probe signal mixed with an rf signal and it gives an impression of the high measurement sensitivity.

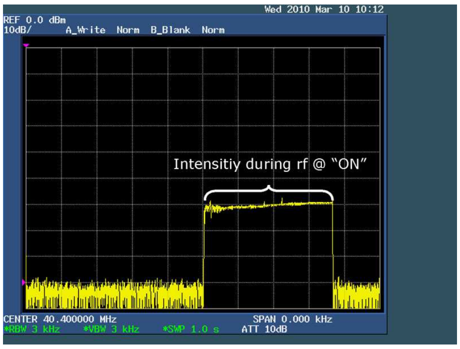

Figure 9: Example for intensity monitoring of $\sim 1.4 \cdot 10^9$ particles $^{238}U^{73+}$ on a logarithmic scale.

Schottky analysis and the measurement of $\Delta p/p$ during machine setup is important as can be seen in Fig. 10. The green line represents the Schottky analysis without rebunching the beam in the transfer channel and the yellow line the same but with rebunching. In this example there is a factor of approximately 3 in $\Delta p/p$ between both measurements. Additionally this measurement is used to determine whether the re-bunchers only bunch the beam or if they accelerate the beam somehow.

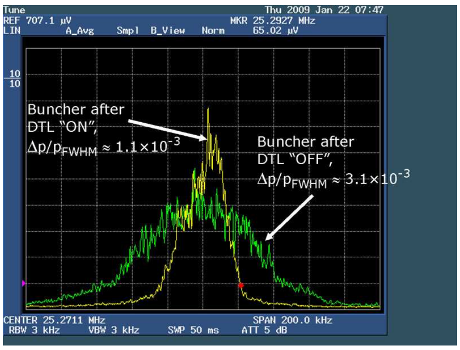

Figure 10: Optimisation of buncher settings.

In the transfer channel to SIS 18 the beam has to be stripped by thin carbon foils (200 up to 600 $\mu g/cm^2$) again to reach highest beam energies at extraction level [4]. As presented in top of Fig. 11 after a certain time of use the foil gets ripply and due to sputtering it gets slightly thinner. This ageing process can be observed by Schottky analysis as shown in the lower part of Fig. 11 because for the used foil (green line) $\Delta p/p$ is larger due to the ripple and the revolution frequency is slightly higher due to less foil thickness. Therefore monitoring the Schottky signals indicates when stripper foils should be substituted.

Certainly there are furhter application tasks, e. g. the observation of the cooling process, but the cases above already show impressively, that it is necessary to implement those measurements in normal operation.

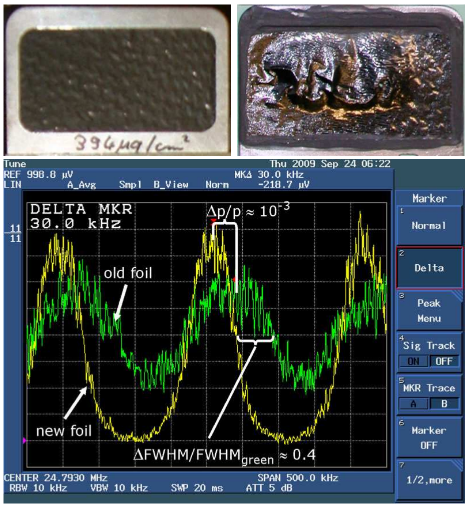

Figure 11: Top left: unused carbon stripper foil, top right: used carbon stripper foil, bottom: observation of stripper foil ageing.

CONCLUSION

The development of the SIS-BeamDiagnostics tool was very successful, as now beam intensity measurement and Schottky analysis for variing beam parameters like energy and ion species can now be performed also by non-experts during beam setup and normal operation. The amount of people who use this tool regularly is steadily growing since a proper runing software is available. Thus, the quality of beam delivery could be increased and even experimentalist observed that.

But it was a good piece of work and the development took longer than estimated. There was a large commitment on side of the operation group so that all requirements for operation could be fulfilled. Many experiences have been made to process similar developments more smoothly in the future.

ACKNOWLEDGEMENT

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