STATUS OF BEAM DIAGNOSTICS FOR SIS100

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Abstract

The FAIR (Facility for Antiproton and Ion Research) accelerator facility presently under construction at GSI will supply a wide range of ion species and beam intensities for physics experiments. Design beam intensities range from 2.5×10^{13} protons/cycle to be delivered to the pBar-target and separator for production of antiprotons, to beams of e.g. 10^9 ions/s in the case of slowly extracted beams. The main synchrotron of FAIR is the fast ramped superconducting SIS100. In the present layout SIS100 will deliver up to 4×10^{11} U^{28+} ions/s with energies of 400-2700 MeV/u, either in single bunches of 30-90 ns, or as slowly extracted beam with extraction times of several seconds for the radioactive ion beam program of FAIR. This contribution gives an overview of the present layout of beam diagnostic instruments for SIS100 and presents the status of the main development projects regarding e.g. the beam position monitor system, ionization profile monitor and the beam current transformers.

FAIR AND SIS100

At the moment extensive civil works take place at GSI to prepare and upgrade the existing accelerator infrastructure for the construction of FAIR [1]. GSI accelerators will act as injectors for FAIR and the production chain for primary beams of proton to uranium ions is based on the two synchrotrons SIS18 and SIS100 [2]. Medium charge state heavy ions, e.g. U^{28+}, accelerated by UNILAC will be injected at 11.4 MeV/u into SIS18 and pre-accelerated to 200 MeV/u at a ramp rate of 10 T/s. Ion beams will then be transferred by bunch-to-bucket transfer to SIS100. One important goal for SIS100 is the acceleration of up to 10^{12} U^{28+}-ions per cycle, which is the principal space charge limit. Whereas at present U^{73+}-ions are used in SIS18, for FAIR the lower charge state will be applied to allow for highest particle numbers. An important drawback of high intensity operation with intermediate charge state ions is their enhanced ionization cross section and high potential for vacuum instabilities due to ion desorption. Thus, high-intensity operation of SIS100 requires precise control of the dynamic vacuum. This aspect is reflected by the decision to use superconducting magnets for SIS100 to enable cryogenic pumping along the full circumference and to reach the required XUV conditions of 5×10^{12} mbar. The operational scenarios for SIS100 foresee acceleration of up to 4×10^{11} U^{28+} ions/s to energies of 0.4-2.7 GeV/u for the production of radioactive ion beams, delivery of 2.5×10^{13} proton beams at 29 GeV with 5 Hz repetition rate for antiproton production, as well as slow extraction of 10^{10} U^{92+}-ions for the condensed baryonic matter program.

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SIS100 BEAM DIAGNOSTICS

Meanwhile, all major accelerator components of SIS100 have passed their final design reviews and have been contracted, featuring various technological challenges, like e.g. ultra-high vacuum requirements, superconducting synchrotron magnets with 4 T/s ramp rate, a special cryo-collimator system for controlled beam losses, as well as rf-compression cavities to generate 30 ns bunches of highest beam intensities. These requirements impose strong performance parameters for the beam diagnostic equipment. Special challenges for SIS100 beam diagnostics are: to cover the large dynamic range of beam intensities, ion species and ion energies of SIS100, precise control of beam position in the sub-mm range in order to allow for stable orbits and feedback procedures, sensitive current measurement devices to enable e.g. detection of small beam losses even during high-intensity operation, online beam profile monitoring to control longitudinal instabilities, as well as early diagnosis of transverse emittance blow-up. In the past years dedicated diagnostic devices were developed for SIS100 and prototypes were tested with beam at GSI accelerators. Thus, all main diagnostic components are now ready for series production.

General Diagnostic Layout

An Overview of beam diagnostic devices for SIS100 is presented in Table 1.

Table 1: Beam Diagnostic Devices of SIS100

Device	# pcs	Acro-nym	Measurand
DC Current Transformer	1	DCCT	dc beam current (1E-6 to 20 A)
Tunnelling Magneto Resist. DCCT	1	TDCCT	dc beam current (1E-4 A to 150 A)
Cryo Beam Pos. Monitors	83	BPM	beam position, orbit feedback
Quadrupolar BPM	1	QBPM	*future option: beam quadrupole moment*
Closed-orbit Feedback	1	COFB	100 Hz steerer control
BTF Exciter	1	TUNE	tune, chromaticity
Schottky Pick-Up	1	SKY	momentum distribution
Fast Current Transformer	2	FCT	intensity, bunch shape

Ionization Profile Mon.	1	IPM	Transverse beam profile
Beam Loss Monitors	74	BLM	local beam-loss
SEM-Grid	6	GRD	transverse profile (1st turn)
Scintillating Screen	2	SCR	transverse profile (1st turn)
Beam Stop-per	6	STP	relative intensity (via SEM-foil)

Apart from the current transformers, beam position monitors and the ionization profile monitor described to more detail in the following sections, both a BTF exciter and dedicated Schottky pick-ups will be installed for the online measurement of beam tune, chromaticity and momentum distribution. In addition, each sextant of SIS100 will be equipped with a first-turn diagnostic chamber including a SEM-Grid and beam stopper, mainly for beam profile measurements during commissioning and setup phases. To determine beam-losses at both, low and high radiation levels, a set of scintillating counters and ionization chambers will be positioned at hot-spots close to the beamline. The ionization chambers are of the CERN BLMI-type and are presently being manufactured and tested at CERN [3].

Beam Intensity Measurement

Four different beam current transformers (1 DCCT, 1 TDCCT, 2 FCTs) will be installed inside SIS100. The two FCTs are commercial products from Bergoz Instrumentation [4], selected with special performance parameters for their different measurement purpose. For the precise measurement of the bunched beam current an FCT type FCT-220-0.50V/A-LLS-H was purchased because of its high current sensitivity and low lateral sensitivity behaviour. To measure the bunch shape the model FCT-22-0.5V/A-LD-H with high bandwidth of 650 MHz was purchased from Bergoz.

For the standard measurement of the dc beam current of the stored ion beam again a commercial DCCT has been obtained from Bergoz. In this case the model NPCT-220-HR-H was selected, due to its high resolution (noise density < 1µArms/√Hz) and improved radiation tolerance.

For the precise online measurement of accelerated and stored beams with a very large dynamic range of beam intensities (mA to above 100 amperes), a novel type of current transformer was developed at GSI. The measurement principle is based on two tunnelling magneto-resistance (TMR) sensors installed inside the air gaps of a slotted high-permeability toroid acting as a flux concentrator for the beam's magnetic field. Test results with a prototype of the Tunnelling magneto resistance DCT (TDCT) show very good linear behaviour and a detectivity D=15.6 nT/√Hz (see ref. [5] and references therein).

Beam Position Monitors

A set of 83 shoe-box type BPMs will be installed inside the cryostats of the SIS100 quadrupole modules. Purpose-built ceramic pick-ups were developed with industrial partners in order to achieve the required mechanical stability of 50 µm even after many warm-cold cycles of the quadrupole modules. The pick-ups consist of a ceramic cylinder (diam.: 135 mm, length: 300 mm) with a metalized inner surface which has been thoroughly optimized using FEM simulations [6]. The prototype pick-up shows the desired flat frequency response over the full range of bunch frequencies of 0.5-2.7 MHz and bunch lengths between 50 - 800 ns. In order to test the pick-up prototype and to allow for quality assurance of the pick-up series production, a dedicated BPM test and calibration setup has been established at GSI. This test stand allows to calibrate the position sensitivity of the BPM under test with an accuracy of better than 50 µm. Inside the cryogenic quadrupole modules the BPM pick-up signal is fed to purpose-built matching transformers [7] to allow for a sufficiently long (e.g. 20 m) cable connection to the pre-amplifiers installed outside the cryo-modules. Installation of the pre-amps inside the cryostats had to be prevented because the introduced thermal load would have been too high. Instead, the pre-amps will be placed inside dedicated concrete-covered niches at the inner walls of the SIS100 tunnel, in order to protect the electronics from the high radiation level.

The BPM pre-amplifiers for FAIR are result of a long-term development project with the Slovene in-kind partner Instrumentation Technologies [8]. These low-noise 50 Ohm input impedance amplifiers feature a large dynamic range of 110 dB (bandwidth 40 kHz - 55 MHz) and include a switchable attenuator stage for input protection. As a result of the short bunch length of SIS100 below 50 ns and high beam intensities the pick-up signals reach the kilovolt range and would severely damage an unprotected input. In the meantime, pre-series boards of this pre-amplifier have been tested in the lab and with beam, the development is finalized and series production of the BPM pre-amplifiers for FAIR has started recently.

Also the digitization and online data treatment of the BPM signals is an important part of the Slovene in-kind contribution. With the Libera Hadron Platform B devices powerful BPM digitizers were developed in close collaboration with Instrumentation Technologies. Each Libera Hadron station features 4 BPM modules, including four ADC channels each, for synchronous digitization of the four pick-up plates. Important performance requirements for the ADC boards were a sampling rate of 250 MSa/s s and minimum 12 effective number of bits (ENOB). For seamless control system integration a FESA-compatible Intel-based CPU with CentOS7 operating system was realized. In addition, a new interface board for I/O control of the new BPM pre-amplifiers had to be implemented for the Libera station, as well as a White Rabbit based FAIR timing receiver node. The closed-orbit feedback system needs real-time input of the position data of all distributed

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Libera stations, thus each station is additionally equipped with an Instrumentation Technologies GDX board. This board features a fast network protocol as well as a powerful FPGA for real-time calculation of the corrector values. Libera Hadron Platform B is meanwhile well tested and series production is about to start.

The SIS100 topology foresees 2 Liberas inside each of the 12 equipment rooms. Data of the 24 Libera Stations will be concentrated in high-performance data concentrators, providing a single software interface for various measurement modes, like raw data, orbit and trajectory plots and is also part of the Slovene in-kind contribution to FAIR, supplied by Cosylab [9].

Ionization Profile Monitor

For online measurement of the beam profile inside SIS100 an Ionization Profile Monitor (IPM) is foreseen [10]. The basic measurement principle of an IPM is the spatially resolved detection of residual gas atoms ionized by the passing ion beam. In order to extract the ionized gas atoms towards a position sensitive detector an electrical field is applied perpendicular to the beam axis. Ionized particles are accelerated by the electric field to a multi-channel plate (MCP) with phosphor screen. Two separate electric field boxes turned by 90 degrees are required for horizontal and vertical beam profiling.

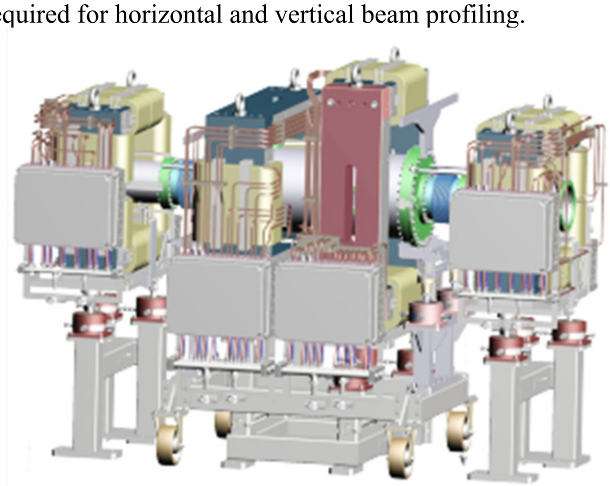

Figure 1: Ionization Profile Monitor with window frame magnets.

As a prototype for SIS100 an IPM has been manufactured and installed inside the existing SIS18. The electric field box has an aperture of 175×175 mm^2 and its 12 side electrodes allow for a field strength of 60 kV/m. In order to be able to detect both products of the ionization process, i.e. electrons or ions, the direction of the electrical field can be reverted on user demand. For the position sensitive detection of the particles (ions or electrons) a two-stage MCP with fast phosphor screen P47 is used. The wavelength of the emitted light is ~400 nm and the screen's decay time is ~100 ns. The light signal of the relatively large active area of 44×94 mm^2 is recorded by a CCD camera which detects profiles at a rate of up to 200 frames/s. The CCD images are corrected with a MCP calibration and noise is reduced with dedicated IPM software. The full IPM setup with an overall insertion length of 2.5 m is schematically shown in Fig. 1.

For the planned high-intensity operation of FAIR the space charge of the beam will strongly affect the path of residual gas particles after ionization, thus the measured beam profiles would be significantly distorted. To improve the quality of the profile measurement an additional magnetic field is applied in parallel to the electric field that guides the charged particles. The two main dipoles (Fig. 1, center), one for horizontal and one for vertical measurement, generate a flux density of 84 mT at the beam center.

In addition, two corrector magnets are needed at the entry and exit of the IPM setup, to compensate for the unavoidable beam steering due to the magnetic field of the main dipoles. At present, the prototype IPM is installed inside the existing SIS18 without the magnet system. The proper operation of the field-box and MCP detection system was intensively tested with beam during various machine experiments. Figure 2 exemplarily shows horizontal and vertical beam profiles obtained with an U^{4+}-beam at 300 MeV/u.

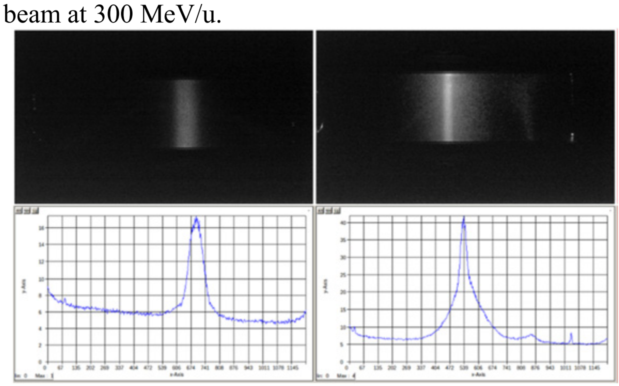

Figure 2: Example IPM data: raw ccd images (top), hor. (bottom, left), vertical profile projection (bottom right).

Presently, the IPM magnet system is being manufactured and will be delivered to GSI in summer 2017. Installation in SIS18 is planned for March 2018 and first beam tests of the IPM including the magnet system are scheduled for June 2018.

CONCLUSION

Up to now prototypes of all main SIS100 diagnostic components have been developed, manufactured and tested with beam. Moreover, for most devices series production has started. The authors wish to acknowledge the Slovene in-kind partners Instrumentation Technologies and Cosylab for their long-standing, excellent collaboration.

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