BEAM DIAGNOSTIC LAYOUT FOR SIS100 AT FAIR*

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Abstract

The SIS100 heavy ion synchrotron will be the central machine of the FAIR (Facility for Antiproton and Ion Research) project currently designed at GSI. The unique features of SIS100, like e.g. the acceleration of high intensity beams of 2.5×10^{13} protons and 5×10^{11} Uranium ions near the space charge limit, the anticipated large tune spread, extreme UHV conditions of the cryogenic system for superconducting magnets and fast ramp rates of 4 T/s, make challenging demands on the beam diagnostic components. This contribution describes the conceptual design for SIS100 beam diagnostics and reports on the present status of prototype studies. Exemplarily the progress concerning beam position monitors, beam current transformers and beam-loss monitors is presented.

THE FAIR FACILITY AND SIS100

At present GSI conducts the final planning and engineering layout of the Facility for Antiproton and Ion Research FAIR. The modularized start version of FAIR, as depicted in Fig. 1 consists of the p-Linac, a dedicated linear accelerator for high current proton beams, the SIS100 synchrotron for the acceleration of protons and heavy ions, the super fragment separator for production of rare-isotope beams, the antiproton target for pBar production, the collector ring CR for accumulation of RIBs and pBar and the High-Energy Storage Ring HESR for pBar experiments. More details about the FAIR project are given in [1].

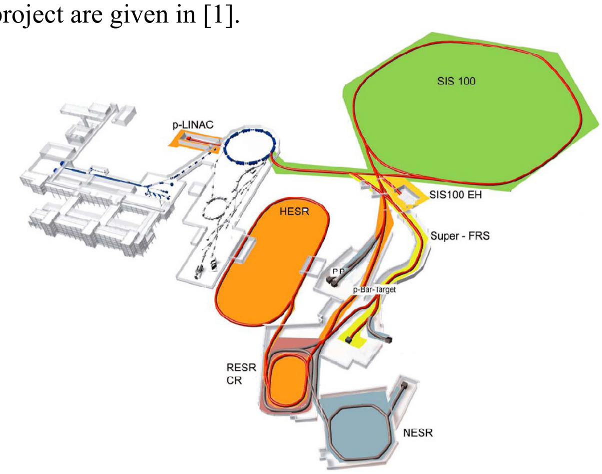

Figure 1: Existing GSI and layout of the FAIR accelerator complex (NESR and RESR not part of the start version).

This contribution concentrates on the beam diagnostic system of SIS100 as the main machine of FAIR. SIS100 will deliver high intensity, high energy proton and ion beams for the various experimental programs of FAIR. Acceleration of up to 4×10^{11} U^{28+} ions/s to energies of 400-2700 MeV/u is required for the production of radioactive ion beams, either compressed to a single bunch of 30-90 ns, or as slowly extracted beam. For the production of pBar 2.5×10^{13} protons per pulse will be accelerated up to the energy of 29 GeV with a repetition rate of 5 Hz and an output bunch length of 50 ns. For the condensed baryonic matter program acceleration of 10^{10} U^{92+} ions per cycle with slow extraction is foreseen.

Moreover, SIS100 includes a number of engineering challenges, like operation at ultra-high vacuum of 5×10^{-12} mbar, superconducting synchrotron magnets with 4 T/s ramp rate, control of beam-losses by implementation of a collimator system and a rf-compression system for single bunches of high intensity, cf. [2]. Beam diagnostic devices for SIS100 have to comply with these technological boundary conditions and have to ensure precise determination of all relevant beam parameters.

BEAM DIAGNOSTIC LAYOUT

An overview of the planned beam diagnostic devices for SIS100 is presented in Table 1.

Table 1: Overview of Foreseen Diagnostic Systems

Device	Parameter	# pcs.	Acro-nym
DC Transformer	dc beam current	1	DCCT
DC-Transformer (novel system)	dc beam current (high current, high rep. rate)	1	NDCCT
Fast Current Transformer	injection efficiency, bunch shape	2	FCT
Beam Position Monitor	beam centre-of-mass, orbit feedback	84	BPM
Schottky Pick-up	momentum distribut., tune of coasting beam	1	SPU
Exciter + BPM	tune determination	1	TUNE
Ionization Profile Monitor	beam profile (stored beam)	1	IPM
Quadrupole Pick-up + Exciter	quadrupole moment	1	QBPM
Beam-loss Monitor	beam-loss	50	BLM
SEM Grid	beam profile (1^{st} turn)	6	GRID
Scintillating Screen	beam profile (1^{st} turn)	2	SCR
Beam Stopper	-	6	STP

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The injection efficiency to SIS100 will be optimized using one FCT. A second FCT will be used for bunch shape measurements and tomography in longitudinal phase space. For precise determination of the stored beam current two transformer types are foreseen. A commercially available DCCT will be accompanied by a novel transformer type with higher bandwidth (see below). A set of 84 BPMs will allow for online beam position monitoring and, together with an exciter for broadband noise excitation of the beam, online tune determination. A pick-up is foreseen for Schottky measurements both, in longitudinal and transverse direction to determine tune, chromaticity etc. of un-bunched beams. For online beam profile measurements an IPM has been developed featuring two operational modes: by detection of residual gas ions a high spatial resolution is achieved, whereas detection of the free electrons allows for fast turn-by-turn profile determination [3]. In order to detect quadrupolar beam oscillations, e.g. resulting from transverse mismatch during injection, purpose-built BPMs are planned. Beam-loss monitors (scintillators and ionization chambers) will be installed at typical hot-spots, e.g. septa, to quantify beam-losses. A combination of GRIDs and STPs will be installed in each sextant for first turn diagnostics. Two scintillating screens at half and full turn position will be used for beam adjustments during commissioning. Exemplarily the following sections describe the ongoing developments for the SIS100 BPM system, the beam current transformers and beam-loss monitors.

BEAM POSITION AND TUNE

Three different working points are foreseen for operation with ions in slow extraction mode, fast extraction and high-energy acceleration of protons. The highest related tune value Q_h=20.84 requires 84 beam position monitors for unambiguous closed orbit determination.

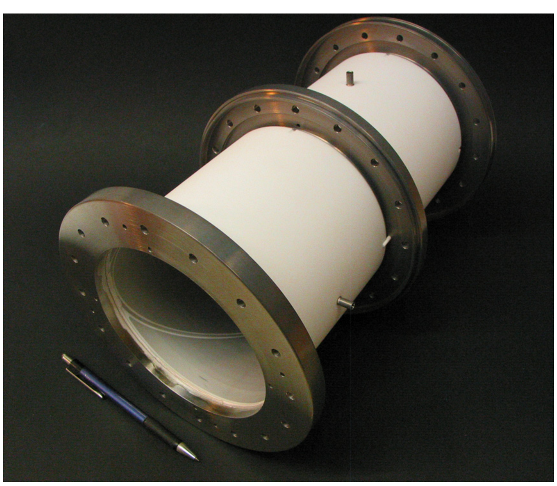

Figure 2: Photo of a ceramic BPM. Metal-deposited areas on inner surface serve as signal pick-ups.

The shoe-box type BPMs for SIS100 will be installed inside the cryostat of the superconducting quadrupoles. In order to achieve the desired mechanical stability of 50 µm unaffected by many warm/cold cycles purpose-built ceramic pickups have been developed in close collaboration with Kyocera [4], see Fig. 2. The pick-up geometry and the structure of the metal-deposited surfaces have been optimized by use of FEM simulations [5] with regard to their frequency response in the range of the relatively low bunch frequencies of 0.5-2.7 MHz.

The BPM pre-amplifiers have to be installed outside the cryostats since the introduced thermal load would be too high for the cryogenic system. In addition the estimated radiation level in close vicinity to the beam line is too high for the pre-amp electronics. Thus the usage of matching transformers is mandatory to allow for longer cable connections to the pre-amps, cf. [6]. To shield the pre-amps against the radiation field of the beam niches are foreseen along the inner accelerator tunnel walls.

After passing the matching transformers the plate signals are fed into low-noise, 50 Ω input impedance amplifiers which are presently designed at GSI. For highest beam intensities and short bunches the plate signals reach the kV region. Thus the pre-amps have to be equipped with a switchable attenuator chain to reach the required dynamic range of 120 dB.

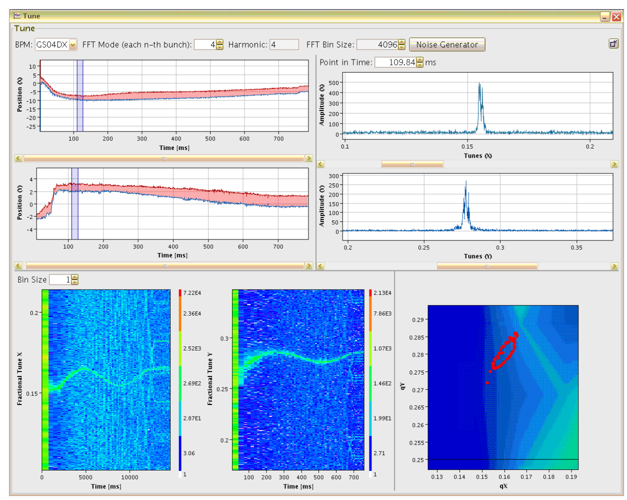

Figure 3: TOPOS GUI for tune measurements: Top and centre: x and y position vs. time at a selected BPM in min/max representation (left) and online FFT of position data (right). Bottom: hor. and vert. tune vs. time and working diagram of SIS18 with online tune values (red).

The TOPOS system (Tune Orbit and POSition) has been developed for SIS18 as a prototype system for future beam position measurements at SIS100. The 12 BPMs of the existing SIS18 synchrotron have been equipped with Libera Hadron devices [7]. Libera FPGA is used for online determination of the beam position for each individual bunch. The window detection and baseline restoration of the pick-up signal is performed digitally on the pick-up signal itself without further input parameters. The Liberas are grouped to 6 devices and connected via a fast 100 Mbit network to two high performance concentrator PCs running FESA, the Front-End Software architecture developed at CERN [8]. FESA will be the standard platform for all data acquisition devices at FAIR.

Thus the TOPOS system serves also as a first test setup for FESA-based data acquisition. In collaboration with Cosylab [9] versatile software has been developed which is presently in the final testing phase. TOPOS is extendible for the usage at SIS100, where 14 Liberas will be grouped together for each sextant. Figure 3 presents the TOPOS graphical user interface with position and tune data. Among other features TOPOS is capable of bunch-by-bunch measurements for each of the BPMs, allows a closed orbit representation for all 12 BPMs simultaneously and, in connection with a pseudo-random noise exciter, features an online tune calculation.

Collaboration with DELTA Dortmund and FZ Jülich aims to enhance the system and to use the online beam position data for a closed-orbit feedback system [10]. The present layout makes use of a state-of-the art FPGA board to collect all position data, to calculate the required corrector set values and to distribute the digital correction signal to the related power supplies.

BEAM CURRENT TRANSFORMERS

Precise online determination of the stored and accelerated beam current is a main task for synchrotron operation. Given the large dynamics in beam intensities and bunch frequencies resulting from the various operational modes of SIS100 a combination of two different transformers has been proposed. For typical beam parameters a commercially available dc current transformer with 10 kHz bandwidth and measurement range of 10 µA- 20 A is sufficient.

As a second transformer system a sensitive magnetic field sensor based on the GMR effect (giant magneto resistance) is presently being developed at GSI [11]. The novel DCCT allows measuring also high current bunched beams with a MHz repetition rate, where the signal of a standard DCCT gets disturbed. The aimed current resolution of the device is 0.1 mA and the detector must be capable of a peak ion beam current of 80 A (2.5×10^{13} protons, 50 ns output bunch length). Presently the prototype device shows a cut-off frequency of 1 MHz and a lower detection threshold of 220 µA.

BEAM-LOSS DETECTION

Beam-loss detection at SIS100 will be performed using both, scintillators and ionization chambers mounted on movable stands outside the vacuum system. Currently the signals of beam-loss monitors at FAIR are not foreseen for machine protection issues. Beam-losses at SIS100 might occur during the injection plateau of 1 s, during the rebunching process or slow extraction. The beam-loss monitor system is designed to present a qualitative view of localized beam-losses along the SIS100. Detailed knowledge about beam-losses is necessary to prevent activation and damage of installations by the beam with up to 10 kW beam power. In addition uncontrolled beam-losses lead to an increased ion-induced desorption yield and as a consequence to detrimental pressure bumps in the vacuum system.

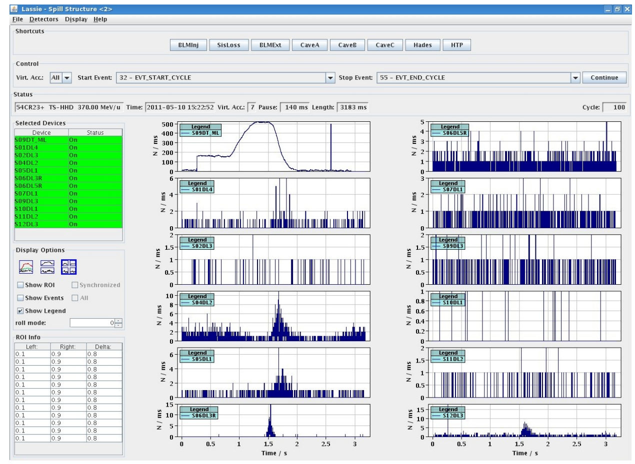

Figure 4: LASSIE GUI showing current transformer data (top left) and 11 beam-loss monitors along SIS18.

For acquisition of beam-loss data the LASSIE system is currently under development at GSI [12]. LASSIE, the Large Analog Signal Scaling Information Environment, distributes and analyzes a large quantity of analog channels. The fully FESA-based system runs on a VME crate with six 32-channel scaler boards for parallel readout of all 192 channels. Analog signals are converted by current-to-frequency or voltage-to-frequency converters and fed into the scalers. In this way the signals of e.g. scintillators and ionization chambers, as planned for beam-loss detection in SIS100, are treated similarly and data are recorded on the same time base. In addition signals of other relevant sources, like e.g. beam current transformers or the measured B-field of quadrupoles can be added to the system to present a synoptic view of a machine cycle. The graphical user interface, as presented in Fig. 4, allows switching a subset of detectors from standard readout at 1 kHz to a high-resolution mode with a readout frequency of up to 1 MHz for detailed investigation of the beam-loss time structure.

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